Technical Resource for Australian Red Meat Market Access

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by

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Foreword

Australia exports more than 70% of our red meat production and therefore, we rely on open and predictable access to a diverse range of international markets. Our red meat processors and exporters deliver a wide range of products to specifications heavily influenced by access conditions determined by high levels of regulation in many markets.

We foster and maintain positive relationships with our customers, and governments, to identify opportunities to diversify our markets. Gaining acceptance of our systems is a critical step in minimising non-tariff barriers in new markets and reducing them in existing ones.

The Australian Red Meat Market Diversification Program, initiated by the Red Meat Advisory Council and funded partly through an Agricultural Trade and Market Access Cooperation grant from the Department of Agriculture, Fisheries and Forestry, aims to maintain, and further diversify, export markets by strengthening and growing market presence in Southeast Asia, the Middle East, and North Africa regions.

The Australian Meat Industry Council (AMIC) represents red meat and pork processors and exporters, through advocating for increased market access, reduced barriers to trade, and a reduction in the regulatory burden on the industry.

This *Technical Resource for Red Meat Market Access* is an asset to assist in creating agreed standard, systems, and protocols with international trading partners, based on science, aimed at reducing technical barriers to trade and showcasing Australia’s strengths in red meat production, processing and export.

Patrick Hutchinson

CEO, Australian Meat Industry Council

Preface

In the mid-1990s, three events occurred that changed the shape of Australia's technical market access for meat:

1. The World Trade Organisation (WTO) concluded the *Agreement on the Application of Sanitary and Phytosanitary Measures*, that prescribed risk as the basis on which one country would accept another country's products.
2. The Codex Alimentarius Commission added an annex on Hazard Analysis and Critical Control Points (HACCP) to their *General Principles of Food Hygiene*, forcing the food sector to think about how to effectively control hazards in food chain.
3. The United States Department of Agriculture released the *Pathogen Reduction/HACCP Rule*, in the wake of the Jack-in-a-Box Shiga toxin-producing *Escherichia coli* outbreak that put the focus on pathogenic bacteria rather than visual defects and made meat processors rather than government inspectors responsible for ensuring that their product was safe.

These events lead Australian regulators and industry to transform their systems to take on an outcome-based approach to meat safety. The Meat Research Corporation (now Meat & Livestock Australia (MLA)) commenced a food safety program in the wake of foodborne disease outbreaks associated with *Salmonella* and Shiga toxin-producing *Escherichia coli* ('Garibaldi' became Australia's Jack-in-a-Box moment). Transformations are not easy or straightforward, especially when potentially 'experimenting' with the systems of a whole industry and having an international jury of importing countries deciding whether the outcomes are acceptable. There have been twists and turns, large steps forward that have been impeded by what can be successfully 'sold' to importing countries, and new actions needing to be taken in response to new issues.

Market access reflects the confidence that trading partners have in the Australian system and the actions of individual supply chains. While the hurdle of gaining access to a country with favourable terms is a significant one, companies purchasing meat, small and individual customers, and consumers all add expectations for supply of safe and suitable food products. Commercial success is dependent on satisfying all actors along the supply chain.

This *Technical Resource* provides the opportunity to record the results of the journey since in the mid-1990s against the expectations of countries, companies, customers, and consumers on topics that are of significant interest in technical market access. This volume records those expectations, identifies how industry and government meet those expectations, and outlines the outcomes that are achieved. By providing both the historical and philosophical position and providing references to scientific work, the intention of this volume is that it will be useful for government and industry for responding to enquiries, defending the current market access position, and continuing to develop an efficient and effective system that meets the expectations of markets.

Ian Jenson

December 2023

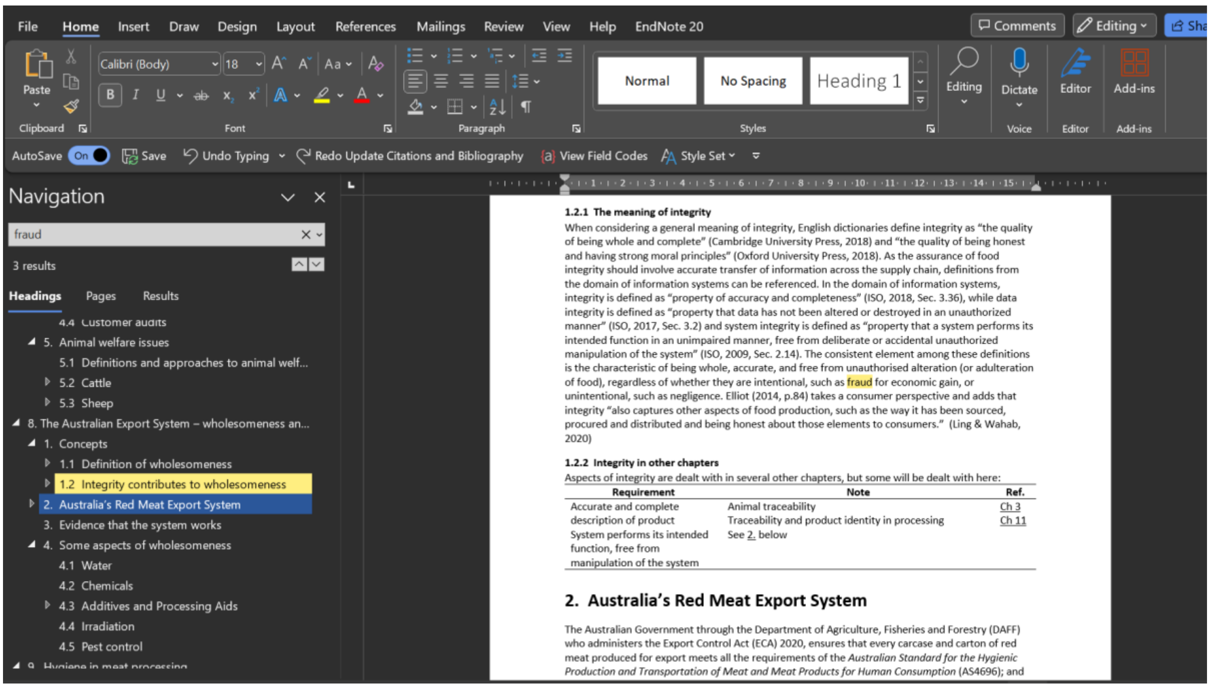
Features of this book

- The high-level Table of Contents introduces the structure of the book, and the main content of each chapter
- Each chapter stands alone with its own detailed table of contents, reference list, and few references to other chapters
- A chapter summary provides a market-oriented overview of the topic, and may provide sufficient detail to explain Australia's position and respond to a market access question
- The body of each chapter generally outlines the international expectations concerning the topic, Australia's position, evidence for Australia's achievements, and then detailed technical information
- Occasional hypertext links are provided to other chapters of the book
- Further detail can be found through reference to footnotes and in-line citations
- Footnotes provide reference regulations, reports, and documents available on the internet
- End of chapter references provide citations for peer-reviewed publications and more formal, and permanent sources of information

Advice for online use

Online viewing can be facilitated using the following features:

- Turn off the ¶ sign in the Home menu
- "hidden text" may appear and can be turned off by following the menu: File – Options – Display – hidden text and unticking the box
- The Navigation pane can be viewed by following the menu: View – Show – Navigation Pane. The Navigation Pane allows you to quickly find a section of the book and can also be used to search for a term, with the section containing the word being highlighted, and the word then being highlighted in the text
- Underlined text is often a hyperlink to another section of the book



Abbreviations

AA	Approved Arrangement
AAHL	Australian Animal Health Laboratory
AAO	Australian Government Authorised Officer
AAWCS	Australian Livestock Processing Industry Animal Welfare Certification System
AAWS	Australian Animal Welfare Strategy
ABM	Animal Based Measure
ABSF	Australian Beef Sustainability Framework
ACDP	Australian Centre for Disease Preparedness
ADI	Acceptable Daily Intake
AEMIS	Australian Export Meat Inspection System
AERP	Adverse Experience Reporting Program
AFNOR	Association Française de Normalisation (French Standardization Association)
AG-CIA	WHO Advisory Group of the Critical Important Antimicrobials for Human Medicine
AGISAR	Advisory Group on Integrated Surveillance of Antimicrobial Resistance
AGMIN	Agriculture Ministers' Forum
AGSOC	Agriculture Senior Officials' Committee
Agvet	Agricultural and Veterinary [Chemical]
AHA	Animal Health Australia
AHC	Animal Health Committee
AIAS	Animal Industries' Antimicrobial Stewardship RD&E strategy
AIMS	automated immunomagnetic separation
AIO	Approved Islamic Organisation
ALFA	Australian Lot Feeders' Association
AMIC	Australian Meat Industry Council
AMILSC	Australian Meat Industry Language and Standards Committee
AMR	Antimicrobial resistance
AMRG	Australian Meat Regulators (Working) Group
AMS	Antimicrobial stewardship
AMU	Antimicrobial usage
ANZFSC	Australia New Zealand Food Standards Code
AOAC	Association of Official Analytical Chemists International
APC	Aerobic Plate Count
APLAC	Asia Pacific Laboratory Accreditation Cooperation
APVMA	Australian Pesticides and Veterinary Medicines Authority
ARfD	Acute Reference Dose
ARGG	[Australian] Antimicrobial Resistance Governance Group
ARS	[USDA] Agricultural Research Service
AS	Australian Standard
AS4696	The Australian Meat Standard; *Australian Standard for hygienic production and transportation of meat and meat products for human consumption*
ASTAG	Australian Strategic and Technical Advisory Group on AMR
ATM	Area Technical Manager
a_w	water activity

BOD	Biological Oxygen Demand
BRD	Bovine Respiratory Disease
BSE	bovine spongiform encephalopathy
CA	Competent Authority
CAC	Codex Alimentarius Commission
CAR	corrective action request
CBAM	Carbon Border Adjustment Mechanism
CCP	Critical Control Point
CDC	US Centers for Disease Control and Prevention
cfu	colony forming units
CGF	Consumer Goods Forum
CIRA	Critical Incident Response Audit
CIU	[DAFF] Certification and Integrity Unit
CN30	Carbon Neutral 2030
CO_2	Carbon dioxide
CO2e	carbon dioxide equivalents
COD	Chemical Oxygen Demand
CSIRO	Commonwealth Scientific and Industrial Research Organisation
CTC	check the checker
CVD	Commodity Vendor Declarations
DAFF	Australian Government Department of Agriculture, Fisheries and Forestry
DENT	[Salmonella] Dublin, Enteritidis, Newport, Typhimurium
DoHAC	Australian Government Department of Health and Aged Care
DPI	Department of Primary Industries
eae	Intimin (attachment and effacing) gene
EC	European Commission
ECA	Export Control Act
ECOFF	epidemiological cut-off values
EDI	Electronic Data Interchange
EDIFACT	Electronic Data Interchange for Administration, Commerce and Transport
EHEC	Enterohaemorrhagic *Escherichia coli*
EMIAC	Export Meat Industry Advisory Committee
EPN	Export Permit Number
EPR	Environmental Performance Review
ERF	Emissions Reduction Fund
ESG	Environmental, Social and Governance [credentials]
ESI	Export Slaughter Interval
ESVAC	European Surveillance of Veterinary Antimicrobial Consumption
EU	European Union
EUCAS	European Union Cattle Accreditation Scheme
EXDOC	Export Documentation System
FAO	Food and Agriculture Organization of the United Nations
FCI	Food Chain Information
FDA	US Food and Drug Administration
FMD	Food and mouth disease
FOG	Fats Oils and Grease
FPP	Fit and Proper Person
FRPERC	Food Refrigeration & Process Engineering Research Centre

FRSC	Food Regulation Standing Committee
FSA	[United Kingdom] Food Standards Agency
FSANZ	Food Standards Australia New Zealand
FSIS	Food Safety and Inspection Service
FSMA	Food Safety Meat Assessors
FTA	Free Trade Agreement
GHG	Greenhouse Gas
GHP	good hygienic practices
GI	gastrointestinal
GLEAM	Global Livestock Environmental Assessment Model
GLP	Good Laboratory Practice
GMP	Good Manufacturing Practices
GPFH	General Principles of Food Hygiene
GRI	Global Reporting Initiative
GRSB	Global Roundtable on Sustainable Beef
GTART	Goat targeted antibacterial residue testing
GWP	Global Warming Potential
H_2S	Hydrogen sulphide
HACCP	Hazard Analysis and Critical Control Points
HACCUT	Harmonised Agvet Chemical Control of Use Taskforce
HDX	half-duplex
HGP	Hormonal growth promotant
HUS	haemolytic uraemic syndrome
ICAR	International Committee for Animal Recording
ICMSF	International Commission on Microbiological Specifications for Foods
IIR	International Institute of Refrigeration
ILAC	International Laboratory Accreditation Cooperation
ISC	Integrity Systems Company
ISO	International Standards Organisation
JECFA	Joint FAO/WHO Expert Committee on Food Additives
JEMRA	Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment
JMPR	Joint FAO/WHO Meetings on Pesticide Residues
JMTA	Japan Meat Traders Association
JVARM	Japanese Veterinary Antimicrobial Resistance Monitoring
KPI	Key Performance Indicator
LAB	Lactic Acid Bacteria
LEAP	Livestock Environmental Assessment Performance Scheme
LPA	Livestock Production Assurance
MEDC	Export Meat Data Collection
MEVS	Meat Establishment Verification System
MHA	meat hygiene assessment
MICoR	Manual of Importing Country Requirements
MINTRAC	National Meat Industry Training Advisory Council
ML	Maximum Level
MLA	Meat & Livestock Australia
MLG	FSIS Microbiological Laboratory Guidebook
MoU	Memorandum of Understanding

MPN	Most Probable Number
MRL	Maximum Residue Limit
MTC	Meat Transfer Certificate
N	Nitrogen
NACMCF	US National Advisory Committee on Microbiological Criteria for Foods
NARM	National antibacterial residue minimisation
NARMS	US National Antimicrobial Resistance Monitoring System
NATA	National Association of Testing Authorities
NBC	National Biosecurity Committee
NCMMP	National Carcase Microbiology Monitoring Program
NEPM	National Environment Protection Measure 2011
NEPP	National Energy Productivity Plan
NEXDOC	Next Export Documentation System
NFAS	National Feedlot Accreditation Scheme
NGHGI	Australian National Greenhouse Gas Inventory
NLIS	National Livestock Identification System
NLISID	National Livestock Identification System (visual) identification number
NORM	National organochlorine residue management
NRS	National Residue Survey
NSQA	National Saleyard Quality Assurance
NTSEP	non-typhoidal *Salmonella*
NTSEP	National Transmissible Spongiform Encephalopathies Surveillance Project
NVD	National Vendor Declaration
NWT	not wild type
OECD	Organisation for Economic Co-operation and Development
OIE	Office International des Epizooties
OPV	On Plant Veterinarian
P	Phosphorus
PCAS	Pasturefed Cattle Assurance System
PCU	Population Corrected Unit
PEF	Product Environmental Footprint
PFAS	Per- and polyfluoroalkyl substances
PHI	Product Hygiene Indicators
PIC	Property Identification Code
PoE	Point (Port) of Entry
PPE	personal protecting equipment
PSL	Practical Shelf Life
PT	(bacterio)phage type
PubCRIS	Public Chemical Registration Information System
QA	Quality Assurance
QRA	Quantitative Risk Assessment
RAM	Restricted Animal Materials
REX	Request for Export Documentation
RFID	Radio Frequency Identification Device
RFP	Request for Permit
RI	Refrigeration Index
RMAC	Red Meat Advisory Council
RSPCA	Royal Society for Prevention of Cruelty to Animals

SDG	[UN] Sustainable Development Goals
SNP	Single Nucleotide Polymorphism
SPC	Standard Plate Count
SPS	Sanitary and Phytosanitary
SSCI	Sustainable Supply Chain Initiative
SSF	[Australian] Sheep Sustainability Framework
SSOP	sanitation standard operating procedures
STAG-AMR	WHO Strategic and Technical Advisory Group for Antimicrobial Resistance
START	Sheep targeted antibacterial residue testing
STEC	Shiga toxin-producing *Escherichia coli*
stx	Shiga toxin gene
TART	Cattle targeted antibacterial residue testing
TBARS	Thiobarbituric acid reactive substances
TBT	Technical Barriers to Trade
TGA	Therapeutic Goods Administration
tHSCW	tonnes of Hot Standard Carcase Weight
TMA	Trimethylamine
TSE	Transmissible Spongiform Encephalopathy
TVBN	Total Volatile Basic Nitrogen
TVC	Total Viable Count
UK-VARSS	Veterinary Antibiotic Resistance and Sales Surveillance
UN	United Nations
UNCEFACT	United Nations Centre of Trade Facilitation and Electronic Commerce
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
USA / US	United States of America
USDA	United States Department of Agriculture
UTAS	University of Tasmania
VP	vacuum-packed
VTEC	verocytotoxic, or verotoxic, *Escherichia coli*
WGS	whole genome sequencing
WHO	World Health Organization
WHP	Withholding period
WOAH	World Organisation for Animal Health, founded as OIE
WT	wild type
WTO	World Trade Organization

Introduction

This volume is designed to be a technical resource for market access. Topics have been chosen because they are of significant interest to Australia's trading partners (government, and non-government), but the coverage is not exhaustive. It is hoped that this resource provides a useful starting point for responding to enquiries, explaining, and defending our systems and product, and negotiating for more efficient technical requirements for access to markets.

This is not a document that should be read 'cover-to-cover' but should be referred to as necessary to learn about a particular topic or to gain an understanding of some technical point. The chapters have been arranged generally from 'farm-to-fork', but the journey is not linear. The initial chapter on food safety frameworks and public health risk is an overview of the entire system against public health expectations and outcomes.

In general, the approach for each chapter is to cover the expectations and requirements of international markets and/or Australian standards, explain the actions Australia takes and the knowledge it has, and ultimately provide evidence for meeting the expected outcomes.

Some topics are well settled science/practice, and others are under active change and development. The chapters reflect the status of knowledge in 2023 and attempts to provide a perspective that will be relevant for several years though it cannot anticipate the development of expectations or research. Chapters on sustainability and antimicrobial resistance are examples of chapters where there is active development that will continue for a number of years.

Each chapter is relatively self-contained, with its own Table of Contents and Reference List. References to 'academic' sources such as journal articles and books are in the reference list at the end of the chapter, and footnotes are used to reference standards and websites with links. Footnotes should contain sufficient detail to locate material even when the link is broken. Repetition of material in multiple chapters has been avoided, but sometimes occurs for the purpose of a chapter making sense when standing alone. Material is referenced between chapters using hyperlinks.

1. International food safety frameworks: public health and trade

Summary

Maintaining public health and public confidence in the safety of the meat supply, while conducting an international trade in meat, is fundamental to successful market access.

International agreements through the World Trade Organisation, the World Organisation for Animal Health, the Codex Alimentarius Commission set standards for trading partner behaviour, as well as setting standards and guidelines to ensure a safe food supply and minimise barriers to international trade. Included in these standards are guidelines on identifying foodborne hazards, assessing risk, and the effectiveness of control measures, that become the basis for negotiations between trading partners.

Australia has a robust system of standards setting and enforcement that ensures a safe food (including, meat) supply. The system harmonises with international norms, assesses risk, and places responsibility firmly on the operators of food businesses. Policy is set at a national level (food Ministers), assessing risk, and proposing management of that risk (Food Standards Australia New Zealand) is separated from policy and science-based. Compliance is managed through State and Territory-based enforcement and focussed on management of risks. Export is managed by the Australian Government Department of Agriculture, Fisheries and Forestry. The whole system is well-informed by public health data, extensive research directed towards providing for the design of a risk-based system and frequent reviews of the effectiveness of the system.

Internationally traded meat is probably a lower food safety risk than it has ever been, and likely to be of lower risk than some other food commodities, but meat does carry a burden of history and suspicion resulting in relatively stringent regulation, beyond the actual risk. Reduction in regulatory burden will likely only occur as acceptance of available data describing hygienic performance, more complete understanding of the human health implications of meat consumption, and the need to redistribute scarce resources leads to gradual change.

Many hazards to public health associated with meat have been identified, but not all of them are likely to occur, or place a significant burden on public health (that is, they are low risk). International agreements specify how concerns about public health are expressed in technical terms. Quantitative risk assessment is the prescribed way of considering a product, how it is used and the risks to public health, but there are other methods (quantitative and qualitative) that provide confidence about the degree of protection provided. Since countries rarely employ identical systems and controls (for technical as well as legal and social reasons), the concept of achieving equivalent outcomes by employing different methods becomes important when negotiating for technical access to another country's market, where demonstrating that the Australian system produces an equivalent food safety outcome (as defined by the Codex Alimentarius) is important. The necessity and desirability of acceptance of other systems is provided through the commitments to the World Trade Organization.

Contents

1. Meat safety and international trade

Since at least the 1960s there has been a desire internationally to ensure safety of food, regulate international trade, and ensure health and nutrition for all. These desires have expressed themselves in international collaborations through the Codex Alimentarius Commission (CAC), The World Trade Organization (WTO), and more recently in the United Nation's Sustainability Development Goals.[1] Australia's policies and approaches to managing food safety and international trade must be understood within this framework.

Food safety and international trade are concerns of international law as well as public health: "food safety has become a matter of ever-increasing international concern and the World Health Organization has defined foodborne diseases as a global public health challenge. Protecting global health from foodborne hazards is a compelling duty and a primary interest of both States and non-State actors;" (Negri, 2009).The legal perspective can be through international human rights, trade or response to health hazards (Negri, 2009).

> Reference to the Codex Alimentarius and WTO agreements when discussing of consumer protection and relevant trade implications at the universal level is a must. As a matter of fact, international cooperation in the field of food safety regulation is steadily institutionalized in the Codex Alimentarius Commission (CAC) and its specialised subsidiary bodies since the 1960s, with the World Trade Organization later offering both the normative framework and the judicial forum to settle trade disputes. (Negri, 2009)

It Is important to engage, not only with the texts produced by these international bodies but also to understand their position and authority in the international arena. Documents have histories, are produced for a purpose, and must be understood in these contexts.

1.1 Codex Alimentarius Commission (CAC)[2]

Codex Alimentarius texts are developed and maintained by the Codex Alimentarius Commission (CAC), a body established by the Food and Agriculture Organization of the United Nations (FAO), and the World Health Organization (WHO). The Commission's main goals are to

- protect the health of consumers,
- facilitate international trade,
- ensure fair practices in the international food trade.[3]

The CAC sets food standards, guidelines and codes of practice contribute to the safety, quality, and fairness of this international food trade.

> The Codex Alimentarius is an ensemble of standards and guidelines regarding food safety and quality, including food additives, veterinary drug and pesticide residues, contaminants, methods of analysis and sampling, and codes and guidelines of hygienic practice. Although standards and guidelines developed by internationally recognized bodies – such as the CAC or the World Organization for Animal Health (WOAH, founded as OIE) – are not binding per se, they are generally recognized and have thus become the accepted norms in international trade, which means that where there is no national legislation, these standards can be used directly, in order to ensure the safety of international food and food related aid. In fact, Codex standards are referred to as fundamental reference points in the area of food safety. Albeit voluntary, their application is strongly incentivized

[1] United Nations, Department of Economic and Social Affairs. Sustainable Development Goals. THE 17 GOALS | Sustainable Development (un.org)

[2] Codex Alimentarius Commission Home | CODEXALIMENTARIUS FAO-WHO

[3] Codex Alimentarius. About Codex Alimentarius About Codex | CODEXALIMENTARIUS FAO-WHO

> because food production that meets these standards is generally viewed as facilitating trade and improving export rates. (Negri, 2009)

The Codex Alimentarius includes standards for all the principal foods, whether processed, semi-processed or raw, for distribution to the consumer. Materials for further processing into foods should be included to the extent necessary to achieve the purposes of the Codex Alimentarius. The Codex Alimentarius includes provisions in respect of food hygiene, food additives, residues of pesticides and veterinary drugs, contaminants, labelling and presentation, methods of analysis and sampling, and import and export inspection and certification. Thus, Codex Committees are both commodity-based, and based on topics that apply across all commodities (horizontal committees).

Codex standards and related texts are not a substitute for, or alternative to national legislation. Every country's laws and administrative procedures contain provisions with which it is essential to comply.

The CAC and its subsidiary bodies are committed to revision as necessary of Codex standards and related texts to ensure that they are consistent with and reflect current scientific knowledge and other relevant information.

The reference made to Codex food safety standards in the WTO Agreement on Sanitary and Phytosanitary measures (SPS Agreement) means that Codex texts can form the basis of 'international standards' used for SPS measures and have implications for resolving trade disputes. WTO members that wish to apply stricter food safety measures than those set by Codex may be required to justify these measures scientifically.

> The Codex Alimentarius is backed up by the trade sanctions of the WTO, since any non-Codex-compliant nation would automatically lose in any food-trade dispute with a Codex compliant country, unless it were in a position to justify a possible ban on food products on the basis of a risk assessment rigorously supported by adequate scientific evidence. (Negri, 2009)

1.2 World Trade Organization (WTO)[4]

The World Trade Organization (WTO), established in 1995 was born out of five decades of negotiations aimed at progressively reducing obstacles to trade. Where countries have faced trade barriers and wanted them lowered, the negotiations have helped to open markets for trade. Conversely, in some circumstances, WTO rules support maintaining trade barriers – for example, to protect consumers or the environment.

The WTO provides a forum for negotiating agreements aimed at reducing obstacles to international trade and ensuring a level playing field for all. At its heart are the WTO agreements, negotiated and signed by the bulk of the world's trading nations. The WTO also provides a legal and institutional framework for the implementation and monitoring of these agreements, as well as for settling disputes arising from their interpretation and application.

The system's overriding purpose is to help trade flow as freely as possible – provided there are no undesirable side effects. Its rules must be transparent and predictable, to ensure that individuals, companies, and governments know what the trade rules are around the world, and to assure them that there will be no sudden changes of policy.

> The advantages of having universally agreed food standards for the protection of consumers, with a view to facilitating trade, are acknowledged by two important WTO Agreements: the Agreement on the Application of Sanitary and Phytosanitary Measures (SPS Agreement) and the Agreement on Technical Barriers to Trade (TBT Agreement). These Agreements recognize that international standards and technical regulations bring benefits to both producers and consumers; their objective is to facilitate secure

[4] World Trade Organization. World Trade Organization - Home page - Global trade (wto.org)

> and predictable access to markets ensuring that health regulations do not create unnecessary obstacles to trade. (Negri, 2009)

1.2.1 Sanitary and Phytosanitary (SPS) Agreement

The Sanitary and Phytosanitary (SPS) Agreement allows WTO members to set their own standards on food safety and animal and plant health. But these standards must be based on science, be risk based, and applied only to the extent necessary to protect human, animal or plant life or health, and not arbitrarily or unjustifiably discriminate between countries where identical or similar conditions prevail.

Members are encouraged to use international standards, guidelines and recommendations but may adopt higher levels of protection if there is scientific justification for it, or if they are based on appropriate assessment of risks. The SPS Agreement allows countries to use different methods of control, inspection, and approval procedures to verify compliance with adopted standards. The SPS agreement also requires members to accept SPS measures as equivalent where they achieve the same level of protection, through determination of equivalence of different approaches based on an assessment of risk.

> The SPS Agreement provides a multilateral framework of rules applying to all measures which may negatively affect the freedom of international trade, in particular to any trade-related measure taken to protect human life or health from risks arising from additives, contaminants, toxins, veterinary drug and pesticide residues, or other disease-causing organisms in foods or beverages. The SPS Agreement incorporates elements of precaution, setting out the right of Governments to restrict trade to pursue health objectives, provided that the measures adopted be based on scientific evidence or on an appropriate risk assessment and according to the principles of non-discrimination and proportionality. Scientific justification (as provided in Article 2.2 and as backed up by the risk assessment discipline under Article 5) is, in point of fact, the pivot of the Agreement's management of the health-trade interface. Therefore, the Agreement tries to balance two conflicting interests: the sovereign right of Members to determine the level of health protection they deem appropriate, on the one hand, and the need to ensure that a sanitary or phytosanitary requirement does not represent an unnecessary, arbitrary, discriminatory, scientifically unjustifiable, or disguised restriction on international trade, on the other. In order to achieve this goal, the SPS Agreement encourages Members to use existing international standards, guidelines and recommendations; it acknowledges the authority of Codex standards by making express reference to them as a privileged basis for internationally harmonised regulation. (Negri, 2009)

Some key provisions of the SPS Agreement (emphasis added)[5]:

> Article 3 Harmonization
>
> 1. To harmonize sanitary and phytosanitary measures on as wide a basis as possible, <u>Members shall base their sanitary or phytosanitary measures on international standards, guidelines or recommendations</u>, where they exist, except as otherwise provided for in this Agreement, and in particular in paragraph 3.
>
> 2. Sanitary or phytosanitary measures which conform to international standards, guidelines or recommendations shall be deemed to be necessary to protect human, animal or plant life or health, and presumed to be consistent with the relevant provisions of this Agreement and of GATT 1994.
>
> 3. <u>Members may introduce or maintain sanitary or phytosanitary measures which result in a higher level of sanitary or phytosanitary protection than would be achieved by measures based on the relevant international standards, guidelines or recommendations, if there is a scientific justification, or as a consequence of the level of sanitary or phytosanitary protection a Member determines to be appropriate</u> in accordance with the relevant provisions of paragraphs 1 through 8 of Article 5.[2] Notwithstanding the above, all measures which result in a level of sanitary or phytosanitary

[5] WTO. AGREEMENT ON THE APPLICATION OF SANITARY AND PHYTOSANITARY MEASURES 15-sps.doc (live.com)

protection different from that which would be achieved by measures based on international standards, guidelines or recommendations shall not be inconsistent with any other provision of this Agreement

[2] For the purposes of paragraph 3 of Article 3, there is a scientific justification if, on the basis of an examination and evaluation of available scientific information in conformity with the relevant provisions of this Agreement, a Member determines that the relevant international standards, guidelines or recommendations are not sufficient to achieve its appropriate level of sanitary or phytosanitary protection.

Article 4 Equivalence

1. Members shall accept the sanitary or phytosanitary measures of other Members as equivalent, even if these measures differ from their own or from those used by other Members trading in the same product, if the exporting Member objectively demonstrates to the importing Member that its measures achieve the importing Member's appropriate level of sanitary or phytosanitary protection. For this purpose, reasonable access shall be given, upon request, to the importing Member for inspection, testing and other relevant procedures.

Article 5 Assessment of Risk and Determination of the Appropriate Level of Sanitary or Phytosanitary Protection

1. Members shall ensure that their sanitary or phytosanitary measures are based on an assessment, as appropriate to the circumstances, of the risks to human, animal or plant life or health, taking into account risk assessment techniques developed by the relevant international organizations.

4. Members should, when determining the appropriate level of sanitary or phytosanitary protection, take into account the objective of minimizing negative trade effects

1.2.2 Technical Barriers to Trade (TBT) Agreement

The Technical Barriers to Trade (TBT) Agreement aims to ensure that technical regulations, standards, and conformity assessment procedures are non-discriminatory and do not create unnecessary obstacles to trade. At the same time, it recognises WTO members' right to implement measures to achieve legitimate policy objectives, such as the protection of human health and safety, or protection of the environment. The TBT Agreement strongly encourages members to base their measures on international standards as a means to facilitate trade.

Some key provisions of the TBT Agreement (emphasis added)[6]

2.1 Members shall ensure that in respect of technical regulations, products imported from the territory of any Member shall be accorded treatment no less favourable than that accorded to like products of national origin and to like products originating in any other country.

2.2 Members shall ensure that technical regulations are not prepared, adopted, or applied with a view to or with the effect of creating unnecessary obstacles to international trade. For this purpose, technical regulations shall not be more trade-restrictive than necessary to fulfil a legitimate objective, taking account of the risks non-fulfilment would create. Such legitimate objectives are, inter alia: national security requirements; the prevention of deceptive practices; protection of human health or safety, animal or plant life or health, or the environment. In assessing such risks, relevant elements of consideration are, inter alia: available scientific and technical information, related processing technology or intended end-uses of products.

2.7 Members shall give positive consideration to accepting as equivalent technical regulations of other Members, even if these regulations differ from their own, provided they are satisfied that these regulations adequately fulfil the objectives of their own regulations.

[6] World Trade Organization. Technical Barriers to Trade (Marrakesh) Agreement. WTO | legal texts - Marrakesh Agreement

1.3 World Organisation for Animal Health (WOAH)[7]

The World Organisation for Animal Health (WOAH) was founded as the Office International des Epizooties (OIE) in 1924. Together, the Organisation and its Members coordinate the global response to animal health emergencies, the prevention of zoonotic diseases, the promotion of animal health and welfare, and better access to animal health care through permanent relations with over 70 international and regional organisations and Regional and Sub-regional Offices worldwide. WOAH helps policymakers and governments create a future in which humans and animals benefit by improving animal health, globally.

WOAH and the WTO cooperate in several ways[8] including on the work of the WTO SPS committee. WOAH and FAO cooperate in several ways.[9]

The SPS Agreement strongly encourages WTO members to base their SPS measures on certain international standards. In the area of animal health and zoonoses, it recognizes the standards developed by WOAH.[10]

1.4 Australian system

Australia's domestic food regulatory system has divided responsibilities between policy (Department of Health and Aged Care), standards setting (Food Standards Australia New Zealand) and enforcement (states and territories). Some aspects of the system are common between Australia and New Zealand, but food safety standards and export systems are not part of the joint system.

Food policy is cooperatively made by a forum of ministers from Australian and New Zealand government jurisdictions - the Food Ministers' Meeting[11]. The Food Ministers' Meeting are the decision makers in the system. The Food Ministers' Meeting is supported by the Food Regulation Standing Committee (FRSC). FRSC members include government department and agencies heads (including Department of Agriculture, Fisheries and Forestry, DAFF) responsible for food regulation in each jurisdiction.

Food Standards Australia New Zealand (FSANZ) [12] is an independent scientific body that develops and sets food standards which become part of food law in the states and territories and in New Zealand.

The Australian state and territory[13] government agencies implement, monitor, and enforce food laws through their own Food Acts and other food related legislation. DAFF enforces these laws in relation to imported and exported food.

Export Systems are based on the Australian domestic system. The key provision is Standard 4.2.3 in the Australia New Zealand Food Standards Code, *Production and Processing Standard for Meat*.[14] The Standard is brief, because of the editorial note:

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[7] World Organisation for Animal Health. Founded as OIE. Home - WOAH - World Organisation for Animal Health

[8] World Organisation for Animal Health. Agreement with the World Trade Organization (WTO) Agreement with the World Trade Organization (WTO) - WOAH - World Organisation for Animal Health

[9] World Organisation for Animal Health. Agreement with the Food and Agriculture Organization of the United Nations (FAO) Agreement with the Food and Agriculture Organization of the United Nations (FAO) - WOAH - World Organisation for Animal Health

[10] World Trade Organization. 2020. Future resilience to diseases of animal origin: the role of trade. resilience_report_e.pdf (wto.org)

[11] [Australia] Food Regulation Secretariat Food Regulation - Home

[12] Food Standards Australia New Zealand Home (foodstandards.gov.au)

[13] Food Standards Australia New Zealand Food enforcement contacts (foodstandards.gov.au)

[14] Australia New Zealand Food Standards Code - Standard 4.2.3 - Production and Processing Standard for Meat (Australia Only) (legislation.gov.au)

> State and Territory laws govern the slaughter and processing of animals for human consumption, … and the preparation, packing, transportation or storage of meat or meat products. These laws require persons involved in such activities to comply with the following Australian Standards…:
>
> AS4696: –07 --*Hygienic Production and Transportation of Meat and Meat Products for Human Consumption*

AS4696, known through the industry as 'The Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption; or simply, 'The Australian (Meat) Standard' has detailed requirements to ensure 'meat and meat products for human consumption comply with food safety requirements and are wholesome.' The Standard is set by Committee FT-021 which is composed of many members of FRSC plus relevant industry groups. While regulatory instruments may reference the 2007 version of the standard, it is subject to reconfirmation or revision by Standards Australia, and new editions are produced (the most recent, in 2023. Note that the 2023 version differs only in some aspects of post mortem inspection procedures and disposition criteria).

DAFF regulates exports of food and agricultural products to assure trading partners that Australian agricultural products meet importing country requirements. The department's responsibilities and powers are defined in the Export Control Act 2020. [15] Export commodities controlled by the department are listed or 'prescribed' in the legislation include live animals and meat and meat products. The legislation sets out the requirements that must be met by an exporter before prescribed goods can be exported from Australia.

Export Control (meat and meat products) Rules 2021[16] provide detailed requirements for meat and meat products that are authorized by the Export Control Act. The Australian Standard (called the Australian Meat Standard) is the basis of technical requirements in the Rules.

2. Public health, hazards, and risks

Public health is "the science and art of preventing disease, prolonging life and promoting health through the organized efforts and informed choices of society, organizations, public and private, communities and individuals."[17] The WHO has defined foodborne diseases as a global public health challenge and food safety therefore is part of the United Nations (UN) Sustainability Development Goals.[18] Provision of safe, nutritious, and sufficient food has a positive impact on public health. Hazards have the potential to cause an adverse health effect, and are generally categorised as biological, chemical, or physical. Risk is a quantification of the hazard in terms of how likely an adverse health effect is to occur, and the severity of the effect.

The safety of meat for human consumption is a prime concern for CAC. The *Code of Hygienic Practice for Meat*[19] states among its general principles that "Meat must be safe and suitable for human consumption" and that "Meat hygiene programmes should have as their primary goal the protection of public health".

[15] Export Control Act 2020 (legislation.gov.au)
[16] Federal Register of Legislation - Australian Government
[17] Public health - Wikipedia
[18] United Nations, Department of Economic and Social Affairs. Sustainable Development. THE 17 GOALS | Sustainable Development (un.org) Target 2.1
[19] Codex Alimentarius Commission. (2005). *Code of hygienic practice for meat* (CAC/RCP 58-2005). https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B58-2005%252FCXP_058e.pdf

The *Code of Hygienic Practice for Meat* notes that meat has traditionally been viewed as a vehicle for a significant proportion of human food-borne disease, and that while the types of meat-borne disease of public health importance have changed over time, there are contemporary examples of meat-borne disease to be addressed.

The definition of "safe for human consumption'' includes the criterion ''does not contain hazards at levels that are harmful to humans".

2.1 Hazards

Hazards, according to CAC, are "biological, chemical or physical agent in, or condition of, food with the potential to cause an adverse health effect."[20] Hazards are therefore identified qualitatively, based on a potential adverse health effect. The process of hazard analysis requires the collection and evaluation of information on hazards identified as being present in the raw materials, environment, in the process, or the food and then deciding whether these are significant. Significance is determined by a knowledge of whether the hazard is reasonably likely to occur at an unacceptable level in the absence of any control.[21]

There are well-known hazards in the food supply, but not all are likely to occur in a particular food. A good knowledge of the public health record (disease statistics, for example, in Australia, the National Notifiable Disease Surveillance System[22]), is therefore, a helpful for identifying hazards likely to occur. For example, the National Notifiable Disease Surveillance System records cases of illness for campylobacteriosis, listeriosis, salmonellosis, Shiga toxin-producing *E. coli*, anthrax, and Q fever, all of which may be associated with the livestock industry (though not all are associated with meat consumption). The public health record may validate that a hazard is unlikely to occur.

In addition to established hazards with a well understood characteristics, some potential hazards are raised from time-to-time, some with a firm qualitative understanding of the hazard but without clear association with meat, and others without being firmly established as a hazard."

2.1.1 Biological hazards

Biological hazards, (mostly, bacteria) are the major hazards in meat identified according to the Codex definition. Viruses are associated with some foods, but not noted to transfer from animals to red meat.

Cooking (roasting, grilling etc) is sufficient to inactivate most pathogens that are on the outside of the meat or reduce them to a safe level. Products that are ground (or comminuted) result in the hazard being on the inside of the product rather than the outside, and thus require more attention to be given to the temperature at the centre of the product during cooking. Some countries (e.g., USA) are inclined to undercook ground products and therefore consider relatively temperature sensitive bacteria, such as Shiga toxin-producing *E. coli* (STEC) to be hazards. Some countries that consume steak tartare, or meat pastes, are also inclined to consider STEC to be hazards.

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[20] FAO and WHO. (2019). *Codex Alimentarius Commission - Procedural Manual* (28th ed.). Procedural Manual | CODEXALIMENTARIUS FAO-WHO

[21] Codex Alimentarius Commission. (2022). General Principles of Food Hygiene. In (Vol. CXC 1-1969): CAC. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf

[22] Australia Department of Health and Aged Care. National Notifiable Disease Surveillance System. National Notifiable Diseases Surveillance System (NNDSS) | Australian Government Department of Health and Aged Care

2.1.2 Chemical hazards

Chemical hazards may arise from agricultural and veterinary chemicals used on farms, environmental sources of chemicals, cleaning chemicals used in meat processing establishments etc. (Pointon et al., 2006).

2.1.3 Physical hazards

Physical hazards are not often considered in a systematic way, because physical hazards are often the results of random events in the supply chain. Horchner, Brett, Gormley, Jenson, and Pointon (2006) considered physical hazards which may enter during primary production—examples include lead shot (in feral stock) and broken needles. At the primary production stage, incorrectly administered barium selenate may result in nodules containing this nutritional supplement, wire etc. may become imbedded in wounds and not found by processing operators and thus find its way into product.

2.2 Risks

Risk expresses the hazard in quantitative terms, considering the probability of an adverse health effect and the severity of that effect.[23] For example, probability may be expressed in the number of illnesses per 100,000 population per year, and the severity may be expressed as the consequence ranging from mild incapacity to death. The combination of likelihood and severity may be expressed in terms of Disability Adjusted Life Years (DALYs) experienced in a population. One DALY represents the loss of the equivalent of one year of full health. DALYs for a disease or health condition are the sum of the years of life lost to due to premature mortality (YLLs) and the years lived with a disability (YLDs) due to prevalent cases of the disease or health condition in a population.[24] When calculated through risk assessment for a particular cause it can be a measure of risk (likelihood of adverse effect), and when calculated for a population can be an expression of the burden of disease (number of years of life lost).

3. Risk Analysis

Risk Analysis, as conceived by the CAC, consists of three parts[25]:

1. risk assessment
2. risk management
3. risk communication

3.1 Codex risk assessment[26]

Risk assessment may be a complex process, and in Codex Alimentarius Commission consists of several steps: hazard identification, hazard characterisation, exposure assessment and risk characterisation. A risk assessment may be qualitative, semi-quantitative or quantitative, also considering the uncertainties of quantitative estimates. Hazards are identified, as described above, and characterised in terms of their adverse health effects, which may also include a dose-response relationship where possible. Exposure assessment determines how often the population is exposed

[23] FAO and WHO. (2019). *Codex Alimentarius Commission - Procedural Manual* (28th ed.). Procedural Manual | CODEXALIMENTARIUS FAO-WHO

[24] Disability-adjusted life years (DALYs) (who.int)

[25] Codex Alimentarius Commission. Working Principles for risk analysis for food safety for application by governments. CAC/GL 62-2007 APPENDIX VIII (fao.org)

[26] Codex Alimentarius Commission PRINCIPLES AND GUIDELINES FOR THE CONDUCT OF MICROBIOLOGICAL RISK ASSESSMENT (fao.org) CAC/GL 30-1999 amendments 2014.

to the hazard (how often the hazard is present and at what level) and how often the food is consumed and in what quantities. The risk is characterised by combining the understanding of the hazard characterisation and exposure assessment to estimate the likelihood and severity of the adverse effects that occur in a given population, with associated uncertainties.[27] "

3.2 Scientific input

There are three expert groups that provide scientific guidance to the CAC.

The Joint FAO/WHO Expert Committee on Food Additives (JECFA) is an international expert scientific committee administered jointly by the FAO and the WHO. JECFA serves as an independent scientific committee which performs risk assessments and provides advice on food additives and ingredients.

The Joint FAO/WHO Meetings on Pesticide Residues (JMPR) provide independent scientific expert advice to the Commission and its specialist Committee on Pesticide Residues, in response to questions asked.

The Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA) provide independent scientific expert advice to the Commission and its specialist Committees in response to questions asked in related to microbiological risk assessment.[28]

3.3 Risk assessment tools

Comprehensive quantitative risk assessments are mathematically complicated with many estimates of factors that may contribute to risk, each with a distribution of values and likelihood that are then combined iteratively to produce an estimate (distribution) of risk. This type of assessment is not frequently performed, or if it is, is only performed for part of the farm to fork supply chain.

More frequently, semi-quantitative assessments are performed, which allow a number of factors to be considered, populated with easily obtainable data, and producing a semi-quantitative risk estimate. One frequently used tool is Risk Ranger, developed by Prof. Tom Ross and Dr John Sumner, at the University of Tasmania (Ross & Sumner, 2002). The Risk Ranger tool is available on via the FAO website[29] and was included in the *FAO guide to ranking food safety risks at the national level.[30]* The tool is in spreadsheet software format and embodies established principles of food safety risk assessment, i.e., the combination of probability of exposure to a food-borne hazard, the magnitude of hazard in a food when present, and the probability and severity of outcomes that might arise from that level and frequency of exposure. The tool requires the user to select from qualitative statements and/or to provide quantitative data concerning factors that that will affect the food safety risk to a specific population, arising from a specific food product and specific hazard, during the steps from harvest to consumption. The spreadsheet converts the qualitative inputs into numerical values and combines them with the quantitative inputs in a series of mathematical and logical steps using standard spreadsheet functions. Those calculations are used to generate indices of the public health risk.

[27] FAO and WHO. (2021). *Microbiological risk assessment - Guidance for food* (Microbiological Risk Assessment Series No. 36, Issue. https://www.fao.org/documents/card/en/c/cb5006en

[28] Microbiological Risk Assessment series (who.int)

[29] Risk Ranger: A Simple Food Safety Risk Calculation Tool | Food safety and quality | Food and Agriculture Organization of the United Nations (fao.org)

[30] FAO. (2020). *FAO guide to ranking food safety risks at the national level* (Food Safety and Quality Series, Issue. Publication preview page | FAO | Food and Agriculture Organization of the United Nations

A risk assessment can also be purely qualitative, sometimes simply ranked as 'low, medium, high', and sometimes using a five-point scale for likelihood (rare to almost certain) and severity (insignificant to catastrophic)[31]"

3.4 Risk assessment in Australia

FSANZ conducts risk assessment activities when setting domestic standards[32]

Risk assessments may help support regulatory decision-making, and access to international markets. Section 5 – Risk Assessment of Australian Red Meat describes some of the risk assessments performed."

3.5 Risk management

Risk Management shares an equal place with Risk Assessment and Risk Communication in the Codex approach to risk analysis[33]. It involves the weighing of policy alternatives, consultation with interested parties, considering the risk assessment and other relevant factors and if needed, selecting appropriate prevention and control measures.

Not surprisingly, different countries approach achievement of a safe meat supply in different ways. A review of meat safety systems (risk management) in Australia, Denmark, the Netherlands, New Zealand, Sweden, and the United States were compared to identify innovations that could offer improved protections for U.S. consumers.[34]

The WTO SPS agreement acknowledges (3.3) that risk management measures may be set as a consequence of the level of sanitary or phytosanitary protection a Member determines to be appropriate. This appropriate level of sanitary of phytosanitary protection (ALOP) acknowledges the sovereign right for a country to determine the level of protection with which it is comfortable. While the SPS and TBT Agreements have recommendation and requirements about setting of standards, ultimately, the ALOP needs to be accepted by exporting countries. Equivalence is achieved through risk assessment and verified implementation of actions by an exporting country against the rules (ALOP) of the importing country. An example of equivalence is described for the USA which has an equivalence process for food safety requiring a country to demonstrate objectively that its food safety inspection system provides the same level of public health protection as the FSIS inspection system (Ebel et al., 2022). To evaluate microbiological testing data that such countries may submit to this end, a possible risk metric has been proposed to inform FSIS's assessment of whether products produced under an alternative inspection system in another country pose no greater consumer risk of foodborne illness than products produced under FSIS inspection. This metric requires evaluation of prevalence estimates of pathogen occurrence in products for the foreign country and the US and determining what constitutes an unacceptable deviance of another 'country's prevalence from the US prevalence.

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[31] Standards Australia. Risk management – Guidelines AS ISO 31000:2018

[32] Food Standards Australia New Zealand. (2013). *Risk Analysis in Food Regulation*. FSANZ. Risk Analysis in Food Regulation (foodstandards.gov.au)

[33] Codex Alimentarius Commission. (2007). Working principles for risk analysis for food safety for application by governments. In (Vol. CAC/GL 62-2007). Rome: FAO WHO. APPENDIX VIII (fao.org)

[34] The Pew Charitable Trusts and Center for Science in the Public Interest (2014) Meat and Poultry Inspection 2.0: How the United States can learn from the practices and innovations in other countries meat-and-poultry-inspection-2.pdf (cspinet.org)

Specific guidelines cover microbiological risk management.[35]

4. Public health record for red meat

As already noted, The *Code of Hygienic Practice for Meat* records that meat has traditionally been viewed as a vehicle for a significant proportion of human food-borne disease, and that while the types of meat-borne disease of public health importance have changed over time, there are contemporary examples of meat-borne disease to be addressed.

Around the turn of the twentieth century, food safety legislation was enacted in many countries. The previous decades had witnessed a great increase in understanding of infectious diseases, and concerns had mounted about adulteration of food. In the United States for example, the Pure Food and Drug Act was passed in 1906 and establishing what is now the Food and Drug Administration (FDA). In response to Upton Sinclair's 1905 novel "The Jungle" which graphically depicted Chicago's meatpacking industry, the Meat Inspection Act of 1906 was enacted. In Germany, veterinarians became intimately involved in the safety of foods (including meat) for human consumption and introduced the concepts of ante-mortem and post-mortem inspection of animals as a means of ensuring safety of the meat supply for human consumption. Infectious diseases were not uncommon, and many could pass from animals to man; tuberculosis and brucellosis are two examples. Gastrointestinal diseases were not uncommon, and Salmonella was closely associated with warm-blooded animals. Botulism caused by the consumption of improperly prepared sausages in which toxin had been produced, was a long-known illness, with recently demonstrated microbiological cause. The meat supply became the most highly regulated part of the food industry.

Disease-free animals and removal of all that might be objectionable to consumers ('safe and suitable') judged by visual (and other sensory) means became the cornerstone of meat inspection until the 1990s. At this time, there was a greater recognition in regulation that microorganisms were a significant risk to meat safety that could not be judged by visual means.

It is not easy, in retrospect, to assess the significance of meat to the burden of disease experienced by human populations in the past, but the assumption of meat being a significant contributor to human illness remains today. Often a close examination of data suggests that the red meat supply makes a small contribution to human illness, and Australian meat presents less risk than that from most countries (Fegan & Jenson, 2018; Hernandez-Jover, Culley, Heller, Ward, & Jenson, 2021).

4.1 International

In 2006 the World Health Organization (WHO), launched the Initiative to Estimate the Global Burden of Foodborne Diseases[36]. The objective of the initiative was partly to provide estimates on the global burden of foodborne diseases for a defined list of causative agents of microbial, parasitic and chemical origin. This represented the first estimates of global foodborne disease incidence, mortality, and disease burden in terms of Disability Adjusted Life Years (DALYs). For the global estimates, thirty-one foodborne hazards causing 32 diseases are included, Together, the 31 global hazards caused 600 (95% uncertainty interval [UI] 420–960) million foodborne illnesses and 420,000 (95% UI 310,000–600,000) deaths in 2010. The most frequent causes of foodborne illness were diarrhoeal disease agents, particularly norovirus and *Campylobacter* spp. Foodborne diarrhoeal

[35] Codex Alimentarius Commission. (2007). Principles and guidelines for the conduct of microbiologcial risk management (MRM). In (Vol. CAC/GL 63-2007). Rome: FAO WHO. PRINCIPLES AND GUIDELINES FOR THE CONDUCT OF MICROBIOLOGICAL RISK MANAGEMENT (MRM) (fao.org)

[36] World Health Organization. (2015). *WHO estimates of the global burden of foodborne diseases: Foodborne disease burden epidemiology reference group 2007-2015*. WHO PRINT-1347-OMS-FOS-FERGreport-20160408.indd (who.int)

disease agents caused 230,000 (95% UI 160,000–320,000) deaths, particularly non-typhoidal *Salmonella enterica* (NTS, which causes diarrhoeal and invasive disease). Other major causes of foodborne deaths were *Salmonella Typhi*, *Taenia solium*, hepatitis A virus, and aflatoxin. The highest burden per population was observed in Africa (AFR), followed by South-East Asia (SEA R) (SEAR B and SEAR D) subregions and the Eastern Mediterranean (EMR) D subregion. Diarrhoeal disease agents were the leading cause of foodborne disease burden in most subregions. NTS was an important burden in all subregions, particularly in Africa. Other main diarrhoeal causes of foodborne disease burden were enteropathogenic *E. coli* (EPEC), enterotoxigenic *E. coli* (ETEC) and *Vibrio cholerae* in low-income subregions, and *Campylobacter* spp. in high-income subregions. Australia was grouped with countries including New Zealand, Japan in Western Pacific subregion A which was ranked as having very low DALYs due to foodborne illness. There was no attempt to attribute illness to food commodities.

A study was conducted to review bacterial disease outbreaks attributed to consumption of red meat and meat products (salted dried meat, cured fermented sausages, fresh sausages, cooked meats etc) (Omer et al., 2018). A survey of the peer-reviewed literature for the period 1980-2015 was performed. Most of the outbreaks were caused by *Escherichia coli* and *Salmonella enterica*, causing 33 and 21 outbreaks, respectively, mostly in Europe and the United States. Fresh processed meat products were the category most frequently implicated. The food category most frequently implicated in those outbreaks was raw-cured fermented sausages. Other organisms linked to meat-associated outbreaks, but less frequently reported, were *Staphylococcus aureus*, *Bacillus cereus*, *Clostridium perfringens*, *Clostridium botulinum*, and *Listeria monocytogenes*.

4.2 Australia

A review of Australian meat-associated outbreaks was conducted for the period 1991-2002 (Sumner, Cameron, et al., 2005). Sixteen outbreaks associated, or suspected to be associated, with meat or meat products, and attributed to the processing sector were recorded, most frequently caused by Salmonella, but sometimes *E. coli* or *Clostridium perfringens*. Twenty-nine outbreaks associated or suspected to be associated with meat or meat products and attributed to the food service sector, were most frequently caused by *C. perfringens*, followed by Salmonella, then a few cases caused by *E. coli*, *Shigella*, viruses or an unknown microorganism.

4.2.1 Attribution of salmonellosis to red meat

Foodborne illness source attribution studies attempt to estimate the most common food categories for illnesses caused by a specific pathogen.[37]. A source attribution study for salmonellosis in the state of South Australia between 2000 and 2010 was conducted (Glass et al., 2016). The study could only identify association of cases with a species, rather than a product. For example, ‘bovine’ could mean direct contact with a cow, or faeces, or contaminated water or food. Eggs and chicken were identified as being responsible for most cases. Bovine and ovine source were implicated in very few outbreak cases, but bovine sources were modelled to be responsible for 6.2-7.4% of sporadic cases and ovine sources for between 1.6 and 2.7% of sporadic cases.

An attribution study was also performed on NSW Salmonella cases between 2008 and 2019 (McLure, Shadbolt, Desmarchelier, Kirk, & Glass, 2022). While layer chickens were considered the likely primary reservoir of Salmonella infections in NSW, other sources, such as ruminants were modelled to be responsible for between 10 and 41% of human cases, depending on the modelling assumptions. The category of ‘ruminant’ included all ruminant species as live animals, their effluents, and products.

[37] Centers for Disease Control and Prevention Attribution of foodborne illness in the United States. Attribution of Foodborne Illness in the United States | Estimates of Foodborne Illness | CDC

4.2.2 Epidemiology of STEC infections

A study of the epidemiology of Shiga toxin-producing *E. coli* (STEC) in Australia reviewed the cases reported between 2000 and 2010 (Vally et al., 2012). For this 11 year period, the annual rate of STEC infections notified in Australia was 0.4 cases per 100,000 (people) per year. The rates varied between states, in part due to the case-definition used. Over the same period there were 11 outbreaks caused by STEC, with these outbreaks generally being small in size and caused by a variety of serogroups. The overall annual rate of notified haemolytic uraemic syndrome (HUS, a severe consequence of infection with STEC) in Australia between 2000 and 2010 was 0.07 cases per 100,000 per year. Overall, the incidence of disease due to STEC in Australia appears comparable or lower than similar developed countries.

4.2.3 Attribution of campylobacteriosis to red meat

A study aimed to identify risk factors for sporadic campylobacteriosis in Australia (Cribb et al., 2022). Beef and lamb consumers appeared to be less likely to report campylobacteriosis than those not consuming beef or lamb, whereas those consuming chicken were more likely to report campylobacteriosis. 38% of lamb kidney and liver samples and 14% of beef kidney and liver samples were found to contain *Campylobacter* spp. *C. jejuni* was generally the most common species isolated. Prevalence was significantly higher in fresh than in frozen offal, and higher in product served over the counter rather than being pre-packaged (Walker et al., 2019).

5. Risk assessments of Australian red meat

Risk assessment is the accepted approach to understanding the impact of hazards in foods on human health and may take several forms. This section provides a short summary of assessments performed on Australian meat and demonstrate a low risk.

5.1 Risk profile 2003

In 2002-3 the Australian red meat sector funded a risk profiling project (Pointon et al., 2006). Risk profiling is one activity in preliminary risk management and has been defined as .a description of a food safety problem and its context. (CAC, 2003a). The scope of the work was microbial, chemical, and physical hazards across the supply continuum for the Australian beef, sheep, and goat meat industries. The aim was to provide a risk rating of hazard: meat and meat product combinations.

5.1.1 Microbiological hazards

Hazards that are recognised animal diseases or are controlled through the production supply chain are described in detail in Ch 2 Sourcing safe and healthy animals.

Some hazards are particularly associated with processed meats, such as *E. coli* or *Salmonella enterica* which may survive in poorly produced fermented meat (such as salami), or *Listeria monocytogenes* which may contaminate cooked meats during cooling, slicing, or packaging, and grow during the shelf life of the product.

Two methods were used to assess risk: a qualitative assessment for preliminary screening of identified hazards, and a semi-quantitative risk rating using Risk Ranger (Sumner, Ross, Jenson, & Pointon, 2005). Risk ratings were prepared using Risk Ranger for hazard–product pairings on a scale of 0–100 where zero represents no risk and 100 represents every member of the population eating a meal which contains a lethal dose of the hazard every day. The scale is logarithmic and is such that an increment of six in the ranking corresponds approximately to a 10-fold increase in risk (Table 1).

5.1.2 Chemical hazards

The data collected by the National Residue Survey (NRS)[38] demonstrate that the risk from chemical residues in Australian meats is negligible. This is supported by the infrequent detection of residues above the maximum residue limit (MRL) and lack of an established link to illness at levels found in meat. Risk from chemical exposure through meat is extremely low (almost zero) in comparison to the risk from microbial hazards. The result demonstrates that current risk management practices for the control of chemical residues in Australian meat products are effective. These controls include a national system of agricultural and veterinary chemical registration (managed by the Australian Pesticides and Veterinary Medicines Authority, APVMA), prescription with written instructions for use and withholding period for a broad range of veterinary medicines. Other relevant components of the management system include Commodity Vendor Declarations for feedstuffs (CVD), Vendor Declarations for the sale of livestock (National Vendor Declaration, NVD), general monitoring of consumer exposure, and residue levels in meat at slaughter, and targeted residue surveillance programs. Nevertheless, these integrated programs demonstrate the importance of effective chemical residue management to underpin market access. Aflatoxins, produced by certain fungi that may grow in fodder, were considered to be a low risk (Sumner, Ross, et al., 2005).

Table 1: Microbiological hazard risk rating for meat and meat products in Australia (Sumner, Ross, et al., 2005)

Product	Identified hazard	Risk rating	
		Qualitative	**Risk Ranger***
Red meat entire cuts (steaks, chops etc.)	*L. monocytogenes*	Low	Not done
	S. aureus	Low	Not done
	Aeromonas	Low	Not done
	M. tuberculosis	Low	Not done
	Bacillus	Low	Not done
	Y. enterocolitica	Low	Not done
	EHEC	Low	Not done
Processed meats –			
cured, cooked sausages, not requiring further cooking	*L. monocytogenes*	Low	25 (low)
	L. monocytogenes	Low	Not done
	S. aureus	Low	Not done
Uncooked fermented meats	*L. monocytogenes*	Low	12 (low)
	Salmonella	Medium	33 (medium)
	EHEC	Medium	33 (medium)
Sous-vide	*C. botulinum*	Low	Not done
	L. monocytogenes	Low	Not done
Beef jerky	aflatoxin	Low	Not done
Deli meats	*L. monocytogenes*	Medium	36 (medium)
Terrines	*L. monocytogenes*	Medium	32 (medium)
Meat products eaten cooked			
Fresh sausages	*L. monocytogenes*	Low	11 (low)
Hamburgers	EHEC	Medium	0
Kebabs	*Salmonella*	Medium	40 (medium)

* (Sumner & Ross, 2002)

[38] National Residue Survey - DAFF (agriculture.gov.au)

5.1.3 Physical hazards

Physical hazards are not often considered in a systematic way, because physical hazards are often the results of random events in the supply chain. Horchner et al. (2006) considered physical hazards which may enter during primary production—examples include lead shot (in feral stock) and broken needles. At the primary production stage, incorrectly administered barium selenate may result in nodules containing this nutritional supplement, wire etc. may become imbedded in wounds and not found by processing operators and thus find its way into product.

5.2 Risk profile 2019

A renewed risk profiling project was conducted by the industry for the year 2017-18 (Hernandez-Jover et al., 2021), following similar approaches to the 2002-3 study, but independently collecting data to cover the years since the initial rating process.

Table 2: Risk rating for microbial hazards in meat products (Hernandez-Jover et al., 2021)

Hazard	Product : process	Qualitative rating	Risk Ranger rating	Predicted number of cases pa
L. monocytogenes	Packaged, cooked ready-to-eat meat products	M	35	3.6
	Unpackaged, cooked, ready-to-eat meat products	M	38	12
	Packaged, cooked, ready-to heat meat products	M	17	2.6×10^{-3}
	Vacuum packed and undercooked primals	M	0	2.2×10^{-14}
C. perfringens	Roast served warm (sliced, cooked primal) in food service	M	Beef: 28 Lamb: 27	1.6 1.1
E. coli O157	Uncooked primals (e.g., steak tartare, carpaccio)	L	34	2
	Doner kebabs	L	32-38	1-10
	Rolled or blade/needle tenderised	L	35	3
	Undercooked and uncooked comminuted meat products (e.g., undercooked hamburgers)	L	Undercooked: 35-39 Uncooked: 34	3-15 2
	Non-GMP UCFM products	L	25	5.9×10^{-2}
Salmonella spp.	Undercooked and uncooked comminuted meat products (e.g., undercooked hamburgers)	L	Undercooked: 33-37 Uncooked: 32	11.6-58
	Doner kebabs	M	28-34	2-19.5
	Rolled or blade/needle tenderised	M	31	5.6
	Non-GMP UCFM products	M	21	1.1×10^{-1}
Campylobacter spp.	Undercooked and uncooked comminuted meat products (e.g., undercooked hamburgers)		Undercooked: 22-26 Uncooked: 21	0.16-0.8
Toxoplasma gondii	Undercooked lamb rolled roast or primal	M	49 (only in pregnant women)	1

The risk rating exercise identified undercooked hamburgers and Shiga toxin-producing *E. coli* O157 and *Salmonella* spp.; and *Listeria monocytogenes* in packaged and unpackaged ready-to-eat products as the combinations posing the highest risk to the Australian population. (Table 2) The authors also concluded that “considering the available information, it suggests red meat products do not pose a high food safety risk.”

5.3 Quantitative assessment *E. coli* O157

One of the few quantitative risk assessments of Australian meat was for cartons of manufacturing beef, containing *E. coli* O157 in a US supply chain, and consumed in hamburgers cooked at home or in quick service restaurants (A. Kiermeier, Jenson, & Sumner, 2015). The risk assessment uses measurements of the concentration of E. coli O157 in cartons of beef from contaminated lots (A. Kiermeier, Mellor, Barlow, & Jenson, 2011) assuming that no product was removed from the supply chain (that is, as though no testing occurred), that hamburgers were made from 100% Australian beef, and that all beef was consumed, even if temperature abused in the supply chain. The risk assessment predicts 49.6 illnesses (95% CI: 0.0–148.6) from the 2.46 billion hamburgers made from 155,000 t of Australian manufacturing beef exported to the United States in 2012. All these illness were due to undercooking in the home and less than one illness is predicted from consumption of hamburgers cooked to a temperature of 68 °C in quick-service restaurants. Further assessment using the model estimated that implementation of the testing program required by the USDA Food Safety and Inspection Service would only reduce the number of illnesses by about 10%, with diminishing returns on additional testing (A. Kiermeier, Sumner, & Jenson, 2015).

5.4 *Clostridium botulinum* in meat at retail

This case provides an interesting example of the use of risk assessment, because it is an assessment of a risk that is now considered negligible. It does not directly involve Australian meat (though partly funded by MLA) but demonstrates the issues that Australian meat may face in international markets.

The UK Food Standards Agency (FSA) has published guidance regarding ‘The safety and shelf-life of vacuum and modified atmosphere packed chilled foods with respect to non-proteolytic Clostridium botulinum’, which advised that, in the absence of other controlling factors, the shelf life be set to a maximum of ten days. These guidelines were first published in 2008 following consultation with the ACMSF and were subsequently updated in 2017, during which fresh meat was specifically mentioned for the first time.[39] While this guidance applied primarily to meat at retail held between 3 and 8°C, there was a risk that the requirement could extend to the beginning of the supply chain and require the whole supply chain to demonstrate that meat was held below 3°C from the time of vacuum packing.

MLA and the British Meat Processors Association funded a study, published as a peer-reviewed scientific paper (Peck, Webb, & Goodburn, 2020). The study consisted of two parts: exposure assessment to determine the level of protection when employing current commercial practice regarding VP/MAP fresh red meat, and a challenge test with non-proteolytic *C. botulinum* and fresh chilled red meat representative of that sold in the UK. A review of the literature demonstrated that commercially produced foods intended to be stored chilled do not appear to have been implicated in foodborne botulism when the shelf-life and storage temperature have been maintained as specified by the manufacturer. The lack of reported associated outbreaks suggests that current practice leaves

[39] Advisory Committee on the Microbiological Safety of Food. (2020). *Final Report. Subgroup on non-proteolytic Clostridium botulinum and vacuum and modified atmosphere packaged foods*. https://webarchive.nationalarchives.gov.uk/ukgwa/20200401154218/https://acmsf.food.gov.uk/acmsfreps/acmsfreports

a good safety margin. UK industry typically applies a retail pack shelf-life at 3°C–8°C to 13 days for fresh red meat, with a maximum of 23 days for beef, 27 days for lamb, and 18 days for pork. More than 10^{10} person servings marketed in the UK without association with foodborne botulism. A challenge test demonstrated that spores of non-proteolytic *C. botulinum* inoculated on chilled vacuum-packed fresh red meat did not lead to detectable neurotoxin at day 50 for beef, day 35 for lamb, or day 25 for pork. The products were visually spoiled many days before these end points. The exposure assessment and challenge test demonstrated the safety of current UK industry practices for the shelf-life of fresh, vacuum-packed beef, lamb and pork held at 3°C–8°C with respect to *C. botulinum*, and that botulinum neurotoxin was not detected within their organoleptic shelf-life.

In December 2020, shelf-life guidance for vacuum and modified atmosphere packed (VP/MAP) chilled fresh beef, lamb and pork was updated by the FSA, allowing food business operators (FBOs) to choose a safe shelf-life for these specific products in line with their existing food safety management systems.[40]

5.5 *Taenia saginata* infection from consumption of Australia beef

Taenia saginata, the beef tapeworm (*Cysticercus bovis*) was once relatively prevalent, and the application of veterinary public health principles has led to improvements in animal health and rare detection at post-mortem inspection in Australia. In Australia, *T. saginata* is not endemic in the human population and cattle are generally not grazed on pastures that have been irrigated with sewage (the main way that cattle become infected). A Quantitative Risk Assessment (QRA) model was used to quantify the risk of human *T. saginata* infection from consumption of Australian beef domestically and in key export markets. The model was used to investigate the effect of reducing current post-mortem inspection (PMI) protocols by removing the need to incise the masseters, or by removing all incisions, for low-risk cattle. The results of the QRA indicate that the risk of human *T. saginata* infection from consumption of Australian beef is very low—a median 0.37 (95% Credibility Interval: 0.03–10.5) and 0.27 (0.01–3.8) cases per 1 billion (10^9) portions consumed in the domestic and top 5 export markets, or equivalently 0.56 (0.04–15.8) and 0.97 (0.05–13.4) illness per year, respectively. Moving to reduced PMI, which only includes incisions of the heart, was estimated to result in a negligible increase in risk, equivalent to one additional infection every 12.5 and 33.3 years in the domestic and all export markets, respectively. This QRA demonstrates that alternative post-mortem inspection procedures for *C. bovis* achieve equivalent food safety outcomes to the current domestic standard (Andreas Kiermeier, Hamilton, & Pointon, 2019).

6. Descriptions of hazards

Identification of hazards in a food is an early step in risk assessment. Brief descriptions of hazards and potential hazards are provided here, indicating the work that has been conducted on to understand their relevance to Australian meat. Some are discussed in detail in subsequent chapters; others will not be mentioned again and are here as a record of past work.

6. 1 Well-established hazards in meat

6.1.1 Shiga toxin-producing *Escherichia coli* (STEC)

Symptoms of Shiga toxin-producing *E. coli* (STEC) infection include abdominal cramps, (bloody) diarrhoea, vomiting and fever. However more serious illness may result, including haemolytic

[40] Food Standards Agency (9 May 2022) News FSA takes revised approach to shelf life safety guidance for chilled fresh beef, lamb and pork following consultation. FSA takes revised approach to shelf-life safety guidance for chilled fresh beef, lamb and pork following consultation | Food Standards Agency

uraemic syndrome (HUS) and its associated complications. In some individuals this can lead to kidney failure and death. Children under five years of age and the elderly are more susceptible to infection and the development of serious illness.

A number of serogroups of STEC can be found in the gut of ruminants (cattle and sheep), though few of them are likely to cause disease in humans (Bettelheim, 2007), but some, particularly *E. coli* O26 and *E. coli* O111 are associated with disease in cattle, including in Australia (Bettelheim, 2007; Cobbold & Desmarchelier, 2000; Hornitzky, Mercieca, Bettelheim, & Djordjevic, 2005). *E. coli* O157 is the most significant STEC for humans in most parts of the world, and in the USA *E. coli* O157 and 6 other serogroups (big 6) have been declared to be adulterants in beef intended for non-intact use (e.g., ground beef, blade tenderised beef).

The serogroups declared to be adulterants in non-intact beef in the USA are all presumed to have a bovine origin (all had been isolated from cattle at least once at the time that the decision to declare these serogroups as adulterants was made).

In a significant Australian survey of adult and young beef and dairy cattle at the time of slaughter (n=1500), across Australia, STEC likely to cause disease (possess *stx*, *eae*, and an O antigen marker for O157 or a big 6 serotype) were isolated from 7.7% samples; 6.7% contained E. coli O157 and 1.3% contained a big 6 serotype (some contained more than one serotype). Among samples confirmed for big 6 STEC, 1% contained *E. coli* O26 and 0.3% contained *E. coli* O111. Serotypes O45, O103, O121, and O145 were not isolated from any sample, even though genes indicative of *E. coli* belonging to these serotypes were detected by PCR (Mellor et al., 2016).

In Australia, a survey of cattle lymph nodes (n=1464) failed to detect STEC (G. Bailey, Huynh, Govenlock, Jordan, & Jenson, 2017).

Contamination rates are low in boned beef products (D. Phillips, Jordan, Morris, Jenson, & Sumner, 2006b) which compare favourably on an international basis (Bosilevac, Guerini, Brichta-Harhay, Arthur, & Koohmaraie, 2007).

Testing of sheep and sheep meat similarly demonstrates very low levels in boned product (D. Phillips, Tholath, Jenson, & Sumner, 2013). Comparable information on carriage in normal lymph nodes is unavailable.

It is also important to note that outbreaks associated with pathogenic *E. coli* (STEC) have not been reported in association with fresh meat or derived products in Australia. In reviewing annual infection data Vally et al., (2012) report infections in Australia have remained fairly steady over the 11 year period. Overall, the incidence and burden of disease due to STEC and HUS in Australia appears comparable or lower than similar developed countries. However, pathogenic *E. coli* should be included as a ‘Hazard likely to occur’ due to outbreaks associated with fresh meat products in export destinations of Australian beef (reviewed by (Jenson & Sumner, 2012).

6.1.2 *Salmonella enterica*

Gastrointestinal illness results when *Salmonella* are able to invade the lining of the intestine and infect the host, producing an enterotoxin. Low numbers of *Salmonella* may cause illness. Symptoms of salmonellosis include nausea, vomiting, diarrhoea, cramps, and fever. The duration of these symptoms is several days.

High carriage rates may occur in live cattle. A survey of 310 cattle faecal samples (10g) collected at slaughter was conducted and 6.8% were found to contain Salmonella (Fegan, Vanderlinde, Higgs, & Desmarchelier, 2004). A survey of cattle faeces at slaughter (n=1500) found Salmonella in 14.4% of samples (10g), more likely from dairy cattle than from beef cattle or calves (Barlow et al., 2015).

Another study isolated Salmonella from 18.4% (n=1001) samples of cattle faeces (Abraham et al., 2022).

Salmonella from the cattle's gastrointestinal tract may be transferred either directly, or via hides etc., from faeces to carcases, primals and other products. Extensive testing over a decade has demonstrated very low levels in boned beef and sheep meat products (D. Phillips, Bridger, Jenson, & Sumner, 2012; D. Phillips, Jordan, Morris, Jenson, & Sumner, 2006a; D. Phillips et al., 2006b; D. Phillips et al., 2013).

Goats present quite a different picture with high levels recorded in live animals (46.3%) and carcases after dressing (28.9%) (L. Duffy, Barlow, Fegan, & Vanderlinde, 2009).

6.2 Well-established hazards that are unlikely to be associated with meat

The microorganisms listed here are known to cause disease in humans and may be found in meat, but it is not clear that they occur frequently enough, or in high enough concentrations, that when meat is prepared in 'usual' ways (assume at least a moderate level of heat is applied), disease is likely to occur.

6.2.1 *Campylobacter coli/jejuni*

Infection by *Campylobacter* spp. has been associated with symptoms include fever, diarrhoea (sometimes bloody), abdominal cramps, headache, nausea, and vomiting. As a result of infection, a small percentage of people develop secondary conditions such as reactive arthritis or Guillain-Barré syndrome.

Occurs relatively commonly in live animals (6% dairy cattle, 58% feedlot cattle, 2% pasture-fed cattle, sheep 0% and lambs 8%) (G. D. Bailey et al., 2003), levels in boned beef and sheep meat products are very low (D. Phillips et al., 2012; D. Phillips et al., 2013). A retail survey of beef (n=91) and lamb (n=95) isolated 0 and 1 *Campylobacter* sp., respectively (D. Phillips, Jordan, Morris, Jenson, & Sumner, 2008). 38% of lamb kidney and liver samples and 14% of beef kidney and liver samples were found to contain *Campylobacter* spp. *C. jejuni* was generally the most common species isolated. Prevalence was significantly higher in fresh than in frozen offal, and higher in product served over the counter rather than being pre-packaged (Walker et al., 2019).

6.2.2 *Yersinia enterocolitica*

Common symptoms in children are fever, abdominal pain, and diarrhea, which is often bloody. In older children and adults, right-sided abdominal pain and fever may be the predominant symptoms and may be confused with appendicitis. Pigs are the major animal reservoir for the few strains of *Y. enterocolitica* that cause human illness.

Yersinia enterocolitica is not generally considered a pathogen of ruminants. In one Australian survey, it was not isolated from any animal (n=475) (feedlot beef, grass-fed beef, dairy cattle, sheep, lambs) (G. D. Bailey et al., 2003).Red meat species are not identified as a source of infection in the EU (EFSA Panel on Biological Hazards, 2013a, 2013b)

6.2.3 *Listeria monocytogenes*

Individuals infected with *L. monocytogenes* may exhibit mild flu-like symptoms such as fever and muscle aches, and sometimes gastrointestinal symptoms such as vomiting and diarrhoea. In at-risk population groups (young, old, immunocompromised) manifestations of the more severe, invasive form of the disease include bacteraemia, septicaemia, meningitis, encephalitis, miscarriage, neonatal disease, premature birth, and stillbirth.

Listeria sp. are infrequently isolated from the faeces of healthy red meat animals (feedlot beef, grass-fed beef, dairy cattle, sheep, lambs). G. D. Bailey et al. (2003) isolated one *L. ivanovii* from a dairy cow (n=475). Only *L. monocytogenes* is considered a human pathogen. Surveys of beef and lamb at processing establishments has detected few *Listeria* sp. (D. Phillips et al., 2012; D. Phillips et al., 2013). When human illness has been associated with a meat product, it has been cooked, and presumably illness is attributed to recontamination post-cooking accompanied by temperature abuse (Hernandez-Jover et al., 2021; Sumner, Cameron, et al., 2005).

6.2.4 *Staphylococcus aureus*

Staphylococcal food poisoning occurs following ingestion of food containing staphylococcal enterotoxins. There is generally a rapid onset of symptoms, appearing around 3 hours after ingestion (range 1–7 hours) which include nausea, vomiting, abdominal cramps, and diarrhoea. While illness is acute, recovery is rapid (within 2 days).
Levels of contamination with *S. aureus* are moderate to high for both boned beef and sheep meat products. This is in most part attributable to cross-contamination form the hands of meat workers (Desmarchelier, Higgs, Mills, Sullivan, & Vanderlinde, 1999; Vanderlinde, Fegan, Mills, & Desmarchelier, 1999). Changes to glove wearing practices is believed to have resulted in a lower prevalence of S. aureus on raw meat (David Phillips, Jenson, & Sumner, 2008). Foodborne illness is attributed to recontamination post-cooking accompanied by temperature abuse.

In comparable reviews of the effectiveness of traditional meat inspection for beef, sheep and goats conducted by the EU (EFSA Panel on Biological Hazards, 2013a, 2013b) the "*decision tree excluded hazards that are introduced and/or for which the risk to public health is associated with growth after carcase chilling (i.e. toxins of S. aureus)*" (EFSA 2013a). Additionally, it is noted "*some of these are caused by pathogens that might have zoonotic implications (e.g., S. aureus) the risk arising to public health from these hazards is not considered to be important as it is mostly related to occupational exposure or the way the meat is handled after it leaves the slaughterhouse*" and "*risk of (foodborne) disease seems not to be correlated with the occurrence in raw meat*".

In a specific review that considered the source(s) of *S. aureus* for meat EFSA (2009) stated "*several reports suggest that S. aureus may become established as part of the endemic flora of food handlers, with subsequent contamination of carcases and meat. Vanderlinde et al (1999)* [Australia] *used microrestriction analysis of the DNA of coagulase positive staphylococci isolated from beef mince and from workers hands and concluded the primary source of contamination was the hands of people working in the slaughterhouse. Desmarchelier et al (1999)* [Australia] *reported increased levels of staphylococci carcase contamination within 72hrs of chilling and these authors suggest that workers' hands were the primary source of contamination for carcases. Based on genotyping Schlegelova (2004) also concluded that the animals were not the source of contaminating strains*".

Similar conclusions are drawn in the risk profile work; (Sumner, Ross, et al., 2005) in which foodborne illness resulting from *S. aureus* intoxication result largely from either undercooking or post-cooking recontamination by food handlers in conjunction with temperature abuse enabling toxin build-up.

6.2.5 *Clostridium perfringens*

Illness is caused by ingestion of a large number ($>10^6$) of cells that multiply and sporulate in the lower small intestine, producing an enterotoxin which causes profuse diarrhoea and abdominal cramps about 16 hours after consumption. Gastrointestinal illness is generally mild.
Clostridium perfringens is recognised as being frequently associated with meat dishes that have been subjected to temperature abuse. While *C. perfringens* is a significant pathogen in ruminants, there is not much evidence that the strains responsible for illness from temperature abused meals have originated from the ruminant. A survey of beef and lamb at retail (D. Phillips et al., 2008) found C. perfringens in 0/94 beef and 1/92 (30 cfu/g) lamb samples.

6.2.6 *Toxoplasma gondii*

Toxoplasma gondii is a protozoan parasite that infects most species of warm-blooded animals, including humans. Acquired infection with *Toxoplasma* in immunocompetent persons is generally an asymptomatic infection. However, 10% to 20% of patients with acute infection may develop cervical lymphadenopathy and/or a flu-like illness. Congenital toxoplasmosis results from an acute primary infection acquired by the mother during pregnancy and may result in vision problems.

Worldwide, toxoplasmosis is a very common parasitic infection in warm-blooded animals including humans (30 – 40% of Australians have antibodies). *Toxoplasma gondii*, the causative parasite, has a complex life cycle, with 3 main routes of infection: from ingestion of sporozoites originating in feline faeces; from ingestion of undercooked infected meat; and from congenital infection in the womb. As with other domestic animals coming to slaughter, sheep and lamb may be infected with Toxoplasma gondii. Human toxoplasmosis can be asymptomatic (no clinical symptoms) or can have more severe consequences such as congenital neurological defects, eye disease, or potentially fatal encephalitis in immunocompromised individuals.

Contact with domestic cats is considered a major source of human toxoplasmosis; the proportion of cases caused by eating raw or undercooked meat is not known, however the consumption of undercooked sheep meat has been identified as a risk factor in epidemiological studies. From being a parasite of cats only worthy of consideration by women in early pregnancy, Toxoplasma has now become a food safety concern.

There is ongoing international interest in the significance of meat as a source of toxoplasmosis. For example, the WHO Global Burden of Foodborne Disease study[41] and a recent publication on the risks to US consumers from US domestic lamb (Guo et al., 2016) highlight the potential burden of disease. An MLA report[42] found the serological prevalence in sheep to be 11.5%, and lower prevalence would be expected in lamb. Genetic analysis suggests that Australian strains are not closely related to South American strains that may be more virulent in humans. *Toxoplasma gondii* can be commonly detected in lamb mince in Australia (Dawson, 2019).

One preventative measure is by properly preparing and cooking and/or freezing food. Relatively mild pasteurisation is required to destroy tissue cysts and temperatures of 67°C and above will render contaminated meat safe[43]. Frozen product storage temperatures are sufficient to inactivate the parasite. (Kotula et al., 1991).

The seroprevalence of T. gondii in cattle is low (Almeria & Dubey, 2021) but beef can be potentially significant because beef is more likely to be consumed raw (EFSA Panel on Biological Hazards et al., 2018). There are no recent studies on the prevalence of *T. gondii* in Australian cattle.

6.2.7 *Bacillus cereus*

Two types of foodborne illness are associated with *B. cereus* – emetic (vomiting) and diarrhoeal. The emetic syndrome is caused by ingesting heat stable pre-formed toxin produced in the food during active growth of the bacteria. The diarrhoeal syndrome is caused by diarrhoeal toxins produced during growth of the bacteria in the small intestine following ingestion of large numbers of the bacteria.

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[41] World Health Organization. (2015). *WHO estimates of the global burden of foodborne diseases: Foodborne disease burden epidemiology reference group 2007-2015*. WHO PRINT-1347-OMS-FOS-FERGreport-20160408.indd (who.int)

[42] Hamilton, D et. al (2021) Investigation of the viability and national serological prevalence of Toxoplasma gondii in Australian sheep. V.MFS.0419 Toxoplasma gondii (sheep) | Meat & Livestock Australia (mla.com.au)

[43] Advisory Committee on the Microbiological Safety of Food. (2012). *Risk profile in relation to toxoplasma in the food chain*. Food Standards Agency. [ARCHIVED CONTENT] ACMSF microbiology reports | Food Standards Agency (nationalarchives.gov.uk)

Bacillus cereus is an accepted foodborne pathogen, causing both emetic and diarrhoeal illness, due to the production of toxins. B. cereus group species (about 12 species have been described in this group, including B. anthracis) are accepted as coming from soil, which may contaminate products such as rice, lentils, and other agricultural products. If found in meat, it is most likely to have no significance, or, in a meat dish could grow to high enough levels to produce sufficient toxin to cause diarrhoeal illness, if the product is temperature abused.

6.2.8 *Mycobacterium tuberculosis*

M. tuberculosis causes tuberculosis in humans and is not usually considered to be foodborne, except through the consumption of unpasteurised milk. See Chapter 2

6.2.9 Aflatoxin

Aflatoxin is a toxin produced by certain species of fungi (moulds) that commonly contaminates maize and other types of crops during production, harvest, storage, or processing. Exposure to aflatoxin is known to cause both chronic and acute injury to the liver and potentially, carcinoma.

The significance for meat is the potential for animals to consume contaminated feed and for residues of aflatoxin to be found in meat. See Chapter 2

6. 3 Potential hazards

These potential hazards are bacteria that cause disease in humans but have not been established as foodborne pathogens.

6.3.1 *Clostridiodes difficile*

Clostridium (now *Clostridiodes*) *difficile* is the main cause of hospital-acquired diarrhoea with identified aetiology although community-acquired cases are increasingly being reported. It is responsible for considerable patient morbidity and is often associated with the use of certain antibiotics.

There is no objective evidence for *C. difficile* as a foodborne pathogen. Hypotheses are based on detection of the organism in foods (e.g., vegetables, molluscs, fresh and processed meats) and the observation of related molecular types present in foods and infected humans*. C. difficile* can be isolated from cattle and sheep and association between cattle and human disease has been suggested (Rodriguez-Palacios et al., 2006). In Australia as well as internationally, some *C. difficile* types are associated with both human and farm animal sources, suggesting possible bidirectional transfer, perhaps through the environment (Knetsch et al., 2018).

In Australian cattle, calves were shedding much more often than cattle (Daniel R. Knight, Thean, Putsathit, Fenwick, & Riley, 2013). Despite high shedding rates, the prevalence of detection on carcases was low and at a low concentration (D. R. Knight, Putsathit, Elliott, & Riley, 2016). In sheep and lambs at slaughter establishments, the prevalence of C. difficile was low, and statistically lower in sheep than in lambs (Daniel R. Knight & Riley, 2013).

6.3.2 *Arcobacter* sp.

Some *Arcobacter* species have been suggested as potential human gastrointestinal pathogens, and they have been isolated from numerous food products and animal carcases.

In an Australian study, surface swab samples were collected from 100 beef carcasses from export processors at the end of processing, prior to chilling. 20 (20.0%) were contaminated with Arcobacter spp., and 5 of these had quantifiable levels of contamination ranging from 0.12 to 0.31 CFU/cm2. Three species of Arcobacter, *A. butzleri*, *A. cryaerophilus*, and *A. skirowii*, were identified by PCR (L. L. Duffy & Fegan, 2012).

6.3.3 *Aeromonas* sp.

Aeromonas sp. were found in the 1980s in the stools of humans with diarrhoea, more frequently than asymptomatic individuals, supporting the hypothesis that it may be responsible for human gastroenteritis. Aeromonas sp. may be found in a range of foods of animal origin, including fish. It is psychrotrophic, which means it is able to grow at refrigeration temperatures, which increases the level of concern. It's significance as a human pathogen is not widely accepted, and the possibility of foodborne transmission is even less frequently investigated.

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2. Sourcing safe and healthy animals

Summary

Safe and healthy animals are assured for processing into meat because of multiple layers of controls managed between the Australian Government, State and Territory Governments, organisations fulfilling specific functions (e.g., Animal Health Australia), and the producers and processors themselves.

Producing safe and healthy animals begins on farms, where strong laws and enforcement, biosecurity, and life-time traceability combine to produce animals with a high degree of confidence about their credentials.

State and Territory governments are responsible for agricultural practices, with a nationally coordinated approach. Field veterinarians providing advice and services to producers to ensure that animal health is maintained. In addition to national biosecurity (restricting incursions of disease) to maintain Australia's status of freedom from many production animal diseases, and the infrastructure to maintain that status exists with state departments, producer awareness, and national coordination through Animal Health Australia. Traceability will assist, in the case of any disease outbreak, to minimize its impact.

A system for Food Chain Information (FCI) is based on the traceability system. Properties that are associated with particular hazards (e.g., persistent chemicals) are identified, and the identification of animals that have been on that property is maintained for life. Food Chain Information (FCI) associated with individual animals also travels through the supply chain with the animal to provide whole-of-life traceability and data. In addition to location data, FCI includes use of feeds, treatments with veterinary chemicals etc. and in the case of cattle, use of hormonal growth promotants. Production chain traceability is legislated by State and Territory Governments, and industry systems provide the means to comply with regulations as well as providing commercial incentives to comply. Properties are audited by commercial auditors.

At meat processing establishments FCI is reviewed, animals are inspected both ante-mortem and post-mortem and data recorded. Animals are admitted to slaughter based on FCI and ante-mortem inspection and may later be excluded from the food supply based on post-mortem inspection. Samples are analysed to monitor compliance with requirements such as agricultural and veterinary chemical usage, compliance with Maximum Residue Limits (MRLs), and hygienic quality. Action is taken for residues and hygiene at levels of concern.

The continuous collection of data about compliance and the outcomes of the system are reviewed by producers, processors, and both State, Territory, and the Australian Government departments with responsibility for the system; there is a high level of motivation for the system to work and continually improve its efficiency.

The data collected at processing establishments supports the claims made for animal health, and production of safe meat.

Contents

1. The system

At the animal production stage, it is critical that animals are raised in a way that ensures that they are safe and suitable for human consumption.

The Codex *Code of Hygienic Practice for Meat*[44] has a Principle (5.1, i) that

> Primary production should be managed in a way that reduces the likelihood of introduction of hazards and appropriately contributes to meat being safe and suitable for human consumption.

And specifically (clause 36) that

> Only healthy, clean and appropriately identified animals should be presented for slaughter

In the *Australian Standard for the hygienic production and processing of meat and meat products for human consumption* (AS4696), there are requirements for raising animals according to good husbandry practices, identifying disease when it occurs, identifying sources of animals, and only admitting animals to slaughter after assessing their suitability.

This chapter will describe systems and infrastructure in place to ensure that safety and suitability of animals for meat processing is assured. Animal diseases and chemical residues that may cause concern for the safety and suitability of meat processed from those animals are managed. The incidence of diseases and chemical residues in Australian animals that may affect the safety of meat demonstrate that the system effectively controls these hazards.

Effective national surveillance and control of animal diseases in Australia relies on an integrated system and cooperative partnerships between government agencies, organisations, commercial companies, and individuals involved in animal industries.

The Australian Government Department of Agriculture, Fisheries and Forestry (DAFF) advises on and assists with the coordination of national animal health policy. This department is responsible for international animal health matters, including biosecurity, export certification, and trade. Individual state and territory governments are responsible for animal health matters within their borders. Such matters include disease surveillance and control, emergency preparedness and response, chemical residues in animal products, livestock identification and traceability and animal welfare. The Australian, State and Territory Governments coordinate policy through the Agriculture Senior Officials' Committee (AGSOC) and the Agriculture Ministers' Forum (AGMIN). National coordination for animal health matters is supported through the Animal Health Committee (AHC). [45]

The National Biosecurity Committee (NBC) provides strategic leadership across state and territory governments to develop and oversee implementation of national approaches and policies for emerging and ongoing biosecurity matters. NBC membership comprises senior officials from the Australian, state, territory, and New Zealand governments, with Animal Health Australia (AHA), Plant Health Australia and the Australian Local Government Association included as observers. NBC is supported the Animal Health Committee (AHC) focusing on national animal health issues. [46]

AHC provides the Australian, state and territory governments with nationally coordinated scientific advice on animal health issues through NBC and AGSOC. AHC leads the development of government

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[44] Codex Alimentarius Commission. 2005 (editorial amendments 2013) Code of Hygienic Practice for Meat. CAC/RCP 58-2005 Code of Hygienic Practice for Meat (fao.org)

[45] Animal Health Australia (2021) Animal Health in Australia System Report. 1st ed. AHAH2001_Dan-AHiA-2020-Systems-Report_FA2_Digital-min.pdf (animalhealthaustralia.com.au)

[46] Animal Health Australia (2021) Animal Health in Australia System Report. 1st ed. AHAH2001_Dan-AHiA-2020-Systems-Report_FA2_Digital-min.pdf (animalhealthaustralia.com.au)

policies, programs, operational strategies and standards in national animal health, animal biosecurity and veterinary public health.

2. Supporting infrastructure

2.1 Animal Health Australia

Australian governments and industry groups recognise a need for high-level decisions on strategic policy for future planning and funding of national animal health service programs. Animal Health Australia (AHA) is an independent national animal health body in Australia, bringing together government and industry to deliver animal health and biosecurity.

In 2023, AHA had 35 member organisations spread across four membership groups:

- Commonwealth, state, and territory governments
- livestock industries
- service providers
- associate members.

Within the framework of a not-for-profit company, AHA manages more than 50 national programs that improve animal and associated human health, biosecurity, market access, livestock welfare, productivity, and food safety and quality.

AHA, with members, scans the horizon for threats and opportunities, advocate for and drive solutions and take a whole-of-sector approach to ensure the long-term success of Australia's animal health and biosecurity system.

2.2 Animal health laboratories

Government laboratory networks[47] There are eight government animal health laboratories in Australia. The Commonwealth Scientific and Industrial Research Organisation Australian Centre for Disease Preparedness (ACDP or CSIRO–ACDP, formerly Australian Animal Health Laboratory [AAHL]) in Geelong, Victoria is the national animal health laboratory. There are also animal health laboratories in all six states and the Northern Territory. All government laboratories play a key role in testing to support disease surveillance and response, biosecurity policy, and domestic and international trade for animals and animal products.

There are seven Australian universities that have veterinary schools that operate as independent entities and are important to the national animal health system. Each veterinary school has its own diagnostic laboratory and experts to support its diagnostic, teaching, and research activities. These experts cover a broad range of animal health laboratory specialties, including pathology, molecular biology, virology, bacteriology, mycology, parasitology, and immunology. Collectively they represent the major national repository of veterinary-trained laboratory diagnosticians.

2.3 Integrity Systems Company (ISC)

Integrity Systems Company (ISC) is a wholly owned subsidiary and business unit of Meat & Livestock Australia (MLA). MLA is a not-for-profit company set up through the Meat and Live Stock Industry Act 1997 and operating under a Statutory Funding Agreement with government.

[47] Animal Health Australia (2021) Animal Health in Australia System Report. 1st ed AHAH2001_Dan-AHiA-2020-Systems-Report_FA2_Digital-min.pdf (animalhealthaustralia.com.au)

ISC runs three programs which are integral parts of the system to ensure that animals presented for slaughter are safe and fit for human consumption:

1. Livestock Production Assurance (LPA) – covering the practices on farm necessary to ensure food safety, biosecurity, and animal welfare on farm (see 3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA)
2. National Vendor Declaration (NVD) – covering supply of essential food safety information when animals are transported to another property (see 3.6 Transmission of information about animals (National Vendor Declaration))
3. National Livestock Identification System (NLIS) – covering the movement of individual animals or groups of animals from one property to another (see chapter 3. Identification of animals)

2.4 National Residue Survey (NRS)

The National Residue Survey (NRS)[48] supports Australia's primary producers and agricultural industries by verifying Australia's status as a producer of clean food and facilitating access to domestic and export markets.

The core work of the NRS is to facilitate the testing of animal and plant products for

- Pesticides that might be applied to crops and result in contamination of feed
- veterinary medicine residues (for both registered and unregistered chemicals)
- environmental contaminants, such as heavy metals and persistent (no longer used) agricultural chemicals.

Product testing is done through either random or specifically designed sampling protocols. NRS programs encourage good agricultural practices, help to identify potential problems, and indicate where follow-up action is needed.

Residue monitoring aims to:

- provide an estimate of the occurrence of residues in products (using systems based on sampling and statistical probability)
- confirm (or otherwise) that residues in products are below set limits

Random residue monitoring includes 19 meat programs. The random programs are designed to:

- ensure participating industries satisfy Australian export certification and importing country requirements
- enable domestic meat processing facilities to satisfy state and territory government regulatory authority licensing requirements
- provide evidence of good practice in the use of pesticides and veterinary medicines by the participating industries
- support quality assurance initiatives in participating industries.

Cattle program

The cattle program has been operating since the early 1960s. Around 5,000 samples are collected for analysis each year (Table 1). The results are compared with the Australian standards and where appropriate, relevant international standards.

[48] National Residue Survey - DAFF (agriculture.gov.au)

Table 1 Analytical screens for the cattle program

Analytical screen	Chemical group	Analytes
Veterinary medicines and pesticides	Anthelmintics	includes macrocyclic lactones, salicylanilides and benzimidazoles
	Antimicrobials	includes aminoglycosides, anticoccidials, beta lactams, quinolones, macrolides, nitrofurans, phenicols, sulfonamides and tetracyclines
	Hormones	includes stilbenes, corticosteroids, resorcylic acid lactones and androgenic steroids
	Other medicines	includes beta-agonists and non-steroidal anti-inflammatory drugs
	Pesticides	insecticides, fungicides, and herbicides
Environmental contaminants	Organochlorines	aldrin, chlordane, dieldrin, DDT, endrin, HCB, HCH, heptachlor, lindane, mirex, PCBs and pentachlorobenzene
	Metals	antimony, arsenic, cadmium, lead, and mercury

Sheep program

The sheep program has been operating since the early 1960s. Each year 2,500-3,000 samples are collected for analysis (Table 2). The results are compared with Australian standards and where relevant, international standards.

Table 2 Analytical screens for the sheep program

Analytical screen	Chemical group	Analytes
Veterinary medicines and pesticides	Anthelmintics	includes macrocyclic lactones, salicylanilides and benzimidazoles
	Antimicrobials	includes aminoglycosides, anticoccidials, beta lactams, quinolones, macrolides, nitrofurans, phenicols, sulfonamides and tetracyclines
	Hormones	including stilbenes, corticosteroids, resorcylic acid lactones and androgenic steroids
	Other medicines	including beta-agonists and non-steroidal anti-inflammatory drugs
	Pesticides	insecticides, fungicides, and herbicides
Environmental contaminants	Organochlorines	aldrin, chlordane, dieldrin, DDT, endrin, HCB, HCH, heptachlor, lindane, mirex, PCBs and pentachlorobenzene
	Metals	antimony, arsenic, cadmium, lead, and mercury

Goat program

The goat program has been operating for a number of years. Around 300 samples per year are collected for analysis (Table 3). The results were compared with Australian standards and where relevant, international standards (Table 3).

Table 3 Analytical screens for the goat program

Analytical screen	Chemical group	Analytes
Veterinary medicines and pesticides	Anthelmintics	includes macrocyclic lactones and benzimidazoles
	Antimicrobials	includes aminoglycosides, anticoccidials, beta lactams, quinolones, macrolides, sulfonamides and tetracyclines
	Hormones	includes corticosteroids
	Other medicines	includes beta-agonists and non-steroidal anti-inflammatory drugs
	Pesticides	insecticides, fungicides, and herbicides
Environmental contaminants	Organochlorines	aldrin, chlordane, dieldrin, DDT, endrin, HCB, HCH, heptachlor, lindane, mirex, PCBs and pentachlorobenzene
	Metals	antimony, arsenic, cadmium, lead, and mercury

3. Production-level controls

The controls in place for managing animal disease and chemical contamination range from national policies and programs, through industry-operated systems and procedures that, together, provide an assurance of animals arriving at slaughter establishments in the best possible condition and with information that assists meat processors to manage the residual risks.

3.1 National Biosecurity

Entry of animals and animal products into Australia is administered by the Department under the Biosecurity Act 2015 (Cwlth), to protect the ongoing health and viability of Australia's livestock, wildlife, agriculture, and other enterprises.

DAFF works across the biosecurity continuum to manage biosecurity risks from imported live animals and biological goods.

3.2 Property Identification Codes (PICs)

A Property Identification Code (PIC) is an eight-character code allocated by the Department of Primary Industries (DPI) or an equivalent authority in each state or territory to identify a livestock-producing property. Producers must have a PIC to move livestock on and off a property – it forms the basis of Australia's traceability programs.

There are differences between states and territories in how PICs are managed. In some states, amalgamation of separate PICs owned by the same entity, into a single PIC, is allowed. In other states, one property can be issued multiple PICs if there are livestock owned by multiple entities on the property.

PIC numbers, rather than properties are the basis for all traceability and integrity programs. PICs may be assigned a status that provides a warning about the status of animals that have resided on that PIC (Table 4).

When animals are transferred from one PIC to another accredited LPA PIC, LPA NVDs are used (see 3.6 Transmission of information about animals (National Vendor Declaration)) to record the livestock movement between the PICs and record information on the NVD, and submit data to the NLIS database.

Table 4 Examples of Property statuses that may be assigned by the state/territory authority

Program	Status	Assigned to…
AQ	AQ	Properties under quarantine due to anthrax.
CT	CTP	Properties that have had cotton trash delivered for use as mulch or stock feed.
EW	EW1	Properties carrying cattle with a high-risk status that may be unfit for human consumption. The early warning status is disclosed when a database user conductsPIC status check to prepare for consignments.
FO	MC	Properties identified as a source of cattle with metal contamination.
NARM National Antibacterial Residue Minimisation	KV	Properties with a history of antibacterial residue detections in bobby calves.
NORM (OC) National Organochlorine Residue Management	M	Properties with a low risk (nil/limited test history) of OC-contamination and/or in areas with significant past OC use.
	R	Properties at minimal risk of producing cattle with unacceptable OC residues.
	T1F T2F	Properties with a reduced risk of OC-contamination. NRS funds a fat-sample OC test of one animal in each consignment
	T3F T3V	Properties with a medium-high OC-contamination risk. NRS funds fat-sample test of one animal in each consignment – commercial arrangements apply if more cattle are tested. Sample and hold carcase and companion cattle until results are available.
	T4	Properties with a high risk of OC-contamination. NRS won't fund tests – commercial arrangements apply.
	X	Properties that should not be trading cattle (for sale or slaughter) as the PIC is under regulatory restrictions. Contact relevant State DPI for instructions.

3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA)

The LPA program is the Australian red meat industry's on-farm assurance program covering food safety, animal welfare and biosecurity. It provides evidence of livestock history and on-farm practices when transferring livestock through the value chain. Producers declare this information on LPA NVDs, which are required for all livestock movements including property-to-property, through saleyards, direct to processors and feedlots, and the live export trade.

The program is managed on behalf of the red meat industry by the Integrity Systems Company. Producers who are LPA-accredited commit to carrying out on-farm practices that support responsible red meat production and the integrity of the traceability system. LPA provides online learning modules that explain the required farm practices and how to meet the requirements during routine farm operations. Animal Welfare is a compulsory training module. An accreditation assessment consisting of an online multiple-choice examination on all program standards is conducted. LPA- accredited properties are independently audited.

The first 5 LPA requirements (not biosecurity or animal welfare) were determined to be the necessary generic critical control points (using Codex approach to HACCP) for delivery of safe animals for processing. (Horchner, Brett, Gormley, Jenson, & Pointon, 2006).

Property risk assessment[49]: any possible risk on the property in which livestock could come into contact with physical and/or chemical contaminants are identified and strategies for how this risk will be controlled are implemented. If livestock encounter persistent chemicals, the meat produced may contain unacceptably high chemical residues, impacting on food safety and market access. Similarly, physical contaminants such as wire could cause harm to animals and people if they become lodged in meat tissue.

Safe and Responsible animal treatments[50]: Every LPA accredited producer must ensure that animal treatments are administered in a safe and responsible manner that minimises the risk of chemical residues and physical hazards. This requirement requires producers to undertake a chemical users course, have records of animals that have received treatments and have written authorisation and directions for any off-label chemical or drug use.

Stock foods, fodder crops, grain, and pasture treatments[51] Livestock owners must undertake safe livestock feeding practices, including minimising livestock exposure to feeds containing unacceptable chemical residues or Restricted Animal Material (RAM, such as blood meal, meat meal, meat and bone meal). Livestock owners keep records of agricultural chemical treatments, Commodity Vendor Declarations (CVDs) that accompany all purchased stock feeds etc.

Preparation for dispatch of livestock [52] Livestock that are dirty, not fit for transport etc., may be an animal welfare concern, and may compromise food safety need to be segregated and not dispatched from the farm. Documentation needs to be prepared.

Livestock transactions and movements[53] Recording livestock movements ensures treatments and exposure to food safety hazards are traceable. Livestock producers keep records and accurately complete NVDs and update the NLIS database.

Biosecurity[54] – To ensure that the risks of introducing infectious diseases to livestock production properties and spreading diseases between properties are minimised, each PIC has a farm biosecurity plan and implements practices such as knowing the health status of arriving animals, keeping them separate for a period of time, inspecting livestock for ill health.

Animal welfare:[55] Livestock health and wellbeing is fundamental to the success and sustainability of every farm. The requirements of the Australian Animal Welfare Standards and Guidelines for cattle, sheep, and goats (as applicable), must be met.

3.4 Maintaining safety at feedlots

The National Feedlot Accreditation Scheme (NFAS) is an audited technical scheme to ensure the safety and integrity of grain-fed beef and is the cornerstone of eligibility for beef to be described as 'grain-fed' within prescribed industry standards. The system is responsive to customer expectations, particularly in relation to cattle welfare and the environment.

[49] Property Risk Assessment | Integrity Systems
[50] Safe and Responsible Animal Treatments | Integrity Systems
[51] Stock Foods, Fodders Crops, Grain and Pasture Treatments | Integrity Systems
[52] Preparing livestock for dispatch | Integrity Systems
[53] Livestock Movements | Integrity Systems
[54] Biosecurity | Integrity Systems
[55] Animal welfare | Integrity Systems

Table 5 Some relevant standards in the National Feedlot Accreditation Scheme

Standard	Name	Explanation
FS1	Property Risk Assessment	Systems have been implemented to minimise the risk of livestock being exposed to sites that are unacceptably contaminated with organochlorine or other persistent chemicals, or other potential source of persistent chemicals, and being exposed to sources of potentially injurious physical contaminants in meat intended for human consumption.
FS2	Safe and Responsible Animal Treatments	Systems have been implemented to ensure that animal treatments are stored and administered in a safe and responsible manner to minimise the risk of chemical residues and physical hazards in livestock intended for human consumption.
FS3	Fodder Crop, Grain and Pasture Treatments and Stock Foods	Systems have been implemented to manage the exposure of livestock to food containing unacceptable chemical contamination to minimise the risk of chemical residues in livestock and to eliminate the risk of animal products being fed to ruminant livestock intended for human consumption.
FS4	Additive, Premix and Liquid Supplement Manufacturer Accreditation	Systems have been implemented to manage the exposure of livestock to foods containing unacceptable chemical contamination to minimise the risk of chemical residues in livestock and to eliminate the risk of animal products being fed to ruminant livestock intended for human consumption.
FS5	Preparaton for Dispatch of Livestock	Systems have been implemented to ensure that the selected livestock are fit for transport and that the risk of stress and contamination of livestock during assembly and transport is minimised.
FS6	Livestock Transactions and Movements	A system has been implemented to ensure traceability of the current status of all livestock with respect to treatment or exposure to relevant food safety hazards for all livestock movements between livestock production enterprises including slaughter and live export.
LM4	Animal Welfare	The welfare of livestock is not compromised and prompt and appropriate remedial action is taken when required.
LM7	Biosecurity	The likelihood of disease entry into and spread from the feedlot and associated utilisation area is minimised.

In order to be Accredited each enterprise must comply in all respects with the NFAS rules and standards (Table 5), meet chemical user training requirements and LPA requirements. Enterprises are audited annually by certified external auditors, AUS-MEAT Limited.[56]

3.5 Commodity Vendor Declarations[57]

The Commodity Vendor Declaration (CVD) requires suppliers of commodities intended for use as livestock feed or fodder to declare whether chemicals have been used during production. This information ensures that only commodities free of unacceptable levels of chemical residues are used

[56] AUSMEAT 2022. National Feedlot Accreditation Scheme Handbook. Rules and Standards of Accreditation. NFAS - Rules and Standards of Accreditation.pdf (ausmeat.com.au)
[57] Stock Foods, Fodders Crops, Grain and Pasture Treatments | Integrity Systems

as livestock feed or fodder and hence that the products of livestock comply with relevant residue standards.

3.6 Transmission of information about animals (National Vendor Declaration)

The LPA NVD [58] communicates the food safety and treatment status of every animal every time it moves along the supply chain – between properties, to saleyards, or to processors.

Producers must be LPA accredited to access to LPA NVDs. The requirement for LPA accreditation has very strong commercial demand. LPA accredited producers can only source livestock from other LPA Accredited properties, and customers (processors, retailers) very often demand LPA accreditation.

The NVD must be backed up by accurate farm records as specified and audited in the LPA program.

National Animal Heath Declarations[59] are a way for producers to provide information about the animal health status of their flocks and herds. The declaration asks questions about the origin of animals, the application of diagnostic tests, treatments applied, and vaccinations given. Buyers use the information provided to determine the health risks associated with the animals offered for sale. These declarations can be generated with the electronic NVD (eNVD).

3.7 Records of animal movements

The NVD also acts as movement documentation throughout the supply chain. Each time livestock are moved off a PIC, a livestock movement must be recorded on the NLIS Database. The NLIS has rules about who is responsible for recording the movement on the database. Some states require the use of waybills, or travelling stock statements, and recognise the NVD as fulfilling the purpose of these documents.

4. Inspection at processing establishments

Meat processing establishments are the last point where the safety and suitability of animals for human consumption are determined. Additionally, they are the relevant and convenient point in the supply chain to collect samples for various monitoring programs.

4.1 Ante-mortem inspection

The *Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS4696) requires animals to be admitted to a meat processing facility for slaughter only after inspection ensures that wholesomeness of the meat is not jeopardised (6.5).

Inspection includes (6.6-6.9 and 8.5,8.6) ensuring that animals:

- are identified according to national standards (see 3. Identification of animals)
- have known previous location to ensure that they have not come from an area subject to animal health restrictions, or in contact with animals being affected by disease (see 3.3 Information passing through the supply chain)
- have not been fed materials that may recycle disease (see 3.5 Commodity Vendor Declarations)

58 National Vendor Declaration | Integrity Systems
59 Farm Biosecurity awareness Campaign Declarations - Farm Biosecurity (AHA, PHA)

- have not been grazed on an area irrigated with sewage (see 3.2 Property identification (PICs))
- are not affected by a contagious or notifiable disease
- have not been exposed to unacceptable levels of dangerous substances (drugs, chemicals above limits) (see 3.3 Information passing through the supply chain)
- have not been exposed to unacceptable levels of irradiation
- have any disease or abnormality that could result in contamination of other animals or meat or jeopardise wholesomeness (see 4.2 Post-mortem inspection)
- are clean
- Inspection includes review of records that are available from the NVD) (see 3.3 Information passing through the supply chain) as well as observation of the animals.

Inspections are performed by meat safety inspectors, and in establishments operating under the Export Control (meat and meat products) Rules, by an authorised officer. Guidelines outline the process of ante-mortem inspection and disposition of animals at export-registered meat establishments.[60]

Disposition of animals after inspection include being passed for slaughter, passed for slaughter subject to conditions, being withheld for further examination, or being condemned. (8.8-8.24). Animals can be condemned, for, among other things, abnormal odour, dying or moribund, fever, acute disease, emaciation, septicaemia (AS4696 – schedule3).

4.2 Post-mortem inspection

Post-mortem inspection includes examination of the carcase, and carcase parts for human consumption as well as other parts needed to be inspected to ensure that the parts for human consumption are not affected by disease or abnormalities (10.4) following detailed procedures[61]. Inspection activities include examination of

- Lymph nodes
- Lungs
- Heart
- Liver
- Gastrointestinal tract
- Spleen
- Kidney
- Masseter muscles (cattle)
- Tongue (cattle)
- Other parts if recovered for human consumption (AS4696 – schedule 2)

The carcase and all its parts may be condemned, or only affected parts may be condemned depending on the condition and circumstances (AS4696- schedule3).

DAFF collects data on total carcase condemnation. These data are reported and analysed by Pointon, Hamilton, and Kiermeier (2018) (supplement 1 – 5.3).

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[60] DAFF. 2023. Export Meat Operational Guideline 3.3 ante-mortem inspection. export-meat-operational-guideline-3-3-ante-mortem-inspection-guideline.pdf (agriculture.gov.au)

[61] DAFF ELMER3 2023 Export Meat Operation Guidelines 3.4 Post-mortem inspection. export-meat-operational-guideline-3.4-post-mortem-inspection.docx (live.com)

4.3 Monitoring programs

Samples are collected post-mortem for various monitoring programs including for chemical residues and contaminants (see 5.3.1 Surveys for residues of agricultural, veterinary chemicals and environmental contaminants) and the National TSE Surveillance Project (5.2.7 Transmissible Spongiform Encephalopathies).

5. Hazards in animals

Some animal diseases can pose a risk to human health by transmission through meat. Additionally, there is a concern that some diseases may spread from one animal to another (and one country to another) via meat and meat products.

Chemicals, whether naturally occurring in the production environment, intentionally used as agricultural or veterinary treatments, or contaminants of feed, water, or the environment, all may impact on the safety and suitability of meat.

5.1 Animal diseases

Australia has a strong track record of freedom from the major epidemic diseases of livestock. Australia's geographical isolation provides a natural biosecurity barrier, which is supported by sound biosecurity policies and a history of successful disease eradication campaigns.

Australia reports to the World Organisation for Animal Health (WOAH) every 6 months on the status of listed diseases[62] (Table 6).

Table 6 Status for WOAH-listed diseases, 2022[63]

Infection / Disease	Cattle	Sheep	Goats	Last occurrence /notes
Anthrax	X	X	X	Limited distribution
Aujeszky disease	Free			Never occurred
Bluetongue virus	X	X	X	Specific zones
Brucella abortus	Free	Free	Free	Freedom declared in 1989
Brucella melitensis	Free	Free	Free	Freedom declared in 1989
Echinococcus granulosus	X			
Epizootic haemorrhagic disease virus	Present			Disease not reported
Foot and mouth disease virus	Free	Free	Free	1872; free without vaccination
Heartwater	Free	Free	Free	Never occurred
Mycobacterium tuberculosis	Free	Free	Free	Australia declared freedom from bovine tuberculosis in 1997; the last case in any species was reported in 2002
Paratuberculosis	X	X	X	
Q fever	X	X	X	
Rabies	Free	Free	Free	1867
Rift Valley Fever				Never occurred
Rinderpest				1923
Surra	Free	Free	Free	Never occurred

[62] Animal Health Australia. Animal Health in Australia Annual Report Animal Health in Australia - Animal Health Australia

[63] Animal Health Australia (2023). Animal Health in Australia Annual Report 2022, Animal Health Australia, Canberra, Australia. AHiA-2022-Annual-Report.pdf (animalhealthaustralia.com.au)

Trichinella spp.				*T. spiralis* is not present
Tularaemia				
West Nile fever				
Anaplasmosis	X			Northern Australia
Babesiosis	X			Northern Australia
Genital Campylobacteriosis	X			
Bovine Spongiform Encephalopathy	X			Never occurred; negligible risk
Bovine viral diarrhoea	X			Bovine viral diarrhoea virus 1 (BVDV-1) is present; BVDV-2 has never occurred
Enzootic bovine leucosis	X			Low prevalence in beef cattle; free in dairy cattle
Haemorrhagic septicaemia	X			Never occurred; strains *of Pasteurella multocida* are present, but not the 6b or 6e strains that cause haemorrhagic septicaemia
Infectious bovine rhinotracheitis / infectious pustular vulvovaginitis	X			Bovine herpesvirus (BHV)-1.2b is present; BHV-1.1 and BHV-1.2a have never occurred
Lumpy skin disease	Free			Never occurred
Mycoplasma mycoides subsp. Mycoides (contagious bovine pleuropneumonia)	Free			1967; Australia declared freedom in 1973
Theileriosis	Free			*Teileria orientalis* is present in Australia but OIE listed species *T. parva* and *T. annulata* are not
Trichomoniasis	X			
Trypanosomiasis	Free			Never occurred
Caprine arthritis / encephalitis			X	
Contagious agalactia		Free		*Mycoplasma agalactiae* has been isolated, but Australian strains do not produce agalactia in sheep
Contagious caprine pleuropneumonia			Free	Never occurred
Chlamydophila abortus				Never occurred
Maedi-visna		Free		Never occurred
Nairobi sheep disease		Free		Never occurred
Ovine epididymitis (*Brucella ovis*)		X		
Peste des petits ruminants		Free	Free	Never occurred; recognized by WOAH as free
Salmonellosis (*Salmonella abortusovis*)		Free		Never occurred
Scrapie		X		1952; atypical scrapie has been detected several times
Sheep pox and goat pox		Free	Free	Never occurred

The National List of Notifiable Animal Diseases of Terrestrial Animals facilitates disease reporting and control by identifying those diseases that must be reported to an agricultural authority. The list, agreed to by the AHC, includes all diseases notifiable to WOAH and endemic diseases of national significance. The requirement to report occurrences of listed diseases to government authorities is contained in state and territory legislation. States and territories also have their own lists of notifiable diseases, which contain all diseases on the national list as well as others that are of particular interest to an individual state or territory. Producers and veterinarians are also encouraged to report any unusual incidents involving animal mortality or sickness to ensure that any diseases of terrestrial or public health significance are investigated.[64]

5.2 Animal diseases with public health implications

The following material is based on the online supplementary information posted in support of the risk assessment underpinning proposed changes to post-mortem inspection practices (Pointon et al., 2018).

5.2.1 *Bacillus anthracis* (Anthrax)

Anthrax can infect humans through the consumption of meat contaminated with spores of Bacillus anthracis.

Anthrax is a nationally notifiable animal disease that affects a wide variety of animals. The disease usually occurs very suddenly in cattle and sheep and is subject to controls including quarantine, stock and livestock product movement control, tracing of at-risk animals and their products, vaccination, decontamination and appropriate carcass disposal (a detailed case study for a 1997 outbreak in north central Victoria is presented by Turner, Galvin, Rubira, and Miller (1999)). Areas at risk of anthrax occurrence are well defined and include central New South Wales and the northern and north-eastern districts of Victoria. In these areas, anthrax occurs only sporadically. Spatial modelling of cases suggests that the ecological niche of *B. anthracis* is defined by a narrow range of high soil pH, low organic content, calcium sulfate, and annual precipitation (Barro et al., 2016).

5.2.2 *Mycobacterium tuberculosis*

Australia declared freedom from bovine tuberculosis in 1997 and has since maintained ongoing surveillance for this disease, primarily through abattoir surveillance of cattle carcases (meat inspection) for TB-like granulomas. The level of confidence in Australia's freedom from bovine TB was >95% after the first year of the analysis and >99.5% from 2007 through to the end of the analysis period in 2015. Meat inspection for granulomas in the head and thorax of slaughtered cattle underpins this result by providing surveillance data on an extremely large number of animals each year (Sergeant, Happold, & Langstaff, 2017).

5.2.3 *Mycobacterium avium subsp. paratuberculosis*

Paratuberculosis or Johne's disease (JD) is a chronic infection caused by Mycobacterium avium subsp. paratuberculosis that produces ill thrift, wasting and death in ruminants. There are two strains found in Australia with some degree of host preference, however they can infect and move between multiple species. The sheep strain is mostly seen in sheep, but is also found in cattle and goats, and the cattle strain affects cattle, goats, deer, sheep and (rarely) alpacas. JD is a nationally notifiable animal disease.

JD has rarely been detected in northern and western beef cattle. JD is also uncommon in beef herds in south-eastern Australia. To help protect this situation, producers are encouraged to use a voluntary assurance system for cattle (the Johne's Beef Assurance Score). Producers are also encouraged to use a national Cattle Health Declaration to provide health information on cattle for sale and to assess the risk among cattle being purchased. JD in cattle remains a regulated disease in the Northern Territory and Western Australia, and state border controls are in place. Dairy cattle JD

[64] Animal Health Australia (2021) Animal Health in Australia System Report. 1st ed. AHAH2001_Dan-AHiA-2020-Systems-Report_FA2_Digital-min.pdf (animalhealthaustralia.com.au)

is endemic in the dairy industry in southeaster Australia. The dairy industry promotes hygienic calf rearing to help reduce the incidence of JD in replacement heifers. Buyers of dairy cattle are also encouraged to ask the seller for a written declaration of their JD Dairy Score.

Mycobacterium avium subsp. paratuberculosis, the causative agent of Johne's disease in cattle and sheep, has been hypothesised to cause, or be involved in the aetiology of, Crohn's disease in humans. Conclusive data supporting MAP as the cause of Crohn's disease is lacking (Agrawal, Aitken, Hamblin, Collins, & Borody, 2021; Honap et al., 2021).

A study of sheep in Australia found MAP in meat of sheep at a concentration of $10^{0.7}$ to $10^{1.4}$ viable cells/g and in peripheral lymph node at $10^{1.4}$ to $10^{1.8}$ viable cells/gram; there were similar findings in a small number of cattle (MLA report PRMS.044A (2004) cited by Richard J. Whittington, Waldron, and Warne (2010)). The effect of cooking temperature on the thermal inactivation of sheep and cattle strains of MAP was determined. At temperatures of 65–70 °C, MAP appeared to be less heat tolerant in skeletal muscle fluid than in previous reports using milk as the medium (Richard J. Whittington et al., 2010). The total thermal exposure of MAP during baking of 16 leg-of-lamb roasts in domestic ovens (R. J. Whittington & Waldron, 2010) was determined to result in more than 20 $\log_{10}$ reductions in most cases; that is, the product was microbiologically safe (Richard J. Whittington et al., 2010).

5.2.4 *Cysticercus bovis* (*Taenia saginata*)

T. saginata is not endemic in Australia and regional surveys even in the 1960's indicate a low prevalence of *C. bovis* (Fewster, 1967 cited by (Kiermeier, Hamilton, & Pointon, 2019)).

There are few recent publications related to *C. bovis* in Australian cattle, presumably because the infection is uncommon. The notable exception is (Pearse, Traub, Davis, Cobbold, & Vanderlinde, 2010) who reported on the first national abattoir survey for *C. bovis* undertaken in Australia during February 2008. As part of routine post-mortem inspection, 493,316 cattle were inspected for *C. bovis* in the 48 licensed Australian export abattoirs at the time (except those that only processed calves). The location of a lesion—heart, masseter, tongue, or other site—was recorded. The 23 suspected *C. bovis* lesions were further subjected to routine histopathology and PCR methods to verify their identity. While the authors did not indicate how many of the lesions were viable, ten lesions were too degenerated to allow DNA extraction. Therefore, while none of the 23 suspect samples were confirmed to be *T. saginata*, the ten degenerated lesions cannot be ruled out.

Data from DAFF for the financial years 2013/14 and 2014/15 indicate a very low total condemnation rate of 1 per 1,000,000 carcases, from export abattoirs each year (Kiermeier et al., 2019)

Evidence for the successful surveillance is provided by findings contemporary with the Pearse survey (above), finding cases (Brown, Dennis, Šlapeta, & Thompson, 2010) and investigations suggesting an imported feed component (D. Jenkins, Brown, & Traub, 2013).

5.2.5 *Sarcocystis hominis*

Sarcocystis spp. is an obligate two-host parasite and while it may cause illness (e.g., abortion) in experimental infections, clinical disease is rarely seen or recognised in the field. Symptoms in humans are very mild and are related to the presence of intramuscular cysts. There is only one species of *Sarcocystis* relevant to public health with respect to the consumption of infected beef and that is *S. hominis* (Jackman & Hathaway 2012). As the definitive host of *S. hominis* is the human species, transmission reflects access by livestock to contaminated pastures or feed ingredients (e.g., plant protein meals).

A survey was carried out to investigate the occurrence of *Sarcocystis* infection in the loin (*Musculus longissimus*) of Japanese and imported beef. Muscle tissue was examined by histological method and 29.5% of Australian samples had cysts. All except one were identified as *Sarcocystis cruzi and the* *remaining one* could not be distinguished as either *Sarcocystis hirsuta* or *Sarcocystis hominis* (Ono & Ohsumi, 1999).

5.2.6 *Echinococcus granulosus* (hydatidosis)

A retrospective study was conducted on cattle slaughtered at an eastern Australian abattoir between 2010 and 2018. This abattoir was selected based on the number of cattle slaughtered each year (approximately 300,000) and the wide geographic range from which cattle are sourced (all states and territories). The apparent prevalence of hydatid disease reported in any organ was 8.8% (n = 104,038; 95% confidence interval [CI] 8.8–8.9%). The liver, lungs, heart, spleen, and kidneys were reported infected with hydatid cysts. Of cattle reported infected with hydatid cysts, 75.6% had both the liver and lungs reported infected. True prevalence was estimated to be 33.0% (95% CI 24.4–44.4%). Three spatio-temporal clusters of hydatid-positive regions were identified. The most likely cluster was located in north eastern New South Wales from June 2012 to September 2015. (Wilson, Jenkins, Brookes, & Barnes, 2019).

Relatively few data are available regarding the presence of hydatids in sheep. D. J. Jenkins (2005) reviewed the control of hydatidosis in Australia and in a later publication (D. Jenkins et al., 2014) noted that the National Sheep Health Monitoring Program regularly reports sheep infected with hydatid cysts but at a lower prevalence of other worms.

5.2.7 Transmissible Spongiform Encephalopathies

Australia is free of bovine spongiform encephalopathy (BSE) and scrapie. WOAH has designated Australia as a ‘negligible risk’ status (the lowest risk).

Animal Health Australia (AHA) manages the National TSE Surveillance Project (NTSESP) to demonstrate that Australia remains free from transmissible spongiform encephalopathies (TSEs) affecting animals.

The NTSESP supports Australian trade by:

- maintaining a surveillance system for TSEs that is consistent with the WOAH Terrestrial Animal Health Code (OIE 2016; see Section 11.4—BSE and Section 14.8—Scrapie)
- providing assurance to all countries that import our cattle and sheep commodities that Australia remains free of these diseases.

Freedom from TSEs is supported by a ban on feeding restricted animal materials (RAM) to ruminants which includes meat, meat and bone meal, blood and bone meal, dog biscuits, poultry, offal meal, feather meal, fishmeal or any other animal meals or manures. The ban is enforced under state-based legislation and the Livestock Production Assurance (LPA) scheme.

5.3 Chemical contaminants

5.3.1 Surveys for residues of agricultural, veterinary chemicals and environmental contaminants

The NRS[65] supports Australia’s primary producers and agricultural industries by confirming Australia’s status as a producer of clean food and facilitating access to domestic and export markets.

Cattle program

Around 5,000 samples are collected for analysis each year. The results are compared with the Australian standards and where appropriate, relevant international standards Table 7).

[65] National Residue Survey - DAFF (agriculture.gov.au)

The results highlight excellent compliance with Australian standards and demonstrate the strong commitment of the cattle industry to good agricultural practice.

Sheep program
Each year 2,500-3,000 samples are collected for analysis. The results are compared with Australian standards and where relevant, international standards (Table 8).

The results highlight excellent compliance with Australian standards and demonstrate the strong commitment of the industry to good agricultural practice.

Table 7 Compliance rates for the past six years relative to Australian standards

Years	Samples collected	Compliance rates (%)
2015–16	4,386	100
2016–17	4,576	99.85
2017–18	4,576	99.89
2018–19	4,877	99.94
2019–20	5,352	99.91
2020–21	5,649	99.96

Table 8 Compliance rates for the past six years relative to Australian standards

Years	Samples collected	Compliance rates (%)
2015–16	2,539	99.68
2016–17	2,590	99.96
2017–18	2,591	99.69
2018–19	2,589	99.73
2019-20	2,682	99.78
2020-21	2,905	99.86

Goat program
Around 300 samples per year are collected for analysis. The results were compared with Australian standards and where relevant, international standards (Table 9).

The results highlight excellent compliance and demonstrate the strong commitment of the industry to good agricultural practice.

Table 9 Compliance rates for the past six years relative to Australian standards

Years	Samples collected	Compliance rates (%)
2015–16	155	98.7
2016–17	294	100.0
2017–18	277	98.92
2018–19	277	99.64
2019–20	273	97.80
2020–21	300	99.33

5.3.2 Per- and polyfluoroalkyl substances (PFAS)
Per- and polyfluoroalkyl substances (PFAS) are a group of over 4,000 manufactured chemicals. Some PFAS are very effective at resisting heat, stains, grease, and water, so have been used globally in a wide range of applications including stain and water protection for carpets, furniture, and apparel;

paper coating (including for food packaging); metal plating; photographic materials; cosmetics and sunscreens; medical devices; and fire-fighting foams. The most often discussed, and of most concern currently are PFOS, PFOA and PFHxS. There are global efforts to phase these chemicals out, including in Australia.[66]

PFAS exposure has not been shown to cause disease in humans. However, it has been associated with mildly elevated levels of cholesterol, effects on kidney function and effects on the levels of some hormones. The differences reported for these associations have generally been small and unlikely to be important to health outcomes.[67]

5.3.3 Lead/Cadmium and other heavy metals

Lead often arises because animals consume lead or lead pieces, or even lick lead surfaces, and absorb enough of the metal to result in samples exceeding limits. At low levels of exposure, they may survive and not show clinical signs of lead poisoning. Even so, there may be unacceptable levels of lead residue in the meat, liver, and kidney from those animals, or in milk that they produce.

Cadmium residues may result from animals being raised on pastures with high levels of cadmium in the soil. Between 2002 and 2006 the National Cadmium Minimisation Strategy (NCMS), working under the Primary Industries Standing Committee coordinated a program to address issues related to the control of cadmium in soils and crops.[68]

Cadmium can infiltrate pastures and livestock via fertilisers; soil or water, especially downstream from mining; and compost or manure. Cadmium accumulates in soil, where it can then be transferred to plants, animals, and humans. Cadmium is concentrated in the kidney and liver (and, to a much lesser extent, muscle, and milk) of livestock and humans. Surveys have shown that the level of cadmium in some Australian foods has occasionally exceeded regulatory health limits; cadmium has been detected at high levels in offal in some parts of Australia.[69]

A Meat Notice requires processors to have systems in place to ensure that standards will be met, for animals sourced from various regions of the country. This management program is based on sourcing from areas where the National Residue Survey (NRS) results show that the offal has historically met specified market requirements[70].

5.3.4 Mycotoxins

Toxins produced by fungi (mycotoxins, including aflatoxins) are of concern in the food supply because some are hepatotoxin, nephrotoxic or carcinogenic. Industry risk profiles (Hernandez-Jover, Culley, Heller, Ward, & Jenson, 2021; Sumner, Ross, Jenson, & Pointon, 2005) have considered the risks posed by mycotoxins in the meat supply to be low, but with little evidence. Food Standards Australia New Zealand conduct surveys as part of the Australian Total Diet Study. The most recent survey for mycotoxins was conducted in 2008[71], and Aflatoxins (B1, B2, G1, G2 and M1), deoxynivalenol, fumonisins (B1 and B2), ochratoxin A, patulin and zearalenone, were not detected in any foods (including beef and lamb) analysed.

[66] Australian Government PFAS Taskforce. PFAS in food and water | Australian Government PFAS Taskforce
[67] Australian Government, Department of Health and Aged Care. Environmental toxins and contaminants | Australian Government Department of Health and Aged Care
[68] CSIRO. CSIROpedia. Australian Cadmium Minimisation Strategy – CSIROpedia
[69] National Cadmium Management Committee. National Cadmium Minimisation Strategy. Managing for cadmium minimisation in Australian livestock (csiro.au) CSIRO. CSIROpedia Fertilizer Australia. fertilizer.org.au
[70] Meat Notice 2020-03 – Establishment sourcing of stock to comply with importing country requirements for cadmium levels in offal (agriculture.gov.au)
[71] Food Standards Australia New Zealand. 23rd Australian Total Diet Study (foodstandards.gov.au)

The potential for mycotoxins to enter the meat supply might best be judged by the incidence of clinical conditions related to mycotoxins reported in the animal health surveillance system[72] which are rare.

The National Residue Survey includes some mycotoxins (zearalanone and similar molecules/derivatives) in their testing program:

5.3.5 Plant toxins

Toxic plants may cause illness in animals and have the potential to cause illness in humans consuming animal products. They may be associated with the plants themselves, or bacterial/fungal metabolites produced while growing on plant material (e.g., annual ryegrass toxicity). Pyrrolizidine alkaloids, produced by Indigofera sp. and Crotalaria sp. are commonly found in Australia, and have been recognised as causing illness in cattle, and death in dogs fed with affected meat (Netzel et al., 2019). Controls centre around weed management, producer awareness, and management of toxic effects in cattle.

The potential for plant toxins to enter the meat supply might best be judged by the incidence of clinical conditions related to these toxins reported in the animal health surveillance system[73] which are rare.

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3. Identification of animals

Summary

Identification of animals (either individually, or as a group) is a fundamental aspect of the Australian meat safety system. Cattle have individual identification and sheep have mob-based identification in many states moving to individual identification by 1 January 2025.

The Australian government takes traceability extremely seriously, and Australia' system is world class from farm through to export certification. For this to be effective animals and groups of animals need to be accurately identified. Not only is this a requirement by many countries, but it is also required to ensure certification reflects the status of the meat in the carton. This is critical to governments and consumers. The Australian animal traceability systems starts on farm and maintains its currency through to the export of meat product. The first link in the animal traceability chain is the identification of animals.

Animal identification allows data on that animal to be linked: animal health, product safety, treatments, eligibility for markets etc. It allows market requirements to be met and give customers a high degree of confidence that product conforms to their requirements.

The National Livestock Identification System (NLIS) is the tool that identifies an animal with a central database that records its location and status. Livestock Production Assurance (LPA) is the quality system that ensures producers have the competency to apply all the rules regarding application and recording of NLIS. The status of animals moved off farms and throughout the system is captured in National Vendor Declarations (NVDs), that are legally binding declarations. LPA ensures producers have records and understanding of animal treatment and health status to accurately complete this declaration NLIS is also supported by feedlot quality programs and the Approved Arrangements that exist in all export registered establishments. .

State governments have the legislation to require identification of animals and recording of their location. The requirement is met through industry-wide systems that involve cooperation of the producer, transporter, saleyards, and meat processors.

Contents

1. Identifying an animal

The Codex *Code of Hygienic Practice for Meat*[74] has a Principle (5.1, i) that

> Primary production should be managed in a way that reduces the likelihood of introduction of hazards and appropriately contributes to meat being safe and suitable for human consumption.

And specifically (clause 36) that

> Only healthy, clean and appropriately identified animals should be presented for slaughter

In the *Australian Standard for the hygienic production and processing of meat and meat products for human consumption* (AS4696), there are requirements identifying animals and the place of production. The National Livestock Identification System (NLIS) is the means by which these objectives are achieved and also in combination with our whole of chain tracing systems, from farm to export, ensures importing country requirements are met.

1.1 National Livestock Identification System (NLIS)[75]

The objective of NLIS is to ensure full traceability of Australia's domestically farmed cattle, sheep, and goats from their property of birth through to slaughter or export, including all other associated movements within Australia. NLIS along with other supporting animal health and information systems supports Australia's export certification system.

The National Livestock Identification System (NLIS) is Australia's system for the identification and traceability of cattle, sheep, and goats.

1. All livestock are identified by a visual or electronic radio-frequency eartag/device.

2. All physical locations are identified by means of a Property Identification Code (PIC)

3. All livestock location data and movements are recorded in a central database

All animals are identified with an accredited NLIS tag or device from their property (PIC) of birth. Electronic radio-frequency identification devices (RFID) contain a half-duplex (HDX) transponder complying with International Standards Organisation (ISO) Standards, encoded with a number that commences with the appropriate International Committee for Animal Recording (ICAR)[76]-issued prefix[77]

In most cases this NLIS tag (RFID or visual) will remain with the animal for their entire life, and it is illegal to remove this tag. As animals are bought, sold, and moved along the supply chain, each movement is recorded centrally on the NLIS database.

If tags are lost or become defective then a new tag can be applied, however if the animal is no longer at its place of birth, then a 'post breeder' tag must be used. This indicates that the animal no longer has 'lifetime' traceability. The accreditation standards for devices allow no more than 3.5% loss of tags (including a maximum 0.5% transponder failure) within 3 years under field conditions.

[74] Codex Alimentarius Commission. (2005). *Code of hygienic practice for meat* (CAC/RCP 58-2005). https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B58-2005%252FCXP_058e.pdf
[75] National Livestock Identification System | Integrity Systems
[76] International Committee for Animal Recording www.icar.org | ICAR
[77] Integrity Systems Company. rfid-standards.pdf (integritysystems.com.au)

All animals leaving the property of birth (identified with a PIC) must be identified with an NLIS electronic/visual eartag/device before moving unless a permit is obtained from the state or territory. Each movement they make to a location with a different PIC must be recorded centrally on the NLIS database.

Using this information, the NLIS is able to provide a life history of an animal's movements. Tracing is important in the case of a disease outbreak. The NLIS database can be used to discern if contact with other livestock occurred. The NLIS facilitates the tracing of animals to meet the National Traceability and Performance Standards (3.2 below).

1.2 Cattle

Before moving an animal off its property of birth, the animal is tagged with an NLIS accredited breeder device (white for cattle).

Once an animal has been tagged, the tag should remain with the animal for life. If a tag is lost and the animal is no longer on its property of birth, the animal is tagged with a post-breeder device (orange for cattle).

It is an offence to remove an NLIS tag from an animal and apply another tag.

NLIS accredited devices for cattle must be an electronic (RFID) device. This can be either a single ear tag, or a rumen bolus[78]/visual ear tag combination, though rumen boluses are not frequently used.

1.3 Sheep and Goat

Sheep and goats can only be identified by ear tags/devices and must be tagged with an NLIS-accredited tag or device before being moved off a PIC.

Before moving an animal off its property of birth, the animal is tagged with an NLIS accredited breeder device (yellow or 'year of birth colour').

Once an animal has been tagged, the tag should remain with the animal for life. If a tag is lost and the animal is no longer on its property of birth, the animal is tagged with an NLIS accredited **post-**breeder device (pink for sheep or goats).

In all states except Victoria, NLIS accredited devices for sheep and goats can be either an electronic (RFID) device or a visual (NLISID) tag. In Victoria, all lambs or kids born since 1 January 2017 must be fitted with individual RFID tags before they leave their PIC of birth.

By 1 January 2025, all sheep and goats will have an individual electronic identification tag[79]

From 1 March 2023, all dairy goats as well as earless and miniature goats must be identified with an accredited visual or electronic ear tag or an accredited electronic NLIS leg band, before they leave their property of birth. This is a legal requirement in all states and territories.[80]

Some tagging exemptions are in place for rangeland goats harvested from the wild and dairy goats in some states and territories.

[78] For example, Rumitag HDX NLIS Cattle Bolus - 4Tags.com.au

[79] Department of Agriculture, Fisheries and Forestry. National Biosecurity Committee. Sheep and Goat Traceability Task Force - DAFF (agriculture.gov.au)

[80] Integrity Systems Company. Goat leg-band option approved for use | Integrity Systems

2. Information about an animal

2.1 Status of the animal

A status can be assigned to livestock (via their device), so that animals can be identified for residue testing and food safety purposes (Table 1). Device statuses are usually assigned to livestock or devices by the responsible authorities. NLIS Database Terms of Use specifies who can assign, remove, and see device statuses. A device status remains active on the database until the animal is killed or until the status duration expires or is removed. Originally, statuses related only to the NLIS (Cattle) program, but the database now accepts electronic sheep and goat devices too.

2.2 Location of the animal

A Property Identification Code (PIC) is an eight-character code allocated by the Department of Primary Industries (DPI) or an equivalent authority in each state or territory to identify a livestock-producing property. Producers must have a PIC to move livestock on and off a property.

There are differences between states and territories in how PICs are managed. In some states, amalgamation of separate PICs owned by the same entity, into a single PIC, is allowed. In other states, one property can be issued multiple PICs if there are livestock owned by multiple entities on the property.

The NLIS program relies on PICs to locate animals (tags/devices) through the supply chain. NLIS tags/devices are issued to specific PICs and are applied to any livestock born there (Breeder Tags) or livestock that have been moved there and require a replacement tag (Post Breeder tags). All livestock movements must be recorded on the NLIS database, identifying the 'from' and 'to' PICs for the movement, as well as the individual animals via their NLIS tags (or mobs of animals for sheep and goats until 2025).

On-farm quality assurance, delivered by the Livestock Production Assurance (LPA) program, is PIC based.

Accredited LPA PICs are required to use LPA National Vendor Declarations (NVDs) (see 3.3.1 Livestock Production Assurance (LPA) National Vendor Declaration (NVD)) for every livestock movement between different PICs and are required to record the PIC numbers on their NVD.

2.3 Status of locations

A status can be assigned to properties so that animals that have been in particular locations can be identified for residue testing and food safety purposes. Regulatory authorities can assign PIC statuses to properties. Some statuses are assigned or removed automatically, based on defined rules. Originally, statuses related only to the NLIS (Cattle) program, but the database now accepts electronic sheep and goat devices too. See Ch 2, 3.2 Property identification (PICs)_for more information on property statuses.

Table 1: Some device-based statuses that may be assigned to cattle

Program	Status	Assigned to …
AV	AV1	Cattle vaccinated against anthrax. The AV1 status converts to AV2 after 42 days.
CT	CTA	Cattle that have or may have accessed cotton trash. Test and hold all animals with CTAstatus. Commercial arrangements apply for tests.
JD	JD1*	Cattle identified as non-clinical reactors to bovine Johne's disease.
	JD2*	Cattle identified as clinical cases of bovine Johne's disease.
	JDV*	Cattle vaccinated against bovine Johne's disease.
LEAD	PB1*	Cattle under restrictions due to lead residues and not to be sold for slaughter. If slaughtered, test meat for lead, at owner's expense. Condemn liver and kidneys.
	PB2*	Cattle under restrictions due to lead residues. Unacceptable residues may not apply to carcase meat. Condemn liver and kidneys, or test for lead at owner's expense.
NARM National Antibacterial Residue Minimisation	K1F*	Cattle where urine and kidneys must be tested for antibacterial residues at slaughter. NRS funds tests.
	K1V*	Cattle where urine and kidneys must be tested for antibacterial residues at slaughter. Commercial arrangements apply for tests.
	K3	Cattle treated by antibiotics such as streptomycin within the last 2 years. Cattle with aK3 status may have antibacterial residues and are unfit for human consumption.
OC National Organo-chlorine Residue Management	N1F*	Cattle that grazed on high-risk contaminated properties and must be tested for organo-chlorines at slaughter. NRS funds tests.
	N1V*	Cattle that grazed on high-risk contaminated properties and must be tested for organo-chlorines at slaughter. Commercial arrangements apply for tests.
	N2F*	Cattle that grazed on low-risk properties to check for evidence of organo-chlorines at slaughter. NRS funds tests.
	N2V*	Cattle that grazed on low-risk properties to check for evidence of organo-chlorines at slaughter. Commercial arrangements apply for tests.
RAM	F1*	Cattle exposed to imported/unknown restricted animal material (RAM) within thelast 30 months. The date of first-known RAM must also be recorded.
	F2*	Cattle exposed to RAM of imported/unknown origin more than 30 months ago.
	F3*	Cattle exposed to RAM of Australian origin.
VBM	CB*	Cattle that grazed on properties where exposure to *Cysticercus bovis* (beef measles) may have occurred, e.g., from discharged sewerage.

3. Movement

When animals are moved, there is a government requirement for that movement to be recorded on the NLIS database. Red meat producers are provided with training materials in the LPA program to document and record animal movements (see Ch 2 3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA)). LPA effectively supports government in ensuring traceability requirements are understood and met by industry.

3.1 NLIS database

A central database (i.e., the NLIS database) is required to record the movement of cattle and to link the individual cattle involved in the movement between properties with the accompanying movement information. It is through interrogation of this database that individual cattle movements throughout their lives can be quickly and reliably traced.

Each time livestock are moved off a PIC, a livestock movement must be recorded on the NLIS Database. The NLIS has rules about which party is responsible for recording the movement on the database and the information that must be recorded Government has access to the database to ensure the integrity of the system and the safety and integrity of the animals recorded.

3.2 National traceability standards[81]

The National traceability performance standards are agreed between all Australian state and territory governments.

Applicable to all Foot and Mouth Disease (FMD) susceptible livestock species

> 1.1— Within 24 hours of the relevant authority being notified, it must be possible to determine the location(s) where a specified animal was resident during the previous 30 days.
>
> 1.2— Within 24 hours it must be also possible to determine the location(s) where all susceptible animals that resided concurrently and/or subsequently on any of the properties on which a specified animal has resided in the past 30 days.

Applicable to cattle only

> 2.1—Within 48 hours of the relevant authority being notified, it must be possible to establish the location(s) where a specified animal has been resident during its life.
>
> 2.2— Within 48 hours of the relevant authority being notified, it must be possible to establish a listing of all cattle that have lived on the same property as the specified animal at any stage during those animals' lives.
>
> 2.3—Within 48 hours of the relevant authority being notified, it must also be possible to determine the current location of all cattle that resided on the same property as the specified animal at any time during those animals' lives.

Animal Health Australia (AHA) undertakes regular audits of the National Livestock Traceability Performance Standards as a process for the continual improvement of the various NLIS programs.

[81] Animal Health Australia Traceability - Animal Health Australia

3.3 Information passing through the supply chain

3.3.1 Livestock Production Assurance (LPA) National Vendor Declaration (NVD)[82]

The LPA NVD communicates the food safety and treatment status of every animal every time it moves along the supply chain – between properties, to saleyards, or to processors. The NVD also acts as movement documentation throughout the supply chain.

Producers must be LPA accredited to access LPA NVDs. Accreditation to LPA is strongly supported by purchasers of livestock, processors, and retailers.

The NVD must be backed up by accurate farm records as specified and audited in the LPA program.

3.3.2 Saleyards[83]

Under the National Saleyard Quality Assurance (NSQA) program, livestock identification procedures are in place to ensure full livestock traceability is maintained throughout the saleyard process. Transactions are recorded in the NLIS database.

3.3.3 Transport[84]

TruckSafe Animal Welfare (formerly, TruckCare) is an audited quality assurance program for livestock transport. It covers animal welfare, food safety and traceability.

3.3.4 Feedlots[85]

The National Feedlot Accreditation Scheme (NFAS) is an independently audited quality assurance program for the Australian lot feeding industry that was initiated by the Australian Lot Feeders' Association (ALFA).

3.3.5 Processor requirements

The *Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS4696) requires animals to be admitted to a meat processing facility for slaughter only after inspection ensuring that wholesomeness of the meat is not jeopardised (6.5)

Inspection includes (6.6-6.9 and 8.5,8.6) examining records as well as observation of the animals to ensure that animals:

- are identified according to national standards
- have known previous location to ensure that they have not come from an area subject to animal health restrictions, or in contact with animals being affected by disease
- have not been fed materials that may recycle disease
- have not been grazed on an area irrigated with sewage (see Ch 2, 3.2 Property identification (PICs))
- have not been exposed to dangerous substances (drugs, chemicals above limits)

The information required is available from the NVD.

[82] Integrity Systems Company National Vendor Declaration | Integrity Systems
[83] National Saleyards Quality Assurance NSQA «
[84] Australian Trucking Association. Animal Welfare. TruckSafe. Animal Welfare | TruckSafe
[85] AUS-MEAT National Feedlot Accreditation Scheme. NFAS Information | AUS-MEAT (ausmeat.com.au)

4. Control of residues and chemical contaminants

Summary

Controlling the levels of residues of agricultural and veterinary chemicals, and environmental contaminants is an important part of ensuring that meat is safe for human consumption and considerable efforts are made to ensure that the system in Australia for the approval and use of these chemicals meets the expectations of our export markets.

Acceptable levels (maximum residue limits) are set by an international science-based process through the Codex Alimentarius Commission though individual countries may set different levels for legitimate reasons.

Aligning residue limits nationally is consistent with Codex guidance and ensures protection of our consumers and alignment with most importing country requirements. The Australian Pesticide and Veterinary Medicines Authority (APVMA) makes an assessment and approves chemicals by taking into account the potential trade implications associated with the use of the chemicals. For example, if many of our trading partners ban the chemical or won't establish an MRL then Australia's use of this chemical may be restricted to avoid the risk of export market closure.

The Department of Agriculture, Fisheries and Forestry, ensure systems, agreements, and equivalence arrangements are in place to enable certification. It is critical that Australia ensures it strictly regulates what chemicals are used, they are fit for purpose, product containing them are withheld from the supply chain until the residues are within approved limits, and/or meet importing country requirements.

Production controls exist in Australia from farm through to export to ensure all the requirements associated with chemical use and the various associated conditions have been met. On- farm, Livestock Production Assurance (LPA) provides the quality system elements that ensure chemicals are recorded, stored, used, and disposed of appropriately. The status of livestock treatments and exposure to chemicals are reflected in National Vendor Declarations (NVDs), which are underpinned by State regulation. Similar controls apply through Saleyards, Feedlots, and the approved arrangements that operate at export establishments. Traceability of animals and transparency of their status ensures the accuracy of export certification to importing countries.

A robust program operates to assure trading partners of compliant chemical use. This is undertaken through the National Residue Survey (NRS), funded through industry levies, sampling across Australian agricultural production. The analytical methods used are consistent with international standards through approved laboratories to ensure results are accepted nationally and internationally; and can withstand international audits and scrutiny. Detections will result in regulatory audits and sanctions as appropriate. Changes in perceived risks, NRS results or audits may require further consideration of MLs or MRLs, and allowable use by APVMA. The data coming from NRS indicates that they system is highly successful at achieving its goal of meeting Maximum Limits/Maximum Residue Limits.

Contents

1. Introduction

The chemical residues being controlled are the small amounts of agricultural and veterinary chemicals, or their breakdown products, that remain in or on an agricultural product. Additionally, the system seeks to control contaminants.

1.1 Definitions[86]

Abbreviated definitions for this document:

Agricultural chemicals -- any substance or organism used to:

- destroy, stupefy, repel, inhibit the feeding of, or prevent pests on plants or other commodities
- destroy a plant or to modify its physiology
- modify the effect of another agricultural chemical product
- attract a pest for the purpose of destroying it.

This encompasses all herbicides, insecticides, and fungicides. Fertilisers are not considered agricultural chemical products unless they modify the physiology of a plant.

Veterinary chemicals -- any substance administered or applied to an animal to:

- prevent, diagnose, cure or alleviate a disease, condition, or pest infestation
- cure or alleviate an injury
- modify the physiology.

Contaminants -- any substance not intentionally added to a product, but that may be present following routine production. For example, some metals and natural toxicants are contaminants. A food will contravene the Australia New Zealand Food Standards Code (ANZFSC) if it contains a contaminant at a concentration greater than the Maximum [permitted] Level (ML).

The use of chemicals (e.g., cleaning chemicals) in processing establishments is dealt with in Ch 8 Wholesomeness (4.2 Chemicals).

1.2 The international system for control of residues and contaminants

Codex Alimentarius Commission agrees Maximum Residue Limits (MRLs) proposed by Joint FAO/WHO Committee on Food Additives (JECFA) and Joint FAO/WHO Meetings on Pesticide Residues (JMPR) (see Ch 1,3.2 Scientific input) consistent with a scientific assessment of the toxicological data.

Codex sets limits (MRLs), but each country may set its own limits, based on its individual circumstances (for example, the amount of the product used for various reasons, the quantity of that food eaten). These technical differences are based on risk assessment in compliance with World Trade Organization (WTO) rules (see ch1,1.2 World Trade Organization (WTO)).

In Australia, Food Standards Australia New Zealand (FSANZ) sets MRLs that apply to Australia and the Australian Pesticides and Veterinary Medicine Authority (APVMA) considers this MRL and those of major export markets when setting the time between the last use and slaughter. The National Residue Survey considers these data when testing samples for compliance with the Australian standards and relevant international MRLs.

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[86] Australian Government. Department of Agriculture, Fisheries and Forestry. National residue Survey. Definitions, abbreviations and acronyms - DAFF (agriculture.gov.au)

1.3 Elements of the residue control system

The Australian Residue Control System encompasses the following elements:

- a requirement for registration of all agricultural and veterinary chemical products by the APVMA prior to marketing;
- compliance activities on unregistered products;
- controls on the use of products and compliance activities when misuse is detected;
- standards for residues of agricultural and veterinary medicines in food (maximum residue limits);
- regulatory requirements for abattoirs to have systems in place to ensure products from livestock will meet relevant requirements; and
- producer and industry quality systems.

(Lutze, Derrick, Korth, & MacLachlan, 2009)

2. Approval of agricultural and veterinary chemicals

The APVMA evaluates, registers, and regulates agricultural and veterinary (Agvet) chemicals up to the point of sale. The states and territories are responsible for control of, and use of, these chemicals.

2.1 Registration of chemicals and products

The National Registration Scheme for Agricultural and Veterinary Chemicals, administered by the APVMA, was established under Commonwealth and state and territory legislation, and ensures that these products are:

- safe when exposed to humans and non-target species either through direct exposure or residues in treated food stuffs
- not a risk to the environment
- effective on target species, and
- labelled and packaged correctly.

Companies wishing to register a product are required to provide extensive data supporting the nature of the product.

Registered active constituents and products are listed in the APVMA's Public Chemical Registration Information System (PubCRIS) database[87] which provides details about Agvet chemical products including the product name, registering company, active constituents, product category (e.g., insecticide, fungicide, or herbicide), and host and pest information. In most cases, it is also possible to view a copy of the product's label.

[87] APVMA PubCRIS database Search registered chemical products and permits | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

2.2 Process and criteria for chemical product approval

2.2.1 Applying for approval[88]

For a new agricultural or veterinary (Agvet) chemical product the active constituent must be approved before products containing the active constituent can be registered.

Each registered product must have a label containing the instructions approved by the APVMA including adequate instructions for the safe and effective use of the product and for its storage, handling, and disposal.

All (with few exceptions) veterinary chemical products must be manufactured in premises that comply with the Code of Good Manufacturing Practice, unless the product is excluded or exempt from the scheme. Australian facilities must be licensed by the APVMA, or hold a permit, and overseas manufacturers must provide equivalent evidence of compliance at the time of application for registration of products.

2.2.2 Trade considerations when granting approval[89]

A chemical product when used in accordance with any approved instructions must not unduly prejudice trade or commerce between Australia and importing countries.

2.2.3 Labels

Labels for chemical products must contains adequate instructions relating to the following as appropriate[90]:

- The circumstances in which the product should be used.
- How the product should be used.
- The times when the product should be used.
- The frequency of the use of the product.
- The withholding period after the use of the product.
- The re-entry period after the use of the product.
- The disposal of the product when it is no longer required.
- The disposal of containers of the product.
- The safe handling of the product and first aid in the event of an accident caused by the handling of the product.
- for a chemical product that is a veterinary chemical product, the duration of any treatment using the product
- the prevention of undue prejudice to trade or commerce between Australia and places outside Australia
- the appropriate signal words (if any) required by the current Poisons Standard
- for a chemical product that is a date-controlled chemical product, the storage of containers for the product

[88] Australian Pesticides and Veterinary Medicine Authority. Chemical Product Registration Applying for approvals, registrations and variations | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

[89] APVMA. Chemical Product Registration. Trade criteria | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

[90] APVMA. Chemical Product Registration Labelling criteria | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

3. Controlled use of chemicals

Both state-based legislative provisions and enforcement, and industry systems for ensuring safe, responsible, and compliant use contribute to the overall outcome of control.

3.1 State-based approaches

The states and territories are responsible for control of use, and each has its own legislation.

Control of use is handled in quite different ways in different jurisdictions. Differences exist at three broad levels: resource intensity of control, philosophy underlying control and departmental and institutional responsibility. There are quite divergent philosophies underlying control of use. At one end of the spectrum is the approach taken in NSW and Tasmania, in which there is a requirement for users to stick to label instructions in most circumstances. At the other end is the approach described by the Victorian Government (2008, p.8) which has '…flexibility provided and the onus placed on primary industries to manage Agvet chemical risks.' Regulatory oversight is intended to involve close ties with industry quality assurance and governance schemes and sufficient resources devoted to monitoring and compliance activities focused to '...address identified/substantiated 'public' risk' (Victorian Government 2008, p.9). Some jurisdictions and some industry stakeholders have argued that there is an important distinction to be made between prescriptive and performance-based controls. In this context, a requirement for all uses to be strictly according to label would be seen as a prescriptive approach.[91]

The Harmonised Agvet Chemical Control of Use Task group (HACCUT) was a working group developing a single national framework to harmonise the regulation of Agvet chemical in the states and territories.[92]

3.2 Industry training on use

ChemCERT Limited[93] is an industry based non-profit organisation which works with all industry sectors throughout Australia for the training, up-skilling, and industry accreditation for users of Agricultural and Veterinary (Agvet) chemicals.

Certification is nationally recognised, valid for 5 years and is required by states for the use of certain chemicals. The course takes approximately 10 hours, at student own pace (depending on student's prior knowledge and skills). It covers transport and storage of chemicals, spray drift (spreading of chemicals during spraying operations), understanding chemical application issues, managing residues and record keeping.

Livestock Production Assurance (LPA) encourages producers to undertake the ChemCert Australia course.

[91]Discussion paper (2009) A national scheme for assessment, registration and control of use of agricultural and veterinary chemicals jk1433 (giav.com.au)
[92] DAFF. The Harmonised Agvet Chemical Control of Use Task group (HACCUT) - DAFF (agriculture.gov.au)
[93] ChemCert Australia - Chemical Accreditation

3.3 Industry systems controlling use

3.3.1 Livestock Production Assurance

Four of the 7 elements of LPA (see Ch 2,3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA) focus on control of residues and contaminants:

1. Property risk assessment. Property owners must identify any possible risk where livestock could come into contact with chemical contaminants and develop strategies for how this risk will be controlled. Chemical storage areas, areas treated with persistent chemicals such as organochlorines, and sources of lead, such as batteries are examples of items covered in a property risk assessment.

2. Safe and responsible animal treatments. Every LPA accredited producer must undertake steps to ensure that animal treatments are administered in a safe and responsible manner that minimises the risk of chemical residues.

3. Stockfoods, fodder crops, grain, and pasture treatments. LPA accredited properties ensure that fodder and purchased feed does not contain unacceptable residues, that the use of agricultural chemicals is controlled on their own property and identify livestock that may have become contaminated.

5. Livestock transaction and movements. The LPA National Vendor Declaration (NVD) communicates the food safety and treatment status of every animal every time it moves along the supply chain – between properties, to saleyards, or to processors.

3.3.2 Information required at processing

The *Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS4696) requires animals to be admitted to a meat processing facility for slaughter only after inspection ensures that wholesomeness of the meat is not jeopardised (6.5)

Amongst many other aspects, inspection includes (6.6-6.9 and 8.5, 8.6) examining records to ensure that animals:

- are identified according to national standards
- have known previous location to ensure that they have not come from an area subject to animal health restrictions, or in contact with animals being affected by disease
- have not been exposed to dangerous substances (drugs, chemicals above limits)

The information required is available from the NVD.

4. Contaminants

The contaminants chosen for analysis in the National Residue Survey (NRS) may be because they are recognised as significant to the health of Australians (maximum limits set by FSANZ), or because there are international concerns, for example, the requirements of trading partners. The contaminants included in the surveys of beef and sheep products are shown in Table 1.

Maximum levels

MLs were established as an effective risk management function for foods which provide a significant contribution to the dietary exposure of a particular contaminant. MLs are set at levels that are consistent with the protection of public health and safety and are reasonably achievable through sound production and natural resource management practices. For meat, the ANZFSC sets MLs[94] for Cadmium, Lead, acrylonitrile, polychlorinated biphenyls (PCBs), and vinyl chloride.

Table 1: Environmental contaminants included in NRS surveillance

Product	Class	Chemicals
Beef	Dioxins	Dioxins and dioxin-like PCBs
	Organochlorines	Aldrin, chlordane, dieldrin, DDT, endrin, HCB, HCH, heptachlor, lindane, mirex, PCBs and pentachlorobenzene
	Metals	Antimony, arsenic, cadmium, lead, mercury
Sheep	Dioxins	Dioxins and dioxin-like PCBs
	Organochlorines	Aldrin, chlordane, dieldrin, DDT, endrin, HCB, HCH, heptachlor, lindane, mirex, PCBs and pentachlorobenzene
	Metals	Antimony, arsenic, cadmium, lead, mercury

5. Residue limits

5.1 National

Before approval, the APVMA must be satisfied that, among other matters, the use of the product would not have an effect that is harmful to humans or would cause undue prejudice to trade between Australia and other countries (Agricultural and Veterinary Chemicals Code Act 1994). Residue assessment consistent with Codex principles (see below) contributes to the decision-making and includes the establishment of maximum residue limits (MRLs) in the APVMA MRL Standard (www.apvma.gov.au), recommendation of MRLs to Food Standards Australia New Zealand and the establishment of withholding periods (WHPs). The latter are the intervals that must elapse between last treatment/application and slaughter for human consumption. (Lutze et al., 2009)

The minimum concentration of the chemical required for efficacy is derived from experiments, and from the toxicity and residue data the MRL is calculated - based on good agricultural practice. In addition, withholding periods (that is, time between application or treatment with a chemical and the time of harvest or slaughter for consumption) is decided based on assuring that the MRL is not exceeded at harvest or slaughter. In addition, an adverse reaction reporting system, involving the manufacturer and State and Commonwealth authorities, is part of registration requirements. With all this regulatory input, and the safety margins employed, it is not surprising that chemical residues in food are only very rarely a cause of human illness (Nicholls, 2000).

The Codex Alimentarius Commission agrees MRLs that are proposed by JECFA and JMPR.

5.2 International

The approach to setting MRLs continues to evolve. Below is an explanation of the system for setting MRLs (MacLachlan & Mueller, 2012):

> Government food safety regulators and consumers are interested in minimising exposure to residues in ready-to-eat food consistently support the conclusion that residues, if present, are at trace levels and unlikely to be a public health concern (Lutze et al., 2009; Anon, 2001). At the time of making decisions as to whether the use of a veterinary drug can be permitted, information on actual levels in

[94] Australia New Zealand Food Standards Code – Schedule 19 – Maximum levels of contaminants and natural toxicants (legislation.gov.au)

food is generally not available and so risk assessors apply conservative models for foods likely to contain residues. The methods for estimating exposure are integral to the risk assessment process used for setting of legally enforceable limits for veterinary drugs (Maximum Residue Limits, MRLs). An MRL is defined as the maximum concentration of residue resulting from the use of a veterinary drug that is acceptable in or on a food (EHC, 2009)

A risk assessment for chemicals is usually defined as the characterisation of the potential adverse health effects of human exposure to a chemical hazard. The process includes both qualitative and quantitative measures of the probability of outcomes and the nature of those outcomes. By convention the process has been divided into four steps: (1) hazard identification; (2) hazard characterisation/dose–response assessment; (3) exposure assessment; and (4) risk characterisation. The first two steps lead to the identification of a health-based guidance value that establishes the maximum level of exposure that is acceptable for a particular drug residue. A common health-based guidance value for long-term daily exposure is the Acceptable Daily Intake (ADI); the estimated amount of a substance in food or drinking water, expressed on a body-weight basis, which can be consumed every day for a lifetime by humans without presenting an appreciable risk to their health. To assess dietary risk, the average drug residues present in food consumed daily and expressed as a function of bodyweight, is compared with the ADI. Levels of exposures that are between zero and the upper bound of the ADI are considered to be associated with an acceptable risk. In recent times it has been recognised that the ADI is probably not an appropriate benchmark for characterising the hazard posed by exposure to residues of a chemical that causes an adverse effect after only a single exposure. This recognition has led to the development of a separate health-based guidance value, the acute reference dose (ARfD) (Solecki et al., 2005). Since an ARfD is derived from an acute dosing study it typically will have a higher numerical value than an ADI which is usually based on a long-term daily feeding study. To determine acute risk, the exposure is calculated by multiplying the maximum expected residue concentration with a high food consumption value (e.g., 97.5th percentile). The calculated exposure is then considered relative to the ARfD.

Instructions for use of a veterinary drug, or the approved use pattern, encompass the reason for use, dose rate, route of administration, interval of application if repeat treatments are required and the withholding period. The latter is the time after administration of a drug that must be observed for residues to decline to safe levels prior to harvesting of animals or animal products (by fishing, milking, slaughtering, collection of eggs, etc.). MRLs are established to provide assurance to producers that if animals are treated according to an approved use-pattern, residue levels in derived foods will be safe for human consumption. They also provide an assurance to consumers that when residue levels are below the MRL their exposure through food will be safe because it is under the upper range of the relevant health-based guidance value.

The main information on residue levels is usually provided by residue depletion studies. These studies are conducted according to well established test guidelines. These test guidelines require that the veterinary drug be administered to groups of animals at the maximum dose and the harvesting of animals or animal products at appropriate time intervals. At slaughter, samples of tissues are collected. Similarly, milk and eggs may be collected from live animals/birds at various time intervals after dosing. An iterative procedure is then used to ensure that the exposure to residues, including those present in edible tissues, milk or eggs are below the ADI. It may be that consumers are already exposed to residues through other sources and only part of the ADI is available for the animal commodity considered. The first time point for which the calculated exposure is below the ADI is selected to determine an acceptable withdrawal period and estimate the MRLs.

The NRS maintains information on maximum residue limits (MRLs) that apply to Australia and major export markets for industries supported by the NRS. All analysis results are checked for compliance with the Australian standards and relevant international MRLs.

The industry implemented systems to provide confidence of compliance with regulatory tolerances applied in major markets. The Australian cattle and sheep industries instigated a scheme of Export Slaughter Intervals (ESIs) that provides for extended withholding periods to allow residues to decline to levels below the tolerances applied in export markets. The system is now managed by the regulator, the APVMA. (Lutze et al., 2009)

6. Performance monitoring

6.1 System monitoring

Livestock Production Assurance audits
Properties accredited to the LPA Program (ch 2, 3.3) are audited for property risk assessment, and use of Agvet chemicals.

Hormonal growth promotant (HGP) audit program
Some markets, such as the European Union (EU) and Non-EU HGP sensitive markets, prohibit the importation of products from animals treated with HGPs. On-farm audits are used to monitor compliance with accreditation requirements. Samples are collected during audits and tested.

Residue management audits
The NRS residue management audit program includes the cattle, sheep, and goat industries. Since 2009, over 30,000 targeted property audits have been undertaken throughout Australia as part of a comprehensive approach to residue management.

APVMA – incident reporting
The APVMA conduct an Adverse Experience Reporting Program (AERP) to assesses reports of adverse experiences associated with the use of a registered chemical product.

Problems reported with chemical products may result in further regulatory action in accordance with the legislation, for instance, through compliance action or chemical review. If the issue reported is related to control of use, or is otherwise outside the jurisdiction of the APVMA, the information may be referred to the appropriate authority.[95]

6.2 Survey – National Residue Survey

The National Residue Survey (NRS) is delivered by the Department of Agriculture, Fisheries and Forestry and monitors residues in animal products through various random and targeted testing programs.

The random programs are designed to:

- ensure participating industries satisfy Australian export certification and importing country requirements
- enable domestic meat processing facilities to satisfy state and territory government regulatory authority licensing requirements
- provide evidence of good practice in the use of pesticides and veterinary medicines by the participating industries
- support quality assurance initiatives in industries.

Targeted animal product residue monitoring programs are designed to meet particular management objectives or monitor potential chemical residues that could pose a risk for access to export or domestic markets.

[95] Adverse Experience Reporting Program | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

Response to detection
Laboratories test samples against an agreed chemical screen which meets market requirement. If a laboratory finds a sample that contains a residue above the Australian Standard, a traceback investigation is undertaken to establish the cause. The responsible state or territory agency then provides advice to the producer to prevent recurrence. In more serious circumstances, regulatory action may also be taken.

All traceback activities and findings are reported to the NRS. This feedback is important in highlighting potential problems, such as inappropriate chemical use and improving farm practices. Where appropriate, traceback information is also forwarded to industry and government authorities for consideration. Traceback information may also be forwarded to the APVMA.

When results of monitoring identify issues, they are used by the APVMA in amending registrations of chemical products and by the red meat industry to modify residue management strategies. (Lutze et al., 2009)

6.2.1 Random programs

The choice of chemicals for measurement in the samples is guided by the likelihood of residues from pesticides, veterinary medicines, or contaminants. The chemicals include those used commonly in agricultural and veterinary practice, as well as those necessary to fulfil export requirements. Some chemicals monitored are not registered for use in Australian animal production systems, nor are likely to be used, but may be important to satisfy the requirements of international trading partners (Table 2).

Table 2: Chemicals included in the NRS survey

Group	Chemicals
Veterinary drugs and animal treatments	
Anthelmintics	Benzimidazoles, closantel, macrocyclic lactones and triclabendazole
Antibiotics	Aminoglycosides, anticoccidials, antimicrobials, beta lactams, cephalosporins, macrolides, nitroimidazoles, phenicols, sulphonamides, fluoroquinolones, quinolones and tetracyclines
Hormones	Resorcyclic acid lactones, steroids, stilbenes and trenbolone
Other veterinary drugs	Beta-agonists, corticosteroids, sedatives, andro and non-steroidal anti-inflammatory drugs
Pesticides, animal treatments and environmental contaminants	
Fungicides, herbicides, and insecticides	Benzoyl ureas, carbamates, fungicides, herbicides, insecticides, organochlorines, organophosphates, persistent organic pollutants and pyrethroids
Environmental Contaminants	Metals

The results of these surveys are posted on the Department of Agriculture, Fisheries and Forestry website and a brief overview is provided in Chapter 2 – sourcing safe and healthy animals (5.3.1 Surveys for residues of agricultural, veterinary chemicals and environmental contaminants).

6.2.2 Targeted programs

National organochlorine residue management (NORM) program
The NORM program focuses on minimising the risks of organochlorine (OC) residues in beef and is jointly funded by the beef industry and state/territory governments. Besides testing cattle from at-

risk properties at abattoirs, the NORM program results assist owners of properties with identified OC contamination hazards to develop and apply on-farm property management plans to minimise the risk of OC residues.

The department coordinates the program and manages the payments to others involved, such as laboratories and state/territory governments.

National antibacterial residue minimisation (NARM) program

The NARM program focuses on minimising the occurrence of antibacterial residues in bobby calves from dairy farms and is funded by the beef industry. State/territory governments support the program through activities related to traceback investigation, and the management of dairy farms found to have consigned bobby calves for slaughter with antibacterial residues above relevant Australian standards.

Investigations have found that residue contraventions occur when management systems are inadequate or break down. Consequently, a major focus of activities is to work with industry quality assurance schemes and stakeholders to introduce initiatives that heighten farmer awareness and minimise the risk of residues occurring. The department coordinates the program and manages the payments to others involved, such as laboratories and state/territory governments.

Targeted antibacterial residue testing programs

There are several programs, each targeted to a different animal species. These programs focus on animals that present at establishments and are suspected by veterinary inspectors of having received antibacterial treatment inside the required withholding period. Each program combines targeted testing, quality assurance, extension, and regulation to minimise antibacterial residues in beef.

The department coordinates each program and manages the payments to others involved, such as laboratories.

The programs are:

- Cattle targeted antibacterial residue testing (TART) program
- Sheep targeted antibacterial residue testing (START) program
- Goat targeted antibacterial residue testing (GTART) program

References

Lutze, J., Derrick, J., Korth, W., & MacLachlan, D. J. (2009). Monitoring of pesticides and veterinary drugs in Australian cattle: verification of the residue control system. *Food Additives & Contaminants: Part B: Surveillance Communications, 2*(2), 99-111. doi:10.1080/19440040903274003

MacLachlan, D. J., & Mueller, U. (2012). A refined approach to estimate exposure for use in calculating the Maximum Residue Limit of veterinary drugs. *Regulatory Toxicology and Pharmacology, 62*(1), 99-106. doi:https://doi.org/10.1016/j.yrtph.2011.12.006

Nicholls, T. J. (2000). Chemical residues related to food safety [Paper based on a presentation at the International Food Safety Conference (1999: Melbourne)]. *Food Australia, 52*(7), 271-273.

5. Hormonal Growth Promotants

Summary

Specific Hormonal Growth Promotants (HGPs) have been approved for use in the Australian beef production system for around 40 years, and the resulting meat and offal has been scientifically found to be extremely safe for consumption by Australian and export market consumers. HGP use across the industry is determined by a number of commercial factors, as reflected below, but within the regulatory settings of being safe for consumers; transparent; and within a system of traceability.

The HGPs approved for use in Australia have all internationally been assessed through the Codex Alimentarius process and have been found safe for use with established Codex MRLs. Typically, HGP use is more likely in northern Australia, where its application to young steers ensures optimal growth and conditioning throughout the wet season. This practice ensures better yields and a more profitable sector to the relevant producers. Arguments can also be made that this practice ensures heavier younger cattle are presented for slaughter requiring less intensive feeding periods, less water with less environmental impact.

The application of HGPs registered for use by the APVMA in Australia, have been extensively tested and assessed through international and domestic scientific risk assessments to ensure our consumers can have the greatest confidence that they are safe for consumption.

Contextually, an Australian steer treated with HGPs will present hormone levels many thousands of times less that hormones naturally produced in men and women.

Our largest markets for beef that has been treated by HPGs include Japan, the US and Korea. The US beef production system is an avid user of HGPs including beta agonists, which are not permitted for use in Australia on cattle or sheep (except as an aid to birthing). The EU's consumer lobby groups are extremely sensitive to HGPs. This has resulted in a range of trade tensions, disputes and WTO legal challenges are continuing in various forms. Australia has taken significant care to ensure our production system and regulatory controls meet importing country requirements, particularly regarding the product's HGPs status.

Overall, it is estimated that around 40% of cattle presented for slaughter have been treated with growth promotants. Another determinant of their use is the end customers and export market to which product is exported. A range of export markets including the EU, UK and China do not permit the use of HGPs. Equally within the domestic market some supermarket chains have differentiated their product as HGP free on the basis of quality factors and marketed accordingly.

Contents

1. What are Hormonal Growth Promotants?

Hormonal Growth Promotants (HGPs) are used extensively in feedlots and in the grass-fed industry of northern Australia. In the northern Australian grass-fed industry, HGP are used as a management tool in preparing steers for higher value markets. The highly seasonal nature of pasture quality in this region means that cattle often must meet market specifications for age and weight before pasture senesces, causing a rapid decrease in the rate of liveweight gain. (Hunter, 2010).

1.1 HGP definition

Like other veterinary chemicals, their use is controlled by the registration process of the Australian Pesticides and Veterinary Medicine Authority (APVMA). Hormonal growth promotant is defined by regulation 3 of the Agricultural and Veterinary Chemicals Code Regulations 1995 (Agvet Regulations) as:

> a veterinary chemical product containing a substance that is, or a mixture of substances that are, responsible for oestrogenic, androgenic or gestagenic activity to enhance growth or production in bovines or bubalines.

1.*2* Non-hormonal growth promotants

There are two other groups of chemicals[96] that are recognised as growth promoters. Ionophores (e.g., lasalocid, monensin) that are used in cattle to prevent diseases like coccidiosis, and acidosis also improve weight gain and feed efficiency, but are usually thought of as antimicrobials (see Ch 20 -antimicrobial resistance). Flavophospholipol is another antimicrobial used for growth promotion. The other group are the beta-agonists, (ractopamine, zilpaterol) which act in a similar way to adrenaline and increase muscle growth. While ionophores and flavophospholipol are registered for use in cattle in Australia, ractopamine and zilpaterol are not. Non-registration of these beta-agonists is a consequence of export market sensitivity to their use, particularly in the EU and China and is not a reflection of their safety. [97]

1.3 Registered HGPs in Australia

Oestrogenic compounds are the major class of growth-promoting hormones. Those registered in Australia:

- Oestrogen (oestradiol-17 β, oestradiol benzoate).
- Zeranol (a non-steroidal compound isolated originally from a fungus and is a β-resorcylic lactone)

Androgenic compounds registered in Australia:

- Testosterone (testosterone propionate).
- Trenbolone acetate (a synthetic androgen).

Gestagenic hormones registered for use in Australia:

- Progesterone (Hunter, 2010).

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[96] Hormones & Other Growth Promotants in Beef Production - BeefResearch.ca

[97] Condon, Jon (2020) Application to allow beta agonist use in feedlot cattle in Australia is polarising industry. Beef Central. 26.5.2020. Application to allow beta agonist use in feedlot cattle in Australia is polarising industry - Beef Central

2. Registration and use of HGPs

Consumers are naturally concerned about the safety of their food, and especially about the effect of hormones in meat on their health. Much of this concern has arisen from historic reports of side-effects of very early synthetic oestrogens used to sterilise male chickens. The use of these early synthetic hormones in the poultry industry has long since been banned. The question of hormone use has become one of the largest 'science vs. public opinion' decisions made in modern food regulation.

2.1 HGPs – international acceptance

2.1.1 World-wide reviews and consensus

Numerous reviews and evaluations of safety and public health risks associated with HGP usage have been conducted by the Joint FAO/ WHO Expert Committee on Food Additives (JECFA); the Veterinary Products Committee of the Department for Environment, Food and Rural Affairs (UK); the Committee for Veterinary Medicinal Products for the European Medicines Agency; the Chemical Review and International Harmonisation Section, the Office of Chemical Safety and the Therapeutic Goods Administration (TGA) of the Australian Department of Health and Ageing. HGPs have also passed rigorous safety and efficacy evaluations by national registering authorities such as the US Food and Drug Administration and the APVMA.

The consensus of these reviews and agencies is that:

- While HGPs do increase hormone levels in meat, these levels are still well within normal limits for untreated cattle (and well below Maximum Residue Limits for synthetic products).
- Hormone levels in treated meat are well below levels in many other foods.
- Meat from HGP-treated animals contributes only a small proportion of total intake of these hormones.
- The absorption and availability of these hormones when meat is digested in the stomach is low.
- The bodies of both women and men naturally produce many thousand times more oestrogen each day than found in a meal of steak.
- Age, sex, reproductive status of the consumer, and exercise can influence the levels of hormone circulating in the body.
- Although oestradiol-17ß, in particular, is recognised as potentially carcinogenic when acting as a hormone, the levels present in a diet are unlikely to increase the risk to consumers.

Thus they consider that HGPs, when used according to good agricultural practice, pose no additional health risk to consumers (Partridge, 2011).

In a paper presented at an FAO meeting a European scientist summarised the data:

> Based on these values, and averages for consumption of various foods, the relative contribution of meat from hormone-treated animals to the total consumption of hormones has been calculated on the assumption of proper use of the hormones … It is clear that in most cases the contribution from meat of treated animals is insignificant when hormones have been properly used …. and must be considered to be biologically without impact. This becomes even more evident when seen in relation to normal endogenous hormone production in man…. It will be seen that even for oestrogens, the hormones considered the greatest risk, the maximal contribution from meat (assuming proper use of the hormones) is less than 0.01% in the prepubertal boy who represents the lowest endogenous oestrogen production.[98]

[98] Velle, Weiert (1981) The use of hormones in animal production. Presented to JECFA. hormones in animal production (fao.org)

The levels reported to JECFA in beef were thousands of times less than found in human tissues.

2.1.2 Codex Alimentarius Commission

The Codex Alimentarius Commission (CAC) has set MRLs for a number of HGPs and beta agonists.[99]

Zilpaterol has not had MRLs set, which means that residues should not be detected in meat. Testosterone and Progesterone MRLs were considered not necessary because residues resulting from the use of these substances as a growth promoter in accordance with good animal husbandry practice are unlikely to pose a hazard to human health. MRLs have been set for zeranol and ractopamine in cattle.

In the early 2020s CAC faced a lack of consensus on setting an MRL for zilpaterol, which would, in effect, allow its use in international trade.[100] The stalemate between CAC members raised questions about the importance of key principles that underpin Codex work for example science, risk assessment and consensus. It recalled the difficult process to establish an MRL for ractopamine.

2.2 Registration and use of HGPs in Australia

Australian Pesticides and Veterinary Medicines Authority[101]

For an HGP to be registered in Australia, the APVMA must be satisfied that, when the product is used according to directions on the label, there will be no appreciable risk to:

- those who eat the meat
- those who handle or apply the HGP
- the environment
- other crops or animals
- the beef trade.

(Partridge, 2011)

Department of Health and Ageing[102]

A review of HGP safety by the Australian Department of Health and Ageing in 2003 concluded that "there is unlikely to be any appreciable health risk to consumers from eating meat from cattle treated with HGPs according to good veterinary practice". They also noted that: "to adequately determine the incremental risk associated with very low levels of HGP residues in meat, the total dietary intake of hormones from all sources would need to be evaluated." (Partridge, 2011).

Industry view

Hormonal growth promotants (HGPs) have been used in the Australian beef industry for the last 40 years. There is sufficient scientific evidence to establish that growth rate of steers and heifers is increased by 10–30%, feed conversion efficiency by 5–15% and fat content of carcasses reduced by 5–8% (Preston 1999). (Hunter, 2010). In the feedlot industry, HGPs improve the efficiency of feed conversion resulting directly in lower feed costs per unit of liveweight gain. Implanting a 400kg steer being fattened for 200 days will save about 100kg of feed as fed (Partridge, 2011).

HGPs are used extensively in feedlots and in the grass-fed industry of northern Australia. It was estimated, in 2010, that at least 80% of cattle are implanted at feedlot induction (D. Rinehart, pers.

[99] Codex Alimentarius (2021) Maximum residue limits (MRLs) and risk management recommendations (RMRs) for residues of veterinary drugs in foods CX/MRL 2-2021. MAXIMUM RESIDUE LIMITS (MRLs) AND RISK MANAGEMENT RECOMMENDATIONS (RMRs) (fao.org)
[100] Codex Alimentarius Commission (2021) Report. 44th session. Microsoft Word - REP21_CACe (fao.org)
[101] NRA (now APVMA) Special Review of HORMONAL GROWTH PROMOTANTS National Registration Authority for Agricultural and Veterinary Chemicals October 2001 Review of Hormonal Growth Promotants (apvma.gov.au)
[102] Food Standards Australia New Zealand Hormonal growth promotants in beef (foodstandards.gov.au)

comm.). In the northern Australian grass-fed industry, HGPs are used as a management tool in preparing steers for higher value markets. The highly seasonal nature of pasture quality in this region means that cattle often must meet market specifications for age and weight before pasture senesces, causing a rapid decrease in the rate of liveweight gain (Hunter, 2010).

Extended or whole-of-life implant programs have been developed to keep cattle growing faster under these seasonal patterns of pasture growth. The choice of HGP program will be determined by how long there is likely to be good quality feed, which breeds of cattle are being fattened, the market for which they are being prepared and how often the cattle are normally mustered.

In southern Australia, fewer cattle have been implanted with HGPs since the European Union (EU) banned the use of HGPs in beef sourced from overseas suppliers as many producers have preferred to keep their market options open. Over past years additional domestic retailers, and importing countries (e.g., China) are HGP-free, which means that less HGPs are used.

2.3 Registration and use of HGPs in the EU

2.3.1 Technical position

The European Commission (EC) enacted its ban on both the production and importation of meat derived from animals treated with growth-promoting hormones in the early 1980s. This ban restricts the use of natural hormones to therapeutic purposes, bans the use of synthetic hormones, and prohibits imports of animals and meat from animals that have been administered the hormones. The ban, however, did not go into effect until January 1, 1989. Initially the ban covered meat and meat products from animals treated with six growth promotants that are approved for use and administered in the United States, including oestradiol, testosterone, progesterone, zeranol, trenbolone acetate and melengestrol acetate. In 2003, the commission amended its policy to permanently ban one hormone—oestradiol-17β—while provisionally banning the use of the five other hormones, as it continued to seek more complete scientific information.[103]

2.3.2 Trade position

The United States has continued to challenge the EU's beef hormone ban in the World Trade Organization (WTO) and to question whether the ban is consistent with the EU's WTO obligations under the Sanitary and Phytosanitary (SPS) Agreement. After a series of WTO consultations, panel decisions, and appeals in the case, both the USA and the EU claim these formal proceedings have vindicated their respective positions in the dispute. In October 2008, the WTO issued a mixed ruling that allows the United States to continue its trade sanctions, but also allows the EU to maintain its ban. As a result, the United States has continued to impose its trade sanctions, while the EU has continued to maintain its ban.[104] The WTO has its own documentation on the dispute.[105]

From the US point of view, from birth to the ultimate final sale of the beef product, production of this product must include costly compliance procedures required to enter the EU market. These include up-front enrolment costs for certification programs for ranchers, lost feed efficiency for feedlots, traceability and testing requirements for packers, and additional transaction cost for exporters. Beyond compliance costs, US non-hormone treated beef also requires higher marketing

[103] Johnson, Renée "The U.S.-EU Beef Hormone Dispute" Federation of American Scientists. Congressional Research Service. The U.S.-EU Beef Hormone Dispute - EveryCRSReport.com

[104] Johnson, Renée "The U.S.-EU Beef Hormone Dispute" Federation of American Scientists. Congressional Research Service. The U.S.-EU Beef Hormone Dispute - EveryCRSReport.com

[105] World Trade Organization. European Communities — Measures Concerning Meat and Meat Products (Hormones)WTO | dispute settlement - the disputes - DS26

and distribution expenditures. These costs are the exact definition of an non-tariff measure (NTM)—added costs for a producer in an exporting country to meet the standards of an importing country (Beckman, Burfisher, Mitchell, & Arita, 2021).

2.4 Registration and use of HGPs in the USA

The US Food and Drug Administration has said (USFDA, 2002): “Consumers are not at risk from eating food from animals treated with these compounds because the amount of added hormone is negligible compared to the amount normally found in the edible tissues of untreated animals and that are naturally produced by the consumer’s own body” (Partridge, 2011).

3. Australia’s controls

3.1 Sale and use

3.1.1 Suppliers[106]

It is an offence to supply HGPs in Australia without a notification number which are assigned to suppliers by the APVMA. The APVMA will assign an HGP notification number for each premises from which HGPs will be supplied.

A person must not supply an HGP to another person unless the recipient of the HGP:

- has been assigned a notification number by the APVMA, and that notification number has not ceased to have effect and has not been withdrawn

OR

- has given to the supplier a declaration in the form approved by the APVMA (hyperlink) stating the following:
    - The total quantity and type of the HGP acquired.
    - The batch number of the HGP.
    - The purchaser declaration number for the premises where animals proposed to be treated with the promotant are to be kept.
- and acknowledging that the recipient is aware that an animal treated with an HGP must be marked as an animal so treated (that is, by making in its ear an equilateral triangular hole 20 millimetres on each side)

Supply under any other circumstances is a contravention of the Agvet Regulations.

On each occasion that a person manufactures and supplies HGPs to another person, the supplier must make a written record of the following information at the time of the supply (Regulation 49):

- The distinguishing name of the HGP entered in the Register of Chemical Products,
- The name and address of the manufacturer of the HGP.
- The notification number assigned to the premises from which the HGP was supplied to the recipient.
- The quantity of the HGP supplied.
- The date of manufacture of the HGP.
- The batch number of the HGP.
- The quantity of HGP manufactured in that batch.
- The date of supply of the HGP.
- The name and address of the recipient.

106 APVMA. Hormonal growth promotants (HGPs) | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)

- If one or more notification numbers have been allotted to the recipient:
    - the notification number, and address, of each premises to which the HGP is supplied; and
    - the quantity of the HGP supplied to each of those premises.
- If no notification number has been allotted to the recipient – the purchaser declaration number for the premises where animals treated with the HGP are to be kept.

3.1.2 Users

When purchasing HGPs, producers must sign a declaration form which is subsequently registered with the APVMA; they then must keep records to account for all the implants they purchased.
The HGP user must:

• be registered
• insert the pellet according to instructions
• identify the implanted animal with an ear mark (triangle punch)
• record the implant on the National Vendor Declaration (NVD) when the animal is sold.
(Partridge, 2011) [107]

3.2 Control of processing for non-HGP markets[108]

Some countries require beef that has not been treated with an HGP. Establishments processing for these markets must have a system in place to ensure the sourcing, identification, and segregation of HGP free cattle.

The establishment program must include verification that cattle presented for slaughter as HGP free are accompanied by a National Vendor Declaration (NVD), or other document(s) indicating that they have not been treated with HGPs.

Establishments are required to verify the HGP treatment status of **all** cattle declared on the NVD as HGP free by palpating all animals consigned under the NVD for the presence of palpable markers and examination for other indications of HGP use such as the triangular ear punch or other markers indicative of a possible HGP implant.

The detection of an implant or triangular ear punch in HGP free declared cattle is reported as a critical incident and is investigated by state-based agricultural authorities.

3.3 Control for supply to EU market

The European Union Cattle Accreditation Scheme (EUCAS) is a national animal production scheme that guarantees full traceability of all animals through the National Livestock Identification System (NLIS), linking individual animal identification to a central database. EUCAS allows Australia to meet the European Union (EU) market requirements for beef by segregating cattle that have never been treated with HGPs at any time from those that may have been treated.[109]

Processing establishments must confirm the eligibility of cattle through the NLIS database, ensure that the NLIS database is notified that the animals are deceased, and these activities are supervised by the On Plant Veterinarian.[110]

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[107] Declare HGPs to protect industry | Integrity Systems
[108] DAFF. Meat Notice 2017-05 - Establishments sourcing of livestock to comply with importing country Hormonal Growth Promotant free requirements (HGP FREE) - DAFF (agriculture.gov.au)
[109] DAFF. European Union Cattle Accreditation Scheme EUCAS - DAFF (agriculture.gov.au)
[110] DAFF. MEAT 2005 / 07 Amendment to European Union Cattle Accreditation Scheme (EUCAS) Requirements for EU Listed Abattoirs (agriculture.gov.au)

3.4 Evidence of control

Livestock Production Assurance (LPA) audits, both random and targeted, will seek evidence of compliance with regulatory responsibilities where HPGs are used by producers (see ch2, 3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA))

The National Residue Survey (NRS) includes hormones in its random monitoring program for beef (ch2, 2.4 National Residue Survey (NRS))

The NRS conducts on-farm audits to monitor compliance with accreditation requirements.

EUCAS accredited farms are audited on both a random and targeted basis. EUCAS feedlots and saleyard are audited annually, and their ongoing accreditation depends on a successful audit.[111]

Both daily verification and monthly testing are required by establishments processing cattle for non-HGP treated markets.[112] One liver sample must be collected each month from establishments slaughtering cattle and producing HGP free meat and meat products eligible for export to HGP free markets other than the EU. The liver sample must be tested for the presence of residues of trenbolone acetate and zeranol. Export processing establishments also palpate the ears of every animal being processed as non-HGP as a control to evidence animals have not been treated, e.g., cattle destined for China. Any treatment inconsistencies identified are officially reported and investigated.

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Hunter, R. A. (2010). Hormonal growth promotant use in the Australian beef industry. *Animal Production Science, 50*(7), 637-659. doi:https://doi.org/10.1071/AN09120

Partridge, I. (2011). *Using hormone growth promotants to increase beef production*. North Sydney: Meat & Livestock Australia.

[111] DAFF. European Union Cattle Accreditation Scheme EUCAS - DAFF (agriculture.gov.au)

[112] DAFF. Meat Notice 2017-05 - Establishments sourcing of livestock to comply with importing country Hormonal Growth Promotant free requirements (HGP FREE) - DAFF (agriculture.gov.au)

6. Australian red meat production: Sustainability and environmental credentials

Summary

The global market for red meat and other agricultural products is an evolving market that is impacted by international changes in government policies, consumer preferences, and a range of other factors outside the core focus of food safety and eating quality of red meat products. The market may be satisfied at a business-to-business, or a government-to-government level. Although many of these factors are still evolving, this chapter provides the reader with a feel of the range of issues that potentially will impact significantly on international trade for the Australian red meat industry. For leaders in government and industry it's imperative that these issues are strategically considered and weighed up carefully in the context of future positioning and investment within the industry. A critical decision is whether Australia positions itself on the front of the innovation curve or purposefully lag to learn the lessons of the early movers. The other key strategic decision with regard to this subject matter is where does industry and government position itself in regard to reform towards future product capabilities that ensure Australian maintains global market access and captures optimal onshore values for commodities exported. Industry investment will be determined by the security of return on capital. If export markets have signalled the likelihood of them incorporating into trade agreement a range of other factors in addition to food safety, it's imperative that our industry and government negotiators are aligned to the best outcome for our industry. Examples where such issues can arise are on the international multilateral standard setting forums such as Codex Alimentarius Commission where the mandate is sufficiently broad to address a range of issues under the "fair practices in the food trade" mandate. Once these other factors are enshrined in approved texts both WTO challenge and like-for-like assessment become increasingly complex.

In combination with the above, the range of production certifications emerging including carbon neutral farming, organic including biodiversity accreditation, raising claims etc. are creating an extremely complex supply chain, particularly when about 65% of red meat is exported and there is the potential for one carcase to be exported to 30 different countries or more under a number of certification schemes all requiring segregation. Overlay this with the different supply chain participants and the potential for breach risks and reputational damage increase.

Notwithstanding the complexities and risks touched upon in this chapter, significant opportunities also exist for the Australian red meat industry to capture the hearts and minds of a range of new and emerging domestic and international consumers that place a heightened importance on provenance, sustainability practices, and ethical and sympathetic handling of animals with the food they eat.

Contents

1. Sustainability concepts

The most often quoted definition of sustainability comes from the UN World Commission on Environment and Development: “sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” Sustainable practices support ecological, human, and economic health and vitality. Sustainability presumes that resources are finite and should be used conservatively and wisely with a view to long-term priorities and consequences of the ways in which resources are used.[113]

The UN Sustainable Development Goals (SDGs)[114] are part of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, which provides a shared blueprint for peace and prosperity for people and the planet, now and into the future. At its heart are the 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries in a global partnership. They recognise that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve our oceans and forests. Red Meat producers and supply chains play a part in meeting several SDGs.

The Australian Government has signed onto the 2030 agenda for sustainable development. Australian agriculture and the red meat and livestock industry support Australia’s contribution to the UN SDGs and recognise that aligning our practices to globally recognised sustainability benchmarks will become increasingly important to continued market access and sustainable food production.[115]

Most activity has been concerned with livestock production, but more attention needs to consider the consumption aspect and the role of consumers in shaping livestock supply chains. Neoclassical economics has failed to put a value on aspects of sustainability. A sustainable livestock economy depends on both production and consumption, inextricably linked in local, national, and global markets. At each scale, technical innovation and production practices need to respond to evolving demand for both market and non-market attributes of livestock systems (Moran & Blair, 2021).

Despite the importance attached to achieving the SDGs and need for action, a consensus on what should be done and even what is important is still developing. A large variety of models has been developed to explore the multidimensional, and sometimes conflicting, sustainability consequences of innovations and policies for European livestock farms. All three sustainability dimensions (environmental, economic, and social) were included in 33% of the models. The median number of sustainability themes, widely used in sustainability assessment, addressed by the models was 4 out of the total of 19 themes (van der Linden, de Olde, Mostert, & de Boer, 2020).

This is a rapidly evolving area; actions, metrics and standards are being developed by non-governmental organisations, governments, and intergovernmental organisations simultaneously and consequently, there will be much revision, reworking and chaos until the system settles.

[113] University of California Los Angeles (2023) Sustainability at UCLA. What is Sustainability? | UCLA Sustainability
[114] United National, Department of Economic and Social Affairs. Sustainable Development. THE 17 GOALS | Sustainable Development (un.org)
[115] Meat & Livestock Australia (2021) Sustainability update 2021. mla_sustainability_report_2021.pdf

2. Definitions and Standards

Definitions and standards for sustainability vary across geographic scope (international, national) and supply chain position (producer, retail). There is a common thread and interest running through them all, and general consistency at the detailed level. One important difference is that national, international, and supply-oriented standards and data-collections tend to be collective, whereas demand-side, retail standards and data-collections are interested in individual businesses and specific supply chain performance.

2.1 International

The UN Sustainable Development Goals (SDGs) recognize that ending poverty and other deprivations must go hand-in-hand with strategies that improve health and education, reduce inequality, and spur economic growth – all while tackling climate change and working to preserve oceans and forests.[116] There are 17 goals covering all of these aspirations, and targets and indicators to assess progress.[117] Annual Reports[118] are produced and meetings held to progress individual goals, as well as high level political forums to review the overall program.

2.2 National

The world's largest economies and more than 50% of Australia's top agricultural export markets have committed to achieving net zero greenhouse gas (GHG) emissions.[119]

2.2.1 EU

The European Union (EU) tends to lead on sustainability issues and is in the process of implementing sustainability reporting standards for corporations with reporting starting in 2024.[120,121]

The EU is taking a lead in driving climate change action through the Green Deal, a collective policy commitment for achieving climate neutrality by 2050. The Green Deal established multiple policies including the Product Environmental Footprint (PEF) scheme and the Carbon Border Adjustment Mechanism (CBAM) which may have significant implications for market access for Australia. The EU Anti-deforestation regulation (EUDR) was approved in 2023 and will require beef and cattle-derived products to be 'deforestation-free' by conducting due diligence on the land the beef was sourced from (e.g., via satellite imagery).[122] Provision of data with each shipment will be required from 30 December 2024.[123] The EU is also taking the lead to establish their own global regulations through

[116] United National, Department of Economic and Social Affairs. Sustainable Development THE 17 GOALS | Sustainable Development (un.org)
[117] United National, Department of Economic and Social Affairs. Sustainable Development Global indicator framework for the Sustainable Development Goals
[118] United National, Department of Economic and Social Affairs. Sustainable Development The-Sustainable-Development-Goals-Report-2022.pdf (un.org)
[119] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack
[120] FISMA - EU Sustainability Reporting Standards (europa.eu)
[121] European Commission -implementing acts Corporate Sustainability Reporting Directive (europa.eu)
[122] European Commission. DG Environment. Deforestation Deforestation (europa.eu)
[123] DAFF 2023. Meat Notice 23-10 European Union Deforestation Regulation. MN23-10: European Union Deforestation Regulation - DAFF (agriculture.gov.au)

the EU Corporate Sustainability Reporting Directive which will apply to more than 50,000 companies and require disclosure according to the Global Reporting Initiative (GRI) standards.[124]

2.2.2 Australia

The Australian Government has established the Emissions Reduction Fund (ERF, now called the Climate Solutions Fund) and the National Energy Productivity Plan (NEPP) as key mechanisms for achieving our international commitments and obligations around climate change. The ERF allows the creation of carbon credits which can be bought by government, and others who wish to offset their own emissions.[125]

The Australian National Greenhouse Gas Inventory (NGHGI) was set up for calculating the net GHG emissions produced each year in Australia. This method is approved by the International Panel on Climate Change as the method for calculating net zero commitments and is the method used by the red meat sector to track the progress towards carbon neutrality (CN30).[126]

The Australian Accounting Standard Board is working with others considering a reporting regime that meets the needs of users of both financial and non-financial information. The Australian Government is also considering the need for climate related financial disclosures.[127]

2.3 Investor oriented

Investors are responding to climate change by minimising risks from investments in companies and sectors that could be affected by climate change events, mandatory emissions targets, or other impacts of policy change towards sustainability. Simultaneously, investors are also seeking to have a positive impact on the environment by investing in companies which are creating solutions for improving sustainability. In turn, companies are increasingly seeking to demonstrate their environmental, social and governance (ESG) credentials to investors.[128]

2.4 Producer-oriented

Producer and other supply chain groups, both internationally, and within Australia, have established, and continue to develop, sustainability standards.

2.4.1 Global Roundtable on Sustainable Beef[129]

The Global Roundtable on Sustainable Beef (GRSB) mission is to advance, support, and communicate continuous improvement in sustainability of the global beef value chain through leadership, science, and multi-stakeholder engagement and collaboration. GRSB members include producer, processor, and retailer organisations, roundtables, and individuals from over 24 countries. Combined, they account for 75% cattle in the global beef chain. There are also regional/country-based sustainability groups.

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[124] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack

[125] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack

[126] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack

[127] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack

[128] Meat & Livestock Australia. 2022. Our sustainability story. Special edition of *Feedback* magazine. MLA : Feedback : Special Edition : Our sustainability story by... - Flipsnack

[129] Global Roundtable for Sustainable Beef Home - Global Roundtable for Sustainable Beef (grsbeef.org)

The GRSB envisions a world where beef is a trusted part of a thriving food system in which the beef value chain is environmentally sound, socially responsible, and economically viable.

GRSB priorities for 2030:

1. Establish a limited number of “Global Goals” for the GRSB Network
2. Communicate to ensure that beef is a trusted part of a thriving food system
3. Support the Roundtable Network
4. Develop an information system to report progress on the GRSB Global Goals
5. Develop and Strengthen partnerships to meet the Global Goals

2.4.2 Australian Beef Sustainability Framework[130]

The Australian Beef Sustainability Framework (ABSF) sets out the key indicators of performance in sustainability for the beef industry. Sustainability includes the production of livestock in a way that is environmentally, socially, and financially responsible, with respect for people, animals, and natural resources, today and for future generations. The reporting boundary covers the actions of the entire Australian beef value chain, including farms, saleyards, feedlots, transport, processing, and live export.

The ABSF enables success to be recognised through evidence-based metrics and empowers the industry to continually improve and demonstrate its values to customers, investors, and stakeholders. Major supermarkets, foodservice and investment groups are utilising the ABSF and aligning their own sustainability processes to it because it is tailored to the beef industry, and articulates what the supply chain, from producer to consumer wants addressed.

The ABSF is aligned to international and national standards and best practice guidelines. It utilises the best science and technology available through Meat & Livestock Australia (MLA) and its partnerships, and it tracks industry performance and reports on progress against key metrics.

The ABSF tracks the performance of the beef industry against a series of indicators grouped under four themes:

- Best animal care
- Economic resilience
- Environmental stewardship
- People and the community

Within the four themes the industry has identified 24 priority issues and created 53 indicators with which to measure sustainability within those priority areas.

The ABSF addresses SDGs 2 (zero hunger), 5 (gender equality), 6 (clean water and sanitation), 7 (affordable and clean energy), 8 (decent work and economic growth), 9 (industry, innovation, and infrastructure), 10 (reduced inequalities), 12 (responsible consumption and production), 13 (climate action), 14 (life below water), 15 (life on land), and 17 (partnerships for the goals).

2.4.3 Australian Sheep Sustainability Framework[131]

The Sheep Sustainability Framework (SSF) encompasses the value chain for Australian sheep meat and wool – from farm to fork and sheep to shelf. Sustainability includes the production of livestock in a way that is environmentally, socially, and financially responsible, with respect for people, animals, and natural resources, today and for future generations. Customers and consumers want to feel confident that the food and fibre they purchase has been responsibly produced. The SSF

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[130] Australian Beef Sustainability Framework. Home | The Australian Beef Sustainability Framework (sustainableaustralianbeef.com.au)

[131] Sheep Sustainability Framework. Home | Sheep Sustainability (sheepsustainabilityframework.com.au)

measures the production of sheep meat and wool for current and future generations in an ethical and environmentally, socially, and financially responsible manner.

The SSF aims to:

- Promote industry transparency with trading partners, customers, and the community
- Better inform investment in continuous improvement in focus areas
- Protect and grow access to financial capital
- Foster constructive relationships with external stakeholders to work collaboratively with the industry

The role of the SSF is to monitor, measure, and report industry performance against sustainability priorities. Data and trends gathered through the SSF identify opportunities on-farm, in transport, processing and at the customer interface where practices can be improved by both the industry and individuals. In doing so, the SSF can be used by industry to help protect and grow access to investment, finance, customers, and markets by providing credible evidence of performance and improvement. Further, individual enterprises may use the Framework to understand the industry's material issues and consider these in their forward planning.

The Framework helps industry better understand its opportunities, challenges, and impacts in four key themes: animal care, the environment and climate, economic resilience, people, and community. These themes are further broken down into focus areas and priorities.

The UN SDGs consist of 17 goals. National governments, including Australia, are expected to contribute to and report on all 17 goals through the UN process. The sheep industry supports Australia's contribution to the UN SDGs. Using a robust methodology based on consideration of each goal's targets and indicators, the Sheep Sustainability Framework demonstrates alignment with 10 of the 17 goals including both leading and supporting contributions or impacts.

2.5 Retail (supply chain)-oriented

There are evolving demand-side challenges focussing on emerging preferences related to environmental (greenhouse gas emissions, biodiversity and ecosystem health, soil and water use, social (animal welfare, use of biotechnology, meat-free alternatives, food waste), dietary and health impacts, arising from both production and consumption (Moran & Blair, 2021).

One example of an organisation articulating demand is the Consumer Goods Forum (CGF)[132] which brings consumer goods retailers and manufacturers together globally, with other key stakeholders, to secure consumer trust and drive positive change, including greater efficiency. With global reach, CEO leadership, and focus on retailer-manufacturer collaboration, the CGF is in a unique position to drive positive change and help address key challenges impacting the industry, including environmental and social sustainability, health, food safety and product data accuracy.

The CGF launched the Sustainable Supply Chain Initiative (SSCI)[133] in 2017 to recognise third-party auditing, monitoring and certification schemes and programmes that cover key sustainability requirements and apply relevant governance and verification. Through a comprehensive benchmarking process built on criteria developed by CGF members and expert stakeholders, the SSCI currently recognises independent auditing, monitoring and certification programmes that meet industry expectations on social sustainability and will later focus on environmental sustainability as well. The SSCI currently operates a social compliance benchmark for auditing schemes covering

[132] The Consumer Goods Forum. Home - The Consumer Goods Forum
[133] The Consumer Goods Forum About - The Consumer Goods Forum

activities in the manufacturing & processing, at-sea operations, and primary production sectors[134]. In the future, SSCI will also evaluate schemes on environmental compliance. The significance of SSCI recognised schemes is that they are more likely to be accepted at the retail end of the supply chain.

3. Sustainability metrics and measurement systems

3.1 International organisations

3.1.1 Food and Agriculture Organization of the United Nations (FAO)

Two key global environmental assessment schemes are the Livestock Environmental Assessment Performance Scheme (LEAP) and the Global Livestock Environmental Assessment Model (GLEAM).

The LEAP Partnership is a multi-stakeholder initiative that is committed to improving the environmental performance of livestock supply chains, whilst ensuring economic and social viability. Although a wide range of environmental assessment methods have been developed, there is a need for comparative and standardised indicators in order to switch focus of dialogue with stakeholders from methodological issues to improvement measures. LEAP leads a coordinated global initiative to accelerate the sustainable development of livestock supply chains and to support coherent climate actions, while contributing to the achievement of the 2030 Agenda for Sustainable Development and the Paris Agreement. LEAP develops comprehensive guidance and methodology for understanding the environmental performance of livestock supply chains, in order to shape evidence-based policy measures and business strategies.[135]

The GLEAM is a geographically based framework that simulates the bio-physical processes and activities along livestock supply chains under a life cycle assessment approach. [136] The aim of GLEAM is to quantify production and use of natural resources in the livestock sector and to identify environmental impacts of livestock. The model can operate at (sub) national, regional, and global scale. GLEAM differentiates key stages along livestock supply chains such as feed production, processing, and transport; herd dynamics, animal feeding and manure management; and animal products processing and transport. The model captures the specific impacts of each stage, offering a comprehensive and disaggregated picture of livestock production and its use of natural resources.

3.2 Private organisations

3.2.1 Global Reporting Initiative

Global Reporting Initiative (GRI) is an independent, international organisation that helps businesses and other organisations take responsibility for their impacts, by providing them with the global common language to communicate those impacts[137]. The GRI Standards are the world's most widely used standards for sustainability reporting. By better understanding, managing, and disclosing impacts, organisations can inform decisions, reduce risks, improve business opportunities, and strengthen stakeholder relationships. This, in turn, enables companies to demonstrate their

[134] The Consumer Goods Forum. Social compliance audit and certification schemes. SSCI Recognition - The Consumer Goods Forum

[135] Livestock Environmental Assessment and Performance (LEAP) Partnership | Food and Agriculture Organization of the United Nations (fao.org)

[136] FAO Livestock Environmental Assessment and Performance Partnership. Global Livestock Environmental Assessment Model (GLEAM) | Food and Agriculture Organization of the United Nations (fao.org)

[137] Global Reporting Initiative. GRI - About GRI (globalreporting.org)

contributions towards environmental stewardship and societal wellbeing. The Standards have been widely adopted by leading companies in more than 100 countries and are referenced in policy instruments and stock exchange guidance around the world. Over 160 policies in more than 60 countries and regions reference or require GRI.

The GRI has released a sector standard, *GRI13 Agriculture, Aquaculture and Fishing*.[138] GRI 13 describes 26 topics identified as likely material for all organizations around the world involved in crop cultivation, animal production, aquaculture, and fishing. These topics include: emissions, biodiversity, soil health, pesticides, water, waste, food safety, animal health and welfare, labour, supply chain traceability The Standard sets expectations for what all companies in these sectors need to report on, their shared and specific impacts on the economy, environment, and people. GRI 13 is shaped by international instruments – including those by the Food and Agriculture Organization, International Labour Organization, International Maritime Organization, and International Organization for Migration. GRI provides detailed methods for measurement for the material topics included in the standard.

3.2.2 Others

Numerous standards, metrics and methods are promulgated by numerous groups.

Australian industry tries to ensure that the way of measuring and reporting is consistent with global schemes, so that the measures in place can be fitted into the numerous and emerging standards.

4. Australia's sustainability performance

4.1 Australia's performance

4.1.1 UN Sustainable Development Goals (SDGs)

Australia's performance against the Sustainable Development Goals (SDGs) is measured and reported.[139]

4.1.2 Organisation for Economic Co-operation and Development (OECD)

The Organisation for Economic Co-operation and Development (OECD) reports on performance against a number of environmental indicators. The environmental performance reviews document environmental practices and make an independent assessment of a country's progress. A review of Australia has been conducted.[140]

OECD also collects statistics on countries covering a wide range of environmental indicators including air, climate, water, waste, forest, land resources, and biodiversity.[141,142]

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[138] Global Reporting Initiative https://www.globalreporting.org/standards/standards-development/sector-standard-for-agriculture-aquaculture-and-fishing/

[139] United National, Department of Economic and Social Affairs. Sustainable Development Statistics. SDG Indicators Database SDG Country Profiles

[140] OECD Environmental Performance Reviews: Australia 2019. Environmental country reviews - OECD

[141] OECD. Stat Data by theme. Environment. Greenhouse gas emissions (oecd.org)

[142] OECD Data. Environment. Environment - OECD Data

4.2 Australia's red meat industry performance

4.2.1 Carbon Neutral 2030 (CN30)[143]

Industry has set an ambitious target to be Carbon Neutral by 2030 (CN30) in recognition that it must become more environmentally and economically resilient to manage the impacts of climate change. CN30 is an aspirational target for the livestock industry to net zero greenhouse gas emissions by 2030, which means the Australian red meat and livestock industry will make no net release of greenhouse gas (GHG) emissions into the atmosphere, as measured by the NGHGI by 2030. The NGHGI reports Australia's emissions annually, from 1990 to present, in keeping with Australia's international GHG emissions reduction commitments, with 2005 set as the baseline year. The NGHGI reports GHG emissions as total carbon dioxide equivalent (CO_2e) and the amount of carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) for each sector.[144] The industry's major GHG emissions are enteric methane (CH_4) a by-product of ruminant livestock digestion, carbon dioxide (CO_2) from soil and vegetation change, and nitrous oxide (N_2O) from soils.[145]

The Australian red meat and livestock industry's vegetation and regrowth management is tightly regulated by federal and state government legislation. In 2020, the beef industry has reduced emissions by 64.1% since the baseline year of 2005[146], largely through significantly improved productivity as well as changes to vegetation management practices that reflect the changed regulatory environment. This equates to a reduction in industry's proportion of national GHG emissions from 21% in 2005 to 10% in 2017.[147] The Global Warming Potential (GWP) is the most commonly used and internationally accepted metric to report GHG emissions and is a measure of how much energy a greenhouse gas traps in the atmosphere in a given time period. The GWP of other gases, including methane, is converted to equivalent amounts of carbon dioxide (CO_2-e) for accounting and reporting purposes.

4.2.2 Australia's beef industry sustainability performance[148]

The Australian Beef Sustainability Framework tracks the performance of the beef industry against a series of indicators grouped under four themes:

- Best Animal Care,
- Economic resilience
- Environmental stewardship
- People and the community.

Within the four themes the industry has identified 24 priority issues and created 53 indicators with which to measure sustainability within those priority areas.

Reports are issued annually against the indicators as well as providing narrative[149]

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[143] MLA. Research & Development. Environmental sustainability. Carbon Neutral 2030. Carbon neutral 2030 R&D | Meat & Livestock Australia (mla.com.au)
[144] Department of Climate Change, Energy, the Environment and Water. Tracking and reporting greenhouse gas emissions - DCCEEW
[145] Meat & Livestock Australia Carbon Neutral by 2030: Your Questions Answered | Meat & Livestock Australia (mla.com.au)
[146] Australian Beef Sustainability Framework absf-annual-update-2023-web.pdf (sustainableaustralianbeef.com.au)
[147] Meat & Livestock Australia (2020). The Australian Red Meat Industry's Carbon Neutral by 2030 Roadmap 2689-mla-cn30-roadmap_d3.pdf
[148] Australian Beef Sustainability Framework 2023 Annual Update Annual update | The Australian Beef Sustainability Framework (sustainableaustralianbeef.com.au)
[149] Australian Beef Sustainability Framework 2023 Annual Update Annual update | The Australian Beef Sustainability Framework (sustainableaustralianbeef.com.au)

4.2.3 Australia's sheep industry sustainability performance[150]
The framework recognises and outlines the sheep industry's sustainability commitments through the four themes:

1. Caring for our sheep
2. Enhancing the environment and climate
3. Caring for our people, customers, and communities
4. Ensuring financial sustainable industry

An annual report is produced.[151]

4.2.4 Raising credentials
Organic and Pasture (grass)-fed credentials are allied to sustainability concepts but are very specific in their application.

Organic
Australia has a National Standard for Organic and Bio-dynamic Produce[152], that is maintained by the Department of Agriculture, Fisheries and Forestry (DAFF), and has animals and meat within its scope.

Organic means the application of practices that emphasise the:

- use of renewable resources; and
- conservation of energy, soil, and water; and
- recognition of livestock welfare needs; and
- environmental maintenance and enhancement, while producing optimum quantities of produce without the use of artificial fertiliser or synthetic chemicals.

DAFF is the Australian government [153]authority responsible for organic and bio-dynamic products. The department provides export certification and declarations in-line with Australia's export legislation and importing country requirements. Organic exports are prescribed goods and controlled through Export Control (Organic Goods) Rules 2021.[154]

Grass-fed
The Pasturefed Cattle Assurance System (PCAS)[155], is an assurance program that enables the industry to prove claims relating to pasturefed or grassfed production methods.

The PCAS Standards cover core and optional requirements. The core module governs the on-farm feed requirements and traceability of cattle, as well as animal handling practices which influence eating quality.

The PCAS Standards also include two optional modules to support claims relating to the freedom from antibiotics (no use of antibiotics, sulphonamides, ionophores or coccidiostats in feed, water or by injection) and hormone growth promotants (HGPs).

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150 Sheep Sustainability Framework Annual Report 2023 sheep-sustainability-framework-2023-annual-report_updated-nov-23_web.pdf (sheepsustainabilityframework.com.au)
151Sheep Sustainability Framework Annual Report 2023 sheep-sustainability-framework-2023-annual-report_updated-nov-23_web.pdf (sheepsustainabilityframework.com.au)
152 National Standard Organic and Biodynamic (agriculture.gov.au)
153 Department of Agriculture Fisheries and Forestry. (2022) National Standard for Organic and Bio-dynamic Produce. Edition 3.8 Organic and bio-dynamic goods - DAFF (agriculture.gov.au)
154 Export Control (organic goods) Rules 2021 https://www.legislation.gov.au/Series/F2021L00339
155 AUS-MEAT Services Pasturefed Cattle Assurance System PCAS | AUS-MEAT (ausmeat.com.au) PCAS Pasturefed | PCAS Pasturefed

4.2.5 Supply chain credentials

A number of Australian supply chains have developed sustainability claims, in various terms. These brands are listed as illustrations rather than being a definitive or endorsed list.

OBE[156]

OBE product claims to meet National Standards for Organic and Bio-Dynamic Produce and the United States Department of Agriculture National Organic Program (USDA NOP).

JBS Great Southern[157]

All Great Southern™ products are grass fed, free range, free from added hormones, never treated with antibiotics or exposed to GMOs. All claims are independently certified. The JBS Farm Assurance program applies to beef and lamb products with respect to animal welfare, raising claims, food safety and quality.

Teys

Teys Group produce a sustainability report against GRI standards.[158]

Greenham

The Greenham Tasmania – Cape Grim Beef Brand has developed their sustainability framework based on the ABSF. The project represents an important milestone as the first project where the framework has been applied at a value-chain level. The ABSF has enabled the Greenham Tasmania – Cape Grim Brand to design their business specific, sustainable value-chain framework, with specific key priorities, measures, and indicators across the four sustainability pillars of the ABSF.

Cape Grim product is certified:

- Humane
- Meat Standards Australia (eating quality)
- HGP free (under Tasmanian law)
- Non-GMO (non-GMP Project verified)
- Global animal partnership (GAP)
- Never Ever – grass-fed, no antibiotics, no HGPs

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van der Linden, A., de Olde, E. M., Mostert, P. F., & de Boer, I. J. M. (2020). A review of European models to assess the sustainability performance of livestock production systems. *Agricultural Systems, 182*, 102842. doi:https://doi.org/10.1016/j.agsy.2020.102842

[156] OBE Organic Organic Beef Exporter in Australia | OBE Organic Australia

[157] Great Southern Great Southern - Greatness comes naturally (greatsouthernfarms.com.au)

[158] Teys Group (2020) Sustainability Report. 21-001-TEYS-BROCHURE-V1-10.pdf (teysgroup.com)

7. Animal welfare

Summary

Australia's commitment to animal welfare begins, in a formal sense, through commitment to the World Trade Organization and to the World Organisation for Animal Health (WOAH). Australia also has commitment to animal health and welfare as foundations of a strong export industry for meat and meat products. Australia has been deeply involved in leading animal health and welfare through WOAH (founded as OIE) and involvement in numerous agriculture capacity building projects internationally.

Australia has had a focus on continual improvement in animal welfare since the 1980s, with the development of Codes of Practice, developing legal frameworks, and welfare science to support best practices. There is a constant interplay between the development of science and ideas, development of international standards, and development of Australian standards and practices, in an evolutionary way, with one not clearly leading the other, but developing together. Animal Health Australia has become the focal point for federal and state/territory governments, professional bodies, primary production organisations and welfare advocates to come together set the standards.

Animal welfare is primarily a state responsibility backed by legislation, robust standards, industry systems to demonstrate compliance with government or additional standards through farms, transport, feedlots, and finally, processing. Auditing occurs by both government and third-party auditors. The Commonwealth Department of Agriculture, Fisheries and Forestry closely supervises animal welfare at export slaughter establishments to ensure that Australian requirements, and agreed international requirements are met.

Australian export establishments are audited from time to time by importing country auditors, who include animal welfare in their audits and issue public reports of their findings, usually with no animal welfare concerns. Australian and international purchasers of Australian meat also have animal welfare standards for both farms and processing, and these requirements are audited.

Contents

1. International standards setting

Australia is a member of the World Trade Organization (Chapter 1, 1.2 World Trade Organization (WTO)) and the Sanitary and Phytosanitary (SPS) Agreement encourages members to base their SPS measures on international standards, guidelines, or recommendations and to participate in the activities of the relevant international organizations. The WTO and World Organisation for Animal Health (WOAH) (Chapter 1, 1.3 World Organisation for Animal Health (WOAH)) work together in several ways [159] and the SPS Agreement references WOAH as the relevant body for animal standards.[160]

WOAH[161] was founded as Office International des Epizooties (OIE) in 1924. Together, the Organisation and its Members coordinate the global response to animal health emergencies, the prevention of zoonotic diseases, the promotion of animal health and welfare, and better access to animal health care.

WOAH and the WTO cooperate in several ways including on the work of the WTO SPS committee. WOAH and the Food and Agriculture Organization of the United Nations (FAO) cooperate in several ways.[162]

1.1 WOAH Terrestrial Animal Health Code

The WOAH Global Animal Welfare Strategy[163] was adopted by all Members in 2017 and aims to be a source of ongoing guidance for the WOAH's activities in this area. The strategy focuses on the development of international standards on animal welfare.

The main standard of interest is the Terrestrial Animal Health Code (the Terrestrial Code) which is maintained by the Terrestrial Animal Health Standards Commission (the Code Commission). The Terrestrial Code contains trade standards for terrestrial animals and their products and attempts to reflect current scientific information.

The guiding principles which inform the World Organisation for Animal Health's work on the welfare of terrestrial animals include the 'Five Freedoms' (see 5.1 Definitions and approaches to animal welfare).

Section 7 of the Terrestrial Code deals with animal welfare, particularly chapters

- 7.1 Introduction
- 7.2 Transport of animals by sea
- 7.2 Transport of animals by land
- 7.4 Transport of animals by air
- 7.5 Slaughter of animals
- 7.9 Beef cattle production systems

which are updated from time to time.

[159] Agreement with the World Trade Organization (WTO) - WOAH - World Organisation for Animal Health
[160] World Trade Organization. Sanitary and Phytosanitary (SPS) Committee WTO | The SPS Committee
[161] World Organisation for Animal Health Home - WOAH - World Organisation for Animal Health
[162] Agreement with the Food and Agriculture Organization of the United Nations (FAO) - WOAH - World Organisation for Animal Health
[163] World Organisation for Animal Health (2017) OIE Global Animal Welfare Strategy. en-oie-aw-strategy.pdf (woah.org)

The contents of the Terrestrial Code influence Australian, and other national standards, and vice versa. In general, Australian standards are consistent with WOAH standards with minor deviations where Australian conditions are significantly different to other countries.

2. Australian Government standards

States and Territories have constitutional authority for enforcement of regulations on animal welfare. Having eight separate state and territories results in eight separate animal welfare legal frameworks, all which contain a primary piece of legislation and secondary or subordinate forms of legislation. Subordinate laws contain crucial details that govern everyday human–animal interactions and industry practices. In 2022, a total of 201 pieces of subordinate legislation were identified in Australia through several categories of animals: companion, production, wild/exotic, and entertainment (Morton & Whittaker, 2022).

Welfare can be conveniently thought of being maintained through production and slaughter phases; one more intense than the other, and in Australia, largely the responsibility of different parts of government.

2.1 Australian Animal Welfare Strategy for on-farm standards

The Australian Animal Welfare Strategy (AAWS) has been in active implementation since 2005, led by the Australian Government Department of Agriculture, Fisheries and Forestry (DAFF). The scope of the AAWS deliberately embraces all sentient animals, irrespective of their circumstances. It provides a working partnership between government and civil society. Its three goals are:

- An enhanced national approach and commitment to ensuring high standards of animal welfare based on a concise outline of current processes;
- Sustainable improvements in animal welfare based on national and international benchmarks, scientific evaluation, and research, taking into account changes in the whole of community standards; and
- Effective communication, education, and training across the whole community to promote an improved understanding of animal welfare (Thornber, 2010).

The Australian Government together with states and territories has developed since the 1980s and continues to develop and implement nationally consistent standards and guidelines for farm animal welfare. The Australian Animal Welfare Standards and Guidelines update and replace the *Model Code of Practice for the Welfare of Animals*, for particular animal industries. Consideration of contemporary animal welfare science, costs to industry, practicalities, community standards and international expectations are utilised to support an evidence-based approach. The standards are accompanied by voluntary guidelines that set out recommended practice for the care and husbandry and animals.

Animal Health Australia[164] is responsible for facilitating the production of the Australian Animal Welfare Standards and Guidelines.[165]

The standards are designed to be implemented in state and territory legislation. The standards provide the basis for developing and implementing consistent legislation and enforcement across Australia. Australia's state and territory governments have primary responsibility for animal welfare and laws to prevent cruelty.

[164] Improving livestock welfare - Animal Health Australia

[165] Animal Health Australia. Australian Animal Welfare Standards and Guidelines. Animal Welfare Standards

The guidelines are the recommended practices to achieve desirable livestock welfare outcomes. Guidelines are designed to complement the standards. Non-compliance with one or more guidelines will not constitute an offence under the law.

The Standards and Guidelines contain:

(i) Objectives describing the intended outcome(s) for each section of the standards;
(ii) Standards or minimum requirements that must be met under animal welfare law; and
(iii) Guidelines for the recommended practices to achieve desirable animal welfare outcomes to guide and describe higher animal welfare outcomes compared to the minimum requirements of the Standards.

This variation in acceptable practices reflects the vast differences in husbandry conditions between different agricultural regions, particularly in the extensive rangelands and tropical northern Australia where livestock farming is more often described as animal "harvesting." Here, the climatic extremes, large areas and distances within and between holdings (stations or farms) and low management inputs are necessary, ensuring that the extensive tropical cattle industry continues to face significant challenges to assure high standards of animal welfare (Windsor, 2021).

The *Australian Animal Welfare Standards and Guidelines for Cattle* [166] were agreed by State and Territory Governments in 2016 and are being regulated into law by most State and Territory governments. The progress of implementation by State and Territory governments is noted on the Standards website.

The *Australian Animal Welfare Standards and Guidelines for Sheep* [167] were agreed by State and Territory Governments in 2016 and are being regulated into law by most State and Territory governments. The progress of implementation by State and Territory governments is noted on the Standards website.

The industry standards and guidelines for goats[168] undergo a review by the Goat Industry Council of Australia (GICA) and Animal Health Australia annually. The industry standards and guidelines apply to all goat farming enterprises in Australia from extensive grazing to fully housed systems to individually owned. The standards and guidelines are voluntary.

2.2 Land transport standards

The *Australian Animal Welfare Standards and Guidelines — Land Transport of Livestock* [169]are regulated into law by State and Territory governments. The development of these standards is described by Edge and Barnett (2009) and de Witte (2009).

The Land Transport Standards cover the process of land transport of livestock by road, rail, and vehicle onboard a ship. From an animal welfare perspective, this process commences at the time that animals are first deprived of feed and water before loading, to the time that livestock have access to water after the journey (destination) and include:

- mustering and assembly
- handling and waiting periods before loading

[166] Animal Health Australia. Australian Animal Welfare Standards and Guidelines Cattle : Animal Welfare Standards
[167] Animal Health Australia. Australian Animal Welfare Standards and Guidelines Sheep : Animal Welfare Standards
[168] Animal Health Australia. Australian Animal Welfare Standards and Guidelines Goat : Animal Welfare Standards
[169] DAFF. Australian Animal Welfare Standards and Guidelines. Version 1.1. September 2012 Land Transport : Animal Welfare Standards

- loading, journey duration, travel conditions, spelling periods
- unloading and holding time.

The Land Transport Standards apply to all people responsible for the care and management of livestock that are transported throughout the entire process including agents, transport operators and people on farms, at depots, sale yards, feedlots, and processing plants. There is a chain of responsibility for the welfare of livestock that begins with the owner or their agent and extends to the final receiver of the livestock.

The Land Transport Standards apply to the major commercial livestock industries in Australia: cattle, sheep, and goats, as well as other species.

2.3 Animal welfare in saleyards

The Australian Animal Welfare Standards and Guidelines for Saleyards and Depots[170] were finalised in February 2018 and regulated into law by State and Territory governments by the same process as the on-farm standards. The progress of implementation by State and Territory governments is noted on the Standards website.

2.4 Slaughter establishment standards

Australian Animal Welfare Standards and Guidelines for Livestock at Processing Establishments are under development and are expected to be completed in 2024[171]. Currently, a model code of practice provides guidance.[172]

DAFF is responsible for the supervision of the majority of animal slaughtered in Australia, particularly for export markets.

The following standards apply for export meat processing.

2.4.1 Australian Meat Standard

Under the export Control (meat and meat products) Rules 2021, exporters must comply with the Australian standard for *Hygienic production and transportation of meat and meat products for human consumption* (AS4696:2023) (The Australian Meat Standard)[173,174] for animal welfare in processing establishments. The desired outcome of the animal welfare requirements is the minimisation of the risk of injury, pain and suffering and the least practical disturbance to animals. The Standard requires attention to the handling of animals, especially young, injured, sick or stress susceptible animals, and stunning prior to severing of the large blood vessels.

The department will ensure that all export registered abattoirs meet the minimum animal welfare requirements as described in the *Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS4696). It will also ensure that market access requirements over and above the Standard are also maintained on export registered abattoirs.

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[170] Animal Health Australia. Australian Animal Welfare Standards and Guidelines Saleyards and Depots : Animal Welfare Standards

[171] DAFF. Australian Animal Welfare Standards and Guidelines. Australian Animal Welfare Standards and Guidelines - DAFF (agriculture.gov.au)

[172] Model code of practice for the welfare of animals: Livestock at slaughtering establishments. August 2001. Model Code of Practice for the Welfare of Animals: Livestock at Slaughtering Establishments, CSIRO Publishing, 9780643069114

[173] Standards Australia. 2007 Hygienic production and transportation of meat and meat products for human consumption. AS 4696:2007 5553 (csiro.au). The 2023 edition differs only in post mortem inspection schedules

[174] DAFF. March 2023. Export Meat Operational Policy 1.0 Animal Welfare. export-meat-operational-policy-1-0-animal-welfare.docx (live.com)

2.4.2 Supervision of export processing

Animal welfare at export-registered meat establishments is the responsibility of the establishment management. Livestock harvesting and livestock handling must be undertaken in a manner that minimises the risk of injury, pain and suffering and causes the least practicable disturbance to animals from the time of arrival on plant to the completion of slaughter[175]. Where animal welfare issues are identified, action must be taken to ensure that these issues are rectified immediately and effectively. The establishment has a responsibility to complete, and DAFF has responsibility to forward, all animal welfare incident reports to state/territory authorities.[176]

Where establishment personnel have not identified and rectified animal welfare incidents, the On Plant Veterinarian (OPV) will direct establishment management to promptly resolve the incident such that any injuries, pain or suffering of affected animals is alleviated.

Examples of reportable welfare incidents:

- Animals arrive at an establishment in an unacceptable condition (blindness, fractures, severe mastitis, late pregnancy, emaciation)
- Poorly constructed or maintained infrastructure
- Animal cruelty by personnel
- Ineffective stunning
- Delated stun to stick interval

DAFF verifies animal welfare on all export registered abattoirs under its Meat Establishment Verification System (MEVS). MEVS is used to underpin DAFF's health certification system for export eligible meat and meat products. There are two verification activities, conducted monthly, prescribed for animal welfare including Check-the-checker process monitoring verification of animal handling (load-in to the knocking box) and Check-the-checker process monitoring verification of slaughter floor or skinning room operations. The latter check covers animal welfare elements that relate to stunning and sticking.

2.4.3 Recognition of industry standards[177]

In recognition of the Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS)(see below), DAFF will accept approved arrangement animal welfare programs on establishments that are certified by AUS-MEAT, by reducing the audit scope for animal welfare during its monthly or six-monthly audit programs. The department will audit non-certified establishments against the Australian Meat Standard requirements for animal welfare and importing country requirements for animal welfare.

AAWCS is a voluntary program owned by the Australian Meat Industry Council (AMIC). It was launched in September 2013 to demonstrate industry's commitment to animal welfare and compliance with the Industry Animal Welfare Standards. The rules for the AAWCS are contained in the AAWCS Program Rules and the AAWCS Notification Protocol. This policy does not replace DAFF's audit policies applicable to export registered establishments. Rather it is an adjunct providing direction in relation to auditing of animal welfare on export registered abattoirs. Because animal

[175] DAFF. March 2023. Export Meat Operational Policy 1.1 Animal Welfare – from arrival to completion of slaughter Export Meat Operational Guideline 1.1 Animal welfare - from arrival to completion of slaughter (agriculture.gov.au)

[176] DAFF. 2023. Export meat Operational Guidelines 1.2 Animal welfare incident reporting. https://www.agriculture.gov.au/sites/default/files/documents/export-meat-operational-guideline-1-2-animal-welfare-incident-reporting.docx

[177] DAFF. 2023. Export meat Operational Guidelines 1.3 Department-recognised animal welfare system Export Meat Operational Guideline 1.3 Department-recognised animal welfare system (agriculture.gov.au)

welfare legislation sits with the relevant state/territory regulatory agencies, the Commonwealth does not have legislative power to take enforcement action to prosecute. It relies on a notification system (i.e., animal welfare incident report) to inform the relevant authority.

3. Industry welfare standards

The Australian Animal Welfare Standards and Guidelines cover producers' responsibilities and set out animals' needs in relation to feed and water; risk management in extreme weather, natural disasters, disease, injury, and predation; facilities and equipment; handling and management/husbandry; breeding management; and humane killing.

In addition to government-initiated Standards and Guidelines, there are industry programs to help producers to comply with welfare expectations.

3.1 Animal welfare on farm

Livestock Production Assurance program (LPA, see Ch 2, Sourcing safe and health animals, 3.3 Maintaining safety of animals on properties (Livestock Production Assurance, LPA))is a voluntary on-farm assurance program that underpins market access for Australian red meat, is often a requirement for source animals for export registered processors. LPA requires producers to maintain familiarity with requirements for animal welfare.

To ensure the handling of livestock is consistent with the requirements of the Australian Animal Welfare Standards and Guidelines for cattle, sheep, and goats (as applicable), LPA requires livestock producers to:

- Have a current copy of the 'Australian Animal Welfare Standards and Guidelines' for cattle, sheep, or goats (as applicable) accessible as a reference.
- Ensure a representative or person responsible for the management of livestock has successfully completed training in relation to the Australian Animal Welfare Standards and Guidelines (complete the LPA Learning Module on Animal Welfare)
- Ensure staff involved in animal husbandry are familiar with the content of the current version of the Standards and Guidelines for cattle, sheep and/or goats (as applicable).

The Royal Society for Prevention of Cruelty to Animals (RSPCA) has a standard for Dairy Calves.[178] The aim is to ensure that dairy calves are raised in a higher welfare environment for either beef or veal.

3.2. Animal welfare in transport

The "Fit to Load" Guideline[179] has been developed to help livestock operators meet the Australian Animal Welfare Standards & Guidelines for the Land Transport of Livestock and decide whether an animal is fit to be loaded for transport and for the entire journey by road or rail to any destination within Australia. Ensuring livestock are fit for transport is also a requirement of the Livestock Production Assurance (LPA) program.

The Guide is a pocket-sized, flip-page book with stout plastic covered pages, divided into three main sections:

1. Roles and responsibilities

[178] RSPCA. Dairy Calves Higher welfare veal and beef farming | RSPCA Approved Farming Scheme
[179] Meat & Livestock Australia. Is the animal fit to load? Fit to load | Meat & Livestock Australia (mla.com.au)

2. Producers/consignors and transporter responsibilities: how to assess if the animal 'is fit to load?'
3. Examples of animals that are unfit to load (photographs)

3.3 Beef feedlots

Beef feedlots are required to minimise risk to cattle welfare by ensuring sufficient space, drainage, heat load management, feed, and water. Daily inspection of animals is required.

The National Feedlot Accreditation Scheme (NFAS)[180] requires that the welfare of livestock is not compromised, and prompt and appropriate remedial action is taken when required (Element LM4). In addition to the general requirements of the *Australian Animal Welfare Standards and Guidelines for Cattle*, the NFAS requires (amongst other items)

- Hospital pens to be identified
- Cleaning and maintenance of surfaces
- Arranging transport on and off and feedlot
- Humane destruction of animals when required
- Investigation of any incident of animal cruelty

Additional elements deal with livestock transport, animal health, excessive heat load, livestock incident reporting, and environmental management. The Australian Lot Feeders Association (ALFA) provides advice to its members on best practices, managing heat, wet pens etc.[181]

3.4 Animal welfare in processing

The Australian Government has animal welfare responsibilities for export abattoirs and the live animal export trade.

Industry-based certification against standards ensures compliance with legislated requirements.

3.4.1 Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS)

The AAWCS Standard[182] was developed to reflect the expectations of both the Australian meat processing industry and the community regarding the management of livestock at Australian livestock processing establishments. The Standard is intended for incorporation into existing livestock processing industry quality assurance programs and to provide support towards demonstrating existing regulatory requirements in the industry. The development of the first edition was described by Edge and Barnett (2008)

> The objectives of the Standard are to enable establishments to demonstrate fulfilment of the regulatory requirements covering the welfare of livestock and ensure good animal welfare outcomes. The Standard sets out requirements for the welfare of livestock during processing. The requirements are structured to address the topics of: a) management procedures and planning; b) resources, including human resources; c) animal management; d) animal handling; and e) stunning, sticking and humane killing.

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[180] AUS-MEAT National Feedlot Accreditation Scheme NFAS | AUS-MEAT (ausmeat.com.au)
[181] Australian Lot Feeders' Association | Grain Fed Beef (feedlots.com.au)
[182] Australian Meat Industry Council (2021) Industry Animal Welfare Standard for Livestock Processing Establishments Preparing eat for Human Consumption AMIC-Ed3-Industry-Animal-Welfare-Standard_effective-1-Jan-2022.pdf (aawcs.com.au)

An implementation Guide accompanies the Standard and provides examples of the evidence that is required to meet the Standard and explain how the Standard may be achieved.[183]

The commercial processing of cattle (including calves), sheep (including lambs), and goats from receival at the processing establishment through to (and including) slaughter are included in the Standard.

AAWCS is independently audited to demonstrate compliance with the industry best practice animal welfare standards.

3.4.2 Industry guidelines to assist animal welfare at processing establishments

The "Animal Fit to Process?" guides were developed, one guide for cattle, one for goats/sheep and one for calves. "Is it fit to process?" guides help small to medium enterprises (SME) processing for the domestic market, as well as Tier 1 export abattoirs. The guides link to the Australian Animal Welfare Standards and Guidelines – Land Transport Standard of Livestock. The guides also contain sections describing how to prepare an animal welfare incident report and emergency animal disease signs. The guides provide a benchmark as the processing industry continually improves animal welfare at Australian abattoirs.[184]

4. Animal welfare performance

Animal welfare checks and audits are always occurring through the work of DAFF and AAWCS audits and through incident reporting, but these data are not available for individual processors or farms. Animal welfare performance is therefore most easily assessed through industry-based reporting: the Australian Beef Sustainability Framework and the Sheep Sustainability Framework. Some additional data are available through importing country audits.

4.1 Australian Beef Sustainability Framework

The Australian Beef Sustainability Framework[185] (ABSF) is an initiative of Red Meat Advisory Council (RMAC) and was launched in 2017 to create a pathway of best practice for the Australian beef industry and track performance against a series of critical indicators including the theme of best animal care.

The Australian beef industry:

- Recognises cattle as being able to feel and perceive the world around them, and supports the five domains of animal welfare to underpin best practice.
- Recognises that Australian law and other industry standards are the minimum expectations of the industry.
- Supports the continuous improvement of animal welfare based on science and supports and invests in alternatives to invasive animal husbandry techniques.
- Recognises the need for punitive action against any individual or organisation knowingly contravening a jurisdiction's animal welfare legislation and/or the national Animal Welfare Standards.
- Supports the Australian Animal Welfare Standards and Guidelines for Cattle and the incorporation of the Standards component into jurisdictional regulations.

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[183] Australian Meat Industry Council (2021) Industry Animal Welfare Standard for Livestock Processing Establishments Preparing eat for Human Consumption. Implementation Guide. AMIC-Industry-Animal-Welfare-Guidance_effective-1-Jan-2022.pdf (aawcs.com.au)

[184] AMPC. Is it fit to process? AMPC_ProcessorsGuide_FinalReport.pdf

[185] Home | The Australian Beef Sustainability Framework (sustainableaustralianbeef.com.au)

- Supports and promotes the industry's "Is the animal fit to load?" Guide and its periodic revision, and the National Standards for the Land Transport of Livestock.
- Encourages greater transparency with the community regarding through-chain animal welfare practices.
- Supports and advocates for the use of low-stress stock handling techniques when handling livestock.
- Continues to lead the world in livestock exporting standards

The ASBF tracks indicators for Best Animal Care and reports annually on:

- Animal husbandry
    - Use of pain relief for invasive husbandry practices
    - Polled calves born in seedstock herds
- Biosecurity
    - Properties covered by a biosecurity plan
- Processing practices
    - Cattle processed in AAWCS accredited establishment
- Livestock transport
    - Live export mortality
- Health and welfare
    - Awareness of Australian Animal Welfare Standards for Cattle
    - Compliance with NFAS animal welfare requirements
    - Access to shade in feedlots
    - Vaccination for clostridial diseases
    - Producers trained in low stress stock handling

4.2 Sheep Sustainability Framework

The Sheep Sustainability Framework (SSF)[186] is a commitment of the RMAC and helps industry better understand its opportunities, challenges, and impacts in key areas such as animal care.

The SSF tracks indicators for animal care and report annually on:

- Reduce, refine, and replace painful husbandry procedures
    - Incidence of mulesing
    - Use of pain management associated with mulesing, castration, and tail docking
- Implement best practice sheep management
    - Use of pregnancy scanning to improve lamb survival
    - Adoption of best practice management of ewes
    - Training in shearing welfare
    - Wild predator management
    - Transported in line with Fit to Load guidelines
    - Sheep sold through National Saleyard Quality Assurance (NSQA) saleyards
    - Mortality on sea voyages
- Ensure humane processing and on-farm euthanasia
    - Awareness of humane on-farm euthanasia standards
    - Processing in establishments accredited to AAWCS

4.3 Importing country welfare audits

Some countries with high animal welfare expectations publish their audits of the Australian system, but it should be remembered that the corrective actions that are raised in these system audits are

[186] Home | Sheep Sustainability (sheepsustainabilityframework.com.au)

frequently minor breaches or differences of opinion about how to achieve a particular outcome; rarely do they amount to real problems with the safety, wholesomeness, or integrity of meat produced in the Australian system.

Reports from EU[187] and USA[188] can be accessed online. Animal welfare concerns are not raised at these audits.

4.4 Customer audits

Several large companies purchasing meat have animal welfare requirements that are audited. These companies include large Australian supermarkets, and large international quick service restaurants. Additionally, claims made to consumers in Australia are subject to laws that are actively enforced to ensure that consumers are not subjected to false or misleading claims.[189]

5. Animal welfare issues

This section discusses some particular issues, from a technical viewpoint, that may sometimes be raised in discussion of animal welfare.

5.1 Definitions and approaches to animal welfare

Animal welfare is a concept that can seem somewhat vague. Often, the animal welfare concept is expressed in various frameworks for measurement.

The ‘five freedoms’ paradigm for animal welfare has been influential since formulation in the early 1990s and consists of freedom:

- From thirst, hunger, and malnutrition
- From discomfort and exposure
- From pain, injury, and disease
- From fear and distress
- To express normal behaviour (Mellor, 2016)

There are considered to be two key disadvantages with the Five Freedoms paradigm (Mellor, 2016): First, the focus on “freedom” from a range of negative experiences and states may be misunderstood to mean that complete freedom from these experiences and states is possible, when in fact the best that can be achieved is for them to be minimised. Second, the major focus of the Freedoms on negative experiences and states is now seen to be a disadvantage in view of current understanding that animal welfare management should also include the promotion of positive experiences and states (Mellor, 2016).

The ’Five Domains’ model, as modified, overcomes some of these problems by emphasising, in its later revisions, positive states. The model distinguishes between four interacting physical/functional domains, i.e., ‘nutrition’, ‘environment’, ‘health’ and ‘behaviour’, and a fifth domain of ‘mental state’ (Mellor & Beausoleil, 2015). This model appears to have favour with the RSPCA.[190]

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[187] European Commission. Health and Food Audits Health and Food Audits and Analysis (europa.eu)
[188] USA Food Safety and Inspection Service. Australia: Foreign Audit Report | Food Safety and Inspection Service (usda.gov)
[189] ACCCC. False or misleading claims. Australian Consumer Law. False or misleading claims | Australian Competition and Consumer Commission (accc.gov.au)
[190] RSPCA. Five Domains. What are the Five Domains and how do they differ from the Five Freedoms? – RSPCA Knowledgebase

The first four physical/functional domains of the Five Domains Model anticipated the Welfare Quality® assessment system on the categories of “good feeding”, “good housing”, “good health” and “appropriate behavior” (Keeling, Evans, Forkman, & Kjaernes, 2013) which has some currency in European civil society groups.

The position taken towards standards development in Australia, has been a pragmatic response to the expectations of the market. Writing of the development of the transport standard, the first to be written under the AAWS, de Witte (2009) explained:

> The development process attempts to achieve a balance between ethical views and practical working arrangements, acknowledging the diverse views of all those who have an interest in livestock. As Dr. John Drinan, Chairman of the AAWS Advisory Committee, said at the third AAWS workshop in December 2007, ‘‘Policy decisions should incorporate good science and good judgment, and reflect common sense and public opinion. It is the art of what is possible and achievable.’’ This philosophy has been the guiding principle for the development of the Land Transport Standards.

5.2 Cattle

The *Australian Animal Welfare Standards and Guidelines for Cattle* also cover castration, dehorning and spaying; calf rearing systems; dairy management; and beef feedlots.

5.2.1 Castration

Castration of cattle must be performed by a person with relevant knowledge, experience, and skills. The age of cattle at the time of castration determines the allowable methods, which must be performed with appropriate tools and methods. Pain relief is required under some circumstances and encouraged in others.

In the Northern industry, musters commonly occur only annually, resulting in a broad range of ages of calves submitted to dehorning and castration, and variable degrees of restraint stress. Additional findings from recent studies a topical anaesthetic formulation (Tri-Solfen ®), include confirmation of rapid onset of surgical wound analgesia with positive welfare outcomes for an extended period, improved pain management when used with a non-steroidal anti-inflammatory drug (NSAID, especially meloxicam) or other products for pain relief (Windsor, 2021).

5.2.2 Dehorning

Dehorning of cattle must be performed by a person with relevant knowledge, experience, and skills. The age of cattle at the time of dehorning determines the allowable methods, which must be performed with appropriate tools and methods. Pain relief is required under some circumstances and encouraged in others.

In the Northern industry, musters commonly occur only annually, resulting in a broad range of ages of calves submitted to dehorning and castration, and variable degrees of restraint stress. Additional findings from recent studies a topical anaesthetic formulation (Tri-Solfen ®), include confirmation of rapid onset of surgical wound analgesia with positive welfare outcomes for an extended period, improved pain management when used with a non-steroidal anti-inflammatory drug (NSAID).

5.3 Sheep

The *Australian Animal Welfare Standards and Guidelines for Sheep* contain additional chapters to address tail docking and castration; mulesing; and intensive sheep production systems.

5.3.1 Tail docking and castration

Tail docking and castration are only performed when necessary, by a person with relevant knowledge, experience, and skills. The method recommended and pain relief requirements depend on the age of the animal. Novel pain relief methods (Small, Jongman, Niemeyer, Lee, & Colditz, 2020) have been developed for this operation.

5.3.2 Mulesing

The “mulesing operation” is a routine procedure with removal of skin from the breech and tail of lambs to create a bare area, providing lifetime prevention against myiasis (flystrike) in susceptible sheep. This mostly involves Merino lambs at high risk of the condition because of their breech conformation (wrinkle) that readily retains urine and faeces and provides an attractive environment for deposition of the eggs of the sheep blowfly *Lucilia cuprina*. Following hatching, the blowfly larvae burrow deeply into adjacent tissues to the penetrating wounds in afflicted animals, rapidly causing the animal to become moribund because of blowfly strike and if untreated, death. Myiasis remains a serious cause of morbidity and mortality in Australian sheep despite long-term genetic improvement to reduce “blowfly susceptibility”. Until 2005, mulesing was performed without analgesia, resulting in welfare concerns for the lambs at and following surgery. Then a product designed to be readily used by producers, comprising a “stay and spray” approach for open wounds using a topical anaesthetic formulation (TAF) to alleviate pain, plus components to minimize haemorrhage and provide antiseptic cover, was introduced (Tri-Solfen ®). On application, it forms a long-lasting biocompatible barrier over the wound, creating its own intrinsic analgesic properties and acting as a slow-release carrier for the actives, including the two local anaesthetics, lidocaine hydrochloride (5% w/w) and bupivacaine hydrochloride (0.5% w/w), in addition to the vasoconstrictor adrenaline acid tartrate (0.00451% w/w) and the antiseptic cetrimide (0.5% w/w). The combined synergies create prolonged analgesia extending to at least 24 h and well beyond the expected duration of the actives, plus enhanced healing of open wounds. The TAF product has been researched extensively prior to and since it was registered for commercial use in 2012 and has been widely adopted by farmers in Australia. It is estimated that 6–7 million lambs are treated annually, with well over 100 million sheep having now received treatment since the product was first registered (Windsor, 2021).

5.3.3 Intensive sheep production

The Standards require intensive production systems to be managed to minimise the risk to the welfare of sheep. The person in charge must ensure feed, water, ventilation, sufficient space, cleanliness, and perform daily inspection of sheep. Guidelines are provided to provide details on how to achieve the requirements.

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8. The Australian Export System – wholesomeness and integrity

Summary

The Australian red meat industry and the Australian Government take extremely seriously the need to ensure that meat products, especially for export, due to importing country requirements, meet the most stringent standards regarding food safety, wholesomeness, product integrity, and ensuring the most ethical animal welfare outcomes.

The Australian Export Meat Inspection System (AEMIS) is the regulatory system used by the Australian Government administered by the Department of Agriculture, Fisheries and Forestry (DAFF) to ensure the above outcomes are consistently achieved. DAFF is Australia's competent authority (CA) for the issue of export certification to the importing country's import authorities attesting to each consignment meeting a range of conditions including food safety, product integrity, authenticity etc. and particularly, any specified importing country requirements.

The powers through which DAFF administers these export requirements are drawn from the Export Control Act (2020), which is further elaborated in the Export Control (Meat and Meat Products) Rules 2021, as well as a range of departmental instructional material and guidelines. The Export Control Act, through the prescription of specific agricultural produce such as meat, seafood, dairy etc. that ensures DAFF can be the only CA for export certification (ensuring this competency therefore does not reside with State or Territory Governments).

This chapter overviews some of the regulatory controls that sit within AEMIS, and DAFF officers that permanently reside in outposted Australian locations to ensure they are able to personally undertake the inspections, checks and audits necessary to meet the requirements of the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696), and AEMIS system requirements including the meeting of importing country requirements.

Australia produces some of the safest red meat products in the world as evidenced by its broad acceptance in a large number of sophisticated markets, good audit reports from importing countries, few problems, and data to support objective claims.

Contents

1. Concepts

1.1 Definition of wholesomeness

The *Australian Standard for hygienic production and transportation of meat and meat products for human consumption*, AS4696 has a clear objective "to ensure meat and meat products for human consumption comply with food safety requirements and are wholesome" (AS4696:2007, Preface). AS4696 defines wholesome (AS4696, 1.3) as meat and meat products "passed for human consumption on the basis that they:

(a) are not likely to cause food-borne disease or intoxication when properly stored, handled and prepared for their intended use;
(b) do not contain residues in excess of established limits;
(c) are free of obvious contamination;
(d) are free of defects that are generally recognised as objectionable to consumers;
(e) have been produced and transported under adequate hygiene and temperature controls;
(f) do not contain additives other than those permitted under the Food Standards Code;
(g) have not been irradiated contrary to the Food Standards Code; and
(h) have not been treated with a substance contrary to a law of the Commonwealth or a law of the state or territory in which the treatment takes place. "

1.1.1 Wholesomeness in other chapters

Aspects of wholesomeness are dealt with in several other chapters, but some will be dealt with here:

Requirement	Note	Ref.
Not likely to cause food-borne disease or intoxication	The public health record provides evidence that Australian meat is safe	Ch 1
	Processes to source safe and healthy cattle including ante-mortem and post-mortem inspection	Ch 2
Not contain residues in excess of established limits	Residues and chemical contaminants are managed	Ch 4
Free of obvious contamination	Process hygiene includes attention to visible contamination	Ch 9
Free of defects generally recognised as objectionable to consumers	Process hygiene deals with defects	Ch 9
	Post-mortem inspection is performed	Ch 2
Produced and transported under adequate hygiene and temperature controls	Control of temperature is required during processing and transportation	Ch 13
Not contain additives other than those permitted under the Food Standards Code	See 4.3 below	
Not irradiated contrary to the Food Standards Code	See 4.4 below	
Not treated with a substance contrary to law	See 4.2 and 4.3 below	

1.2 Integrity contributes to wholesomeness

Maintaining integrity contributes to product wholesomeness. As explained, in the Preface to AS4696:

> "This Standard incorporates other objectives so that wholesomeness can be assured. These objectives include the need for systems to be in place for the accurate identification, traceability, effective recall and integrity of meat and meat products."

Identification, traceability, and integrity are dealt with in the standards together in Chapter 11. The outcome is that "meat and meat products are accurately identified. Meat and meat products that should be recalled can be recalled."

1.2.1 The meaning of integrity

When considering a general meaning of integrity, English dictionaries define integrity as "the quality of being whole and complete" (Cambridge University Press, 2018) and "the quality of being honest and having strong moral principles" (Oxford University Press, 2018). As the assurance of food integrity should involve accurate transfer of information across the supply chain, definitions from the domain of information systems can be referenced. In the domain of information systems, integrity is defined as "property of accuracy and completeness" (ISO, 2018, Sec. 3.36), while data integrity is defined as "property that data has not been altered or destroyed in an unauthorized manner" (ISO, 2017, Sec. 3.2) and system integrity is defined as "property that a system performs its intended function in an unimpaired manner, free from deliberate or accidental unauthorized manipulation of the system" (ISO, 2009, Sec. 2.14). The consistent element among these definitions is the characteristic of being whole, accurate, and free from unauthorised alteration (or adulteration of food), regardless of whether they are intentional, such as fraud for economic gain, or unintentional, such as negligence. Elliot (2014, p.84) takes a consumer perspective and adds that integrity "also captures other aspects of food production, such as the way it has been sourced, procured and distributed and being honest about those elements to consumers." (Ling & Wahab, 2020)

1.2.2 Integrity in other chapters

Aspects of integrity are dealt with in several other chapters, but some will be dealt with here:

Requirement	Note	Ref.
Accurate and complete description of product	Animal traceability Traceability and product identity in processing	Ch 3 Ch 11
System performs its intended function, free from manipulation of the system	See 2. below	

2. Australia's Red Meat Export System

The Australian Government through the Department of Agriculture, Fisheries and Forestry (DAFF) who administers the Export Control Act (ECA) 2020, ensures that every carcase and carton of red meat produced for export meets all the requirements of the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696); and importing country requirements. Components of this system include strong regulatory controls, traceability, product authenticity; high ethical standards throughout the production chain and particularly regarding animal welfare; strong assurance and monitoring systems; all resulting in accurate export certification.

2.1 Export Control Act (ECA)(2020)

DAFF regulates exports of agricultural product to assure trading partners that Australian agricultural products consistently meet their import requirements. The department's responsibilities and powers are defined in the Export Control Act (ECA) 2020.[191]

Export commodities controlled by the department are listed or 'prescribed' in the legislation. This includes live animal exports, red meat and meat products, seafood, dairy, etc. The legislation sets out the list of requirements that must be met by an exporter before prescribed goods can be exported from Australia.

The objective of the legislation is to enable trade by ensuring that export commodities meet importing country requirements and are fit for purpose. Exported meat products must be:

- fit for human consumption
- accurately described and labelled
- fully traceable, if necessary.

All premises where prescribed goods are prepared for export must be registered to undertake those operations by the DAFF under the ECA 2020.

Preparation for export includes:

- slaughter of animals and dressing of carcasses
- processing, packing or storage of goods
- pre-export quarantine or isolation, treatment, and testing of livestock
- treatment of goods
- handling or loading of goods

People participating in Australia's export industry are subject to an integrity test called the fit and proper person test when applying for export licences and other regulatory approvals. The Fit and Proper Person (FPP) Test is where the Secretary of the Department decides whether a person, or company, is of a trustworthy nature and demonstrates the personal integrity necessary to export agricultural goods from Australia. It is applied when someone is applying for an export licence, registering an export establishment, proposing an export arrangement, or being appointed as an authorised officer, approved assessor, or approved auditor ECA 2020, section 372)

2.2 Export control rules

Export Control (meat and meat products) Rules 2021[192] provides more detailed specific commodity regulatory requirements than the ECA, in this case specifically for meat and meat products.

2.3 The Australian Meat Standard

Australian Meat Standard means Australian Standard AS4696, *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption*.
The Standard applies across all meat processing in Australia, no matter which competent authority is responsible (state, territory, Commonwealth). The Standard is now maintained by the Australian Meat Regulators (Working) Group (AMRG), comprising representatives from each jurisdiction. The Standard becomes an Australian Standard through Standards Australia Committee FT-021 (Meat for Human and Animal Consumption) that has AMRG members at its core.
The Standard is referenced by Export Control (meat and meat products) Rules 2021.

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[191] Australian Government. Export Control Act 2020 Export Control Act 2020 (legislation.gov.au)
[192] Export Control (meat and meat products) Rules 2021 Federal Register of Legislation - Australian Government

2.4 ECA Approved Arrangement

The documentation of how a registered establishment will meet its export regulatory requirements is called an Arrangement[193]. It becomes an Approved Arrangement (AA) after the Secretary of DAFF or delegate approves it.

The purpose of the AA is to clearly describe those processes, procedures, and practices which, when applied by the occupier as described in the arrangement, provides the fundamental regulatory foundation as to how the department can issue export certification to an importing country with the appropriate confidence levels they require as to the accuracy and integrity of the consignment being exported.

Before an export establishment can be registered by DAFF for export it is the responsibility of the food business operator to develop, implement, maintain, and have approved their arrangement to ensure ongoing compliance with:

- food safety and product integrity requirements
- good hygienic practices (GHP) to ensure that food is wholesome
- the application of hazard analysis and critical control points (HACCP) for food safety
- product integrity through the application of product identification, segregation, and traceability practices ensuring that product is accurately described and maintains relevant importing country identification
- importing country requirements
- animal welfare requirements.

2.5 The Australian Export Meat Inspection System (AEMIS)

The Australian Export Meat Inspection System (AEMIS) provides the food business operator with the choice of implementing one of two arrangements for the export of red meat products, which ultimately will be determined by the requirements of the importing country.

Tier 1 export-registered establishments fully align and meet all regulatory requirements of Australia's State and Territory registered meat processing establishments which fully comply with the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* AS4696. These establishments, although registered for export by DAFF, are directly regulated under a Memorandum of Understanding (MoU) by state and territory governments on behalf of the department. On a regular basis, the department verifies the state or territory ability to ensure the establishments are compliant with the AS, and that AAs are assessed, and any non-compliances are dealt with appropriately.

Tier 2 export-registered establishment have in addition to the requirements of Tier 1 above, the need to maintain full time DAFF regulatory presence on plant as well as additional technical requirements. These plants are under the direct regulatory control and supervision of DAFF officers.

2.6 Regulatory Supervision

2.6.1 Daily regulatory meat inspection and supervision

AEMIS is a government certification and inspection system implemented by food business operators and verified by the government to ensure the safety, suitability, and integrity of Australian meat and meat products; and that all importing requirements have been met prior to export certification.

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[193] DAFF ELMER3 https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/export/approved-arrangements-guidelines-meat.pdf

Underpinning AEMIS are objective hygiene and performance standards that are continually monitored.[194]

A departmental On Plant Veterinarian (OPV) is responsible for ante-mortem inspection and verification of post-mortem inspection and processor hygiene practices. The Meat Establishment Verification System (MEVS) has two key components that are linked to specific legislative requirements of the ECA 2020 and its subordinate legislation:

- Inspection (ante-mortem, post-mortem)
- Verification (post-mortem, food safety, animal welfare, market access requirements and product integrity/certification).[195]

The *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696) requires that a suitably qualified meat safety inspector performs post-mortem inspection and makes decisions on each carcase and its carcase parts.

Due to importing country requirements, inspection activities are delivered by Australian Government Authorised Officers (AAOs) contracted by the establishment or employed by a departmental approved third-party provider that operates under an agreement with the department to ensure all importing country requirements for Australian Government health certification are met. If a country has a requirement for a department official to provide online inspection, Food Safety Meat Assessors (FSMAs) are provided.

OPV supervisory activities may lead to non-compliance issues being recorded and corrective action requests (CARs) being issued. Weekly meetings are held between the OPV and plant management with written minutes to review CARs. Area Technical Managers (ATMs) supervise the work of OPV and review records.[196]

2.6.2 Regulatory meat audits

The DAFF Export Meat Program is responsible for auditing Tier 2 export registered establishments and independent boning rooms.[197] The routine audit for processing establishments is a systems audit, utilised for compliant establishments[198]. A critical incident response audit (CIRA) is utilised for non-compliant establishments with three levels of regulatory response.[199]

As a routine, the OPV prepares a monthly report of verification activities in accordance with the MEVS Operational Policy.

[194] DAFF ELMER 3 - Electronic legislation, manuals and essential references - DAFF (agriculture.gov.au)
[195] DAFF ELMER3 Export Meat Operational Guideline 9.2 Meat Establishment Verification System (MEVS) – establishments. October 2022. Meat Establishment Verification System (MEVS) - Establishments - DAFF (agriculture.gov.au)
[196] DAFF ELMER3 Export Meat Operational Guideline 9.2 Meat Establishment Verification System (MEVS) – establishments. October 2022. Meat Establishment Verification System (MEVS) - Establishments - DAFF (agriculture.gov.au)
[196] DAFF ELMER3 Export Meat Operational Guideline 5.2 Export Meat Systems Audit Program (EMSAP) - DAFF (agriculture.gov.au)
[197] DAFF (2022) Export Meat Operational Guideline 9.3 Meat Establishment Verification System (MEVS) – Independent Boning Rooms. Export Meat Operational Guideline - 9.3 Meat Establishment Verification System (MEVS) – Independent boning room (agriculture.gov.au)
[198] DAFF (2016) Guideline. Auditing export red meat and wild game processing establishments and independent boning rooms. audit-processing-establishments-guideline.doc (live.com)
[199] DAFF (2016) Guideline. Auditing export red meat and wild game processing establishments and independent boning rooms. audit-processing-establishments-guideline.doc (live.com)

Systems audits are conducted by veterinary ATMs who are qualified, competent systems auditors. The team consists of two people: the lead auditor who has not had recent supervisory ATM role for that establishment and the establishment's supervisory ATM.

The purpose of the systems audit is to ensure that the establishment's AA is compliant with the relevant export legislation, including importing country requirements, and the department is confident that it can continue to maintain that standard with a twice-yearly audit frequency.

2.7 Regulatory sanctions[200]

Regulatory actions and sanctions will be applied where non-compliance and/or breach of the legislation are identified such as in the case of a failure to register to export, critical non-compliance at audit and/or port of entry rejection. During inspection, verification, and auditing activities, regulatory actions will be taken to ensure that non-compliant product does not continue to be produced or exported. During an audit, departmental officers have a role as both an auditor and a regulator. As an audit is a fact-finding process that is facilitated by the establishment, if a departmental officer detects a non-compliance, in their role as an auditor, which requires regulatory action the departmental officer must notify the auditee (occupier, exporter or their representative) that the audit is suspended prior to gathering further evidence or applying regulatory action under the legislation.

Both the department, occupiers, and exporters receive rejection notifications from importing countries for a variety of reasons. These notifications can be of a non-compliance and/or breach of the legislation (including the importing country requirements). As the regulator, the department has an obligation to investigate these non-compliances, as does the occupier through their commitment to meet the legislated requirements.

3. Evidence that the system works

The Australian export certification regulatory system is highly regarded internationally. Australia exports red meat to over 100 countries, issues around 500,000 export certificates annually, for around 1.3 million tonnes meat exported meat. This represents around 65% of Australian livestock production. It is vitally important that the Australia export regulatory system continues to work to modernise itself to ensure its able to maintain integration into international supply chains; evolves with the emerging technology, challenges, and customer demands; and continues to produce the safest food internationally to the highest ethical standards.

Confidence in the Australian red meat certification system is high due to the number of Australian meat processing companies that undergo numerous audits – from DAFF and AUS-MEAT as required by the Export Control (meat and meat products) Rules, from importing countries (either for the purpose of listing them for export to that country, or as part of an audit of the Australian meat export system), and from on-plant government authorised officers who are checking and monitoring the system daily.

Australia has very few food safety incidents associated with red meat pathogens and our product rates as some of the cleanest internationally (see Ch 9, process hygiene).

[200] DAFF ELMER3 Regulatory Action and Sanctions. Export Meat Systems Sanctions Policy regs-sanctions.pdf (agriculture.gov.au)

Reports from EU[201] and USA[202] can be accessed online. Significant wholesomeness issues are rarely raised at these audits.

4. Some aspects of wholesomeness

4.1 Water

AS4696 requires the use of potable water for most applications around animals and meat if there is a risk of the water coming into contact with, or contaminating, meat. Use of non-potable water in these circumstances requires approval (clause 21.6). 'Potable' water means water that is acceptable for human consumption (AS4696).

Used water may be reused (recycled), for another purpose, with or without treatment, including for potable purposes, subject to validation and approval.[203]

The *Australian Drinking Water Guidelines*[204] provide a reference point for potable water. They provide a framework for the good management of drinking water supplies that if implemented will assure safety at the point of use. The *Guidelines* are not mandatory legally enforceable standards, and the implementation of the guidelines is at the discretion of each state and territory. The Guidelines are used by state and territory health departments and drinking water regulators, local health authorities and water utilities. The Guidelines undergo a rolling revision to ensure they represent the latest scientific evidence on good quality drinking water.

Establishments are required to test water samples for a range of microbiological parameters regularly.[205] Additionally, EU listed establishments test water for chemical parameters and additional microbiological parameters.[206,207]

4.2 Chemicals

The use of chemicals at meat processing establishments is strictly controlled to ensure that chemicals used are not hazardous to animals and does not result in contamination or unacceptable residues in edible meat.[208] The chemicals controlled include cleaning chemicals, sanitising chemicals, pesticides, water treatments, lubricants, marking inks.

4.3 Additives and Processing Aids

Whilst additives are mentioned specifically in the AS4696 definition of wholesomeness (f), processing aids are considered other substances (h).

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201 European Commission. Health and Food Audits Health and Food Audits and Analysis (europa.eu)
202 USA Food Safety and Inspection Service. Australia: Foreign Audit Report | Food Safety and Inspection Service (usda.gov)
203 DAFF (2008) Efficient use of water in export meat establishments. Meat Notice 2008/06. _ (agriculture.gov.au)
204 Australian Drinking Water Guidelines | NHMRC
205 DAFF (1998) Water, Ice testing at export registered establishments. Meat Notice 98/12 98/12 Water, Ice testing at export registered establishments (agriculture.gov.au)
206 DAFF (1999) Water testing requirement for EU listed meat establishments…. Meat Notice 99/15 _ (agriculture.gov.au)
207 DAFF (1999) Amendment to AQIS meat notice 99/15. Meat Notice 99/15 _ (agriculture.gov.au)
208 DAFF ELMER3 October 2022. Export Meat Operational Guideline 3.13 Use of hazardous materials on-plant. https://www.agriculture.gov.au/sites/default/files/documents/ELMER-export-meat-operational-guideline-3-13-use-of-hazardous-materials-on-plant.pdf

The *Codex Alimentarius* definition of a food additive (abbreviated):

> intentionally added to food for a technological (including organoleptic) purpose which results in it becoming a component of or otherwise affecting the characteristics of such foods[209]

The *Codex Alimentarius* definition of a processing aid (abbreviated):

> any substance or material, not consumed as a food ingredient by itself, intentionally used in the processing of raw materials, foods or its ingredients, to fulfil a certain technological purpose during treatment or processing and which may result in the non-intentional but unavoidable presence of residues or derivatives in the final product[210]

The *Australia New Zealand Food Standards Code* – Standard 1.3.1 – Food Additives[211], and Schedule 15 – Substances that may be used as food additives[212], do not allow any additives to be used in raw red meat (section 8.1 of schedule 15).

The *Australia New Zealand Food Standards Code* – Standard 1.3.3 – Processing Aids[213] allows substances to be used as processing aids, either generally permitted, or for specific purposes. Schedule 18 – Processing Aids[214] lists permitted processing aids.

Generally permitted processing aids include ammonia, ethanol, isopropyl alcohol, phosphoric acid, potassium hydroxide, sodium hydroxide and sulphuric acid (1.3.3 – 4(2)(b) and S18 -- 2)

Some enzymes are permitted, including, bromelain, and papain (1.3.3 – 6 and S18 – 4).

A large number of processing aids for water are permitted including chlorine, chlorine dioxide, ozone (1.3.3 -- 8 and S18 – 6).

Additionally, a number of other processing aids are allowed for specific purposes (1.3.3 – 11 and S18 – 9):

- Carbonic acid for bleached tripe as a washing agent
- Cetyl alcohol as a coating agent on meat carcasses and primal cuts to prevent desiccation (maximum 1.0 mg/kg)
- Colour permitted as additives or colouring – for application to the outer surface of meat as a brand for the purposes of inspection or identification
- Lactoperoxidase from bovine milk, to reduce the bacterial population or inhibit bacterial growth on meat surface
- Octanoic acid as an antimicrobial agent for meat
- Salmonella phage preparation to reduce the population of Salmonella species on the surface of raw meat during processing
- Sodium chlorite as an antimicrobial agent for meat (no detectable chlorite, chlorate, chlorous acid or chlorine dioxide to remain)
- Sodium sulphide, sulphur dioxide, sulphurous acid as a treatment of hides for use in gelatine or collagen manufacture

[209] Codex Procedural Manual Procedural Manual | CODEXALIMENTARIUS FAO-WHO
[210] Codex Procedural Manual Procedural Manual | CODEXALIMENTARIUS FAO-WHO
[211] Australia New Zealand Food Standards Code – Standard 1.3.1 – Food Additives Federal Register of Legislation - Australian Government
[212] Australia New Zealand Food Standards Code – Schedule 15 – Substances that may be used as food additives Federal Register of Legislation - Australian Government
[213] Australia New Zealand Food Standards Code – Standard 1.3.3 – Processing Aids Federal Register of Legislation - Australian Government
[214] Australia New Zealand Food Standards Code – Schedule 18 – Processing aids Federal Register of Legislation - Australian Government

- Sodium thiocyanate to reduce and/or inhibit bacterial population on meat surface
- Stearyl alcohol as a coating agent on meat carcasses and primal cuts to prevent desiccation

4.3.1 Added water

USA Retained Water Rule

The Food Safety and Inspection Service (FSIS) of the US Department of Agriculture (USDA) have enacted a rule obliging establishments to demonstrate and document that carcases and parts do not retain any water from post-evisceration processing unless the establishment can substantiate that the water retained by the carcase or parts is due to an unavoidable consequence of a process used to meet applicable food safety requirements. If water is retained, then the product must be labelled with the possible maximum percentage of retained water in the raw product.

This rule applies to all meat and poultry products exported to the USA. FSIS noted that the US meat industry "is already achieving zero percent retained water", but note that, the most likely meat products to be affected by this rule will be edible organs. Retained water does not appear to be an issue in relation to chill boned carcases, hot boned carcases, spray chilled carcases assuming that boning does not occur within a short timeframe after the food safety intervention using the application of water (e.g., washing, spraying); offal may retain water from washing or cooling in water[215]

4.4 Irradiation

Australia New Zealand Food Standards Code Standard 1.1.1 – general provisions[216], paragraphs 10(5)(d) and (6)(h) provide that a food for sale must not be irradiated, unless expressly permitted by Standard 1.5.3 of the *Code*[217]. No irradiation of meat is allowed except that imparted to a food by measuring or inspection instruments (FSC 1.5.3 –2).

4.5 Pest control

The presence of pest and vermin in or around a meat processing facility is a potential human health risk and an indicator of poor sanitation. To minimise these hazards, the occupier must maintain current and approved procedures in their approved arrangement to control pests and vermin.[218]

References

Ling, E. K., & Wahab, S. N. (2020). Integrity of food supply chain: going beyond food safety and food quality. *International Journal of Productivity and Quality Management, 29*(2), 216-232. doi:10.1504/ijpqm.2020.105963

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[215] DAFF (2002) Compliance with retained water rules for carcases, meat and offals exported to the USA. Meat Notice 2002/18 (agriculture.gov.au)

[216] Australia New Zealand Food Standards Code – Standard 1.1.1 – Structure of the Code and general provisions Federal Register of Legislation - Australian Government

[217] Australia New Zealand Food Standards Code – Standard 1.5.3 – irradiation of food Federal Register of Legislation - Australian Government

[218] DAFF ELMER3 export-meat-operational-guideline-pest-control.pdf (agriculture.gov.au)

9. Hygiene in meat processing

Summary

This chapter overviews how and what hygiene measures are applied in a red meat processing establishment in Australia. Australia has a reputation for producing the safest red meat products in the world which is the result of a scientifically underpinned food standards; strong regulations; a professional industry workforce; ongoing funding of research and development activities; and at the industry level, ensuring long commercial relationships with our international customers.

The requirements of the *Australian Standard for hygienic production and transportation of meat and meat products for human consumption* (AS4696) and the and food safety authority (including the Department of Agriculture, Fisheries and Forestry, DAFF) prerequisites are science-based standards drawn from a range of international standard setting bodies particularly Codex Alimentarius and specifically the committees on food hygiene, meat hygiene, food import and export certification system and methods of analysis and sampling.

These requirements are reflected in a range of State food safety legislation, and the Export Control Act (2020) which is used to regulate red meat processing operators in Australia by State food safety authorities and DAFF. Australia has an open and transparent food safety system that is audited and viewed by many countries every year. Australia verifies that importing country requirements are being met by the Australian Export Meat Inspection System (AEMIS), which incorporates many of the requirements reflected in this chapter. Additionally, AEMIS is audited and verified regularly by the department's senior auditors, and from the industry side their commercial customers.

The consequences of this collective effort to ensure a strong and robust food safety program results in the production of extremely safe meat products as evidence by a range of independent baseline studies providing objective evidence of exemplary hygienic achievement.

Industry and government recognise that as customer preferences change; and production systems, cold chain, and transport systems evolve, there is a continual need to ensure the science is contemporary, and potential hazards are not overlooked. In this regard Australia strongly supports the international standards setting organisations, particularly Codex Alimentarius Commission , and the scientific bodies that advise them. Additionally, in Australia significant investment in R&D through the Australian Meat Processor Corporation, and Meat & Livestock Australia are designed to ensure a whole of supply chain approach to food safety, as well as alternate technologies to improve the effectiveness of measures currently in place.

Contents

1. Hygiene: safety and suitability

1.1 Australian commitment to safe and hygienic product

The *Australian Standard for hygienic production and transportation of meat and meat products for human consumption*, AS4696 has a clear objective: "to ensure meat and meat products for human consumption comply with food safety requirements and are wholesome" (AS4696:2007, Preface).

The *Standard* specifies food safety outcomes at each stage of production and specified the requirements to ensure safety throughout the chain. Food safety means that food (meat) will not cause harm to the consumer when prepared as intended. Hygiene is a broader concept than safety and encompasses characteristics and factors that make the food suitable and acceptable for consumers.

The requirements of the *Australian Standard* are applied throughout Australia, including by the Department of Agriculture, Fisheries and Forestry (DAFF) when supervising and certifying export meat processing (see Chapter 8 – The Australian Export System – wholesomeness and integrity).

1.2 Objective

Food hygiene is fundamental to all trade in food, including meat. One of the earliest Codex Alimentarius documents are the *General Principles of Food Hygiene* (GPFH), first adopted in 1969 and most recently revised in 2020:[219]

> "People have the right to expect the food that they eat to be safe and suitable for consumption. Foodborne illness and foodborne injury can be severe or fatal or have a negative impact on human health over the longer term. Furthermore, outbreaks of foodborne illness can damage trade and tourism. Food spoilage is wasteful, costly, threatens food security and can adversely affect trade and consumer confidence." (Introduction to the GPFH)

Other Codex texts reflect these general principles (e.g., Code of Hygienic Practice for Meat[220]), and national legislation and standards[221] do also. There is a steady evolution of these documents to incorporate consensus of best practices and concepts to achieve safe and suitable food.

The GPFH acknowledge that not all recommendations are applicable to all foods, and introduces the concept of relevance, based on risk:

> There will be situations where some of the specific recommendations contained in this document are not applicable. The fundamental question for each food business operator in every case is "what is necessary and appropriate to ensure the safety and suitability of food for consumption?"
>
> The text indicates where such questions are likely to arise by using the phrases "where necessary" and "where appropriate". In deciding whether a measure is necessary or appropriate, an evaluation of the likelihood and severity of the hazard toward establishing the potential harmful effects to consumers should be made, taking into account any relevant knowledge of the operation and hazards, including available scientific information. This approach allows the measures in this

[219] Codex Alimentarius Commission (2020) General Principles of Food Hygiene CXC 1-1969 https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf

[220] Codex Alimentarius Commission (2005) Code of Hygienic Practice for Meat CAC/RCP 58-2005. Code of Hygienic Practice for Meat (fao.org)

[221] Australian standard for the hygienic production and transportation of meat and meat products for human consumption. FRSC technical report No 3 AS 4696:2007 https://www.publish.csiro.au/ebook/download/pdf/5553 5553 (csiro.au)

> document to be flexibly and sensibly applied with a regard for the overall objectives of producing food which is safe and suitable for consumption. In so doing it takes into account the wide diversity of food chain operations and practices and varying degrees of risk to public health involved in producing and handling food.

1.3 Principles

In general, the principles in the GPFH require food businesses to have systems and plans and take actions to ensure that food is both safe and suitable. The foundations are the responsibility of the food business, their systems, the use of good hygienic practices, in a suitable environment, and adequate control of critical points in the process. An excerpt from the principles:

> (i) Food safety and suitability should be controlled using a science-based preventive approach, for example a food hygiene system. GHPs should ensure that food is produced and handled in an environment that minimizes the presence of contaminants.
>
> (ii) Properly applied prerequisite programmes, which include GHPs, should provide the foundation for an effective HACCP system.
>
> (iv) … it may be sufficient to apply GHPs, including, as appropriate, some that require more attention than others, as they have a greater impact on food safety. When the application of GHPs alone is not sufficient, a combination of GHPs and additional control measures at CCPs should be applied.

1.4 Definitions

Critical Control Point (CCP): A step at which a control measure or control measures, essential to control a significant hazard, is/are applied in a HACCP system.

Food hygiene: All conditions and measures necessary to ensure the safety and suitability of food at all stages of the food chain.

Food safety: Assurance that food will not cause adverse health effects to the consumer when it is prepared and/or eaten according to its intended use.

Food suitability: Assurance that food is acceptable for human consumption according to its intended use.

Good Hygiene Practices (GHPs): Fundamental measures and conditions applied at any step within the food chain to provide safe and suitable food.

HACCP System: The development of a HACCP [hazard analysis and critical control points] plan and the implementation of the procedures in accordance with that plan.

Hazard: A biological, chemical or physical agent in food with the potential to cause an adverse health effect.

Hazard analysis: The process of collecting and evaluating information on hazards identified in raw materials and other ingredients, the environment, in the process or in the food, and conditions leading to their presence to decide whether or not these are significant hazards.

Prerequisite programme: Programmes including Good Hygiene Practices, Good Agricultural Practices and Good Manufacturing Practices, as well as other practices and procedures such as training and traceability, that establish the basic environmental and operating conditions that set the foundation for implementation of a HACCP system.

1.5 Safety, Hazards, and Risks: GHP and HACCP in meat processing

The assessment of meat safety can always be maximised by arguing that when it is 'prepared and/or eaten according to its intended use' thorough cooking is required, so that pathogens are destroyed. However, the consumption of uncooked or undercooked products in many parts of the world provide clear evidence that such products are an 'intended use'. Products such as salami and other fermented meats do not receive a heat treatment. Additionally, some hazards are not destroyed by cooking (the BSE prion, some parasitic cysts in rare meat, toxic chemicals). The safety of meat, therefore, needs to be maximised by the careful attention to processing and handling prior to preparation for consumption.

The safety of meat is not assured by testing for the presence of pathogens (such as Shiga toxin-producing *Escherichia coli*, or *Salmonella enterica*), nor by testing the levels of indicators of good hygiene (generic *E. coli*, total bacterial count). There is no clear relationship between the presence or level of indicators and pathogens, nor is testing at the processor predictive of the final safety outcome after product has passed through the supply chain and been prepared for consumption. The International Commission on Microbiological Specifications for Foods (ICMSF)(2011 p. 3) wrote:

> When using microbiological tests to evaluate safety or quality of food it is important to select and apply these with knowledge of their limitations, their benefits and the purposes for which they are intended. In many instances, other assessments are faster and more effective than microbiological testing for food safety assurance. It is well recognized that application of prerequisite programs (e.g., …GMP etc) and a HACCP program is the most effective food safety management strategy.

Additional to safety concerns, suitability encompasses matters that are of concern to consumers: aesthetic defects (injection site lesions, bruises), pathologies, foreign matter (grass seeds, pieces of metal, broken injection needles), but also invisible attributes such as chemical residues. These aspects are rarely (except for injection needles or sharp pieces) food safety concerns.

Meat processing is a very challenging process for production of a safe product. Animals arrive at a processing establishment and leave as meat in a box (or a carcase). From a safety and suitability perspective, it is necessary to minimise transfer of microorganisms from surface of animal, gastrointestinal tract, humans, or equipment to the meat, to cool the meat to minimise the growth of microorganisms, and to package the meat to protect it from further contamination. Additionally, extraneous material carried by the animal, and defects need to be removed. Processing consists of a series of operations on individual animals, each of which may present with different processing needs, but the process needs to result in a uniformly acceptable outcome.

A couple of reviews have been written, from the Australian perspective, to canvass approaches and issues about meat safety and the means of achieving an acceptable level of protection (I. Jenson & Sumner, 2012; I. Jenson, Vanderlinde, Langbridge, & Sumner, 2014).

In general, good practices are sufficient to ensure safe meat. Some importing countries have expectations about the application of HACCP and implementation of CCPs. The application of HACCP may be confused because there are significant differences between the 2003 and 2020 versions of the GPFH with respect to HACCP, particularly how it is used in conjunction with GMP, several definitions, and the decision tree which assists in identifying critical control points.[222] At the time of writing (2023) the concepts of the 2003 version of GPFH are reflected in national legislation.

[222] CAC. 2022. General Principles of Food Hygiene CXC1-1969 (revised in 2022). fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf

2. Good Hygienic Practices in Australia

2.1 Australian operational food hygiene

The Australian Government through DAFF who administers the Export Control Act (ECA) 2020, ensures that every carcase and carton of red meat produced for export meets all the requirements of the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696); and importing country requirements. The objective of the legislation is to enable trade by ensuring that export commodities meet importing country requirements and are fit for purpose. Exported meat products must be:

- fit for human consumption
- accurately described and labelled
- fully traceable, if necessary.

The documentation of how a registered establishment will meet its export regulatory requirements is called an Arrangement[223]. It becomes an Approved Arrangement (AA) after it is approved by the Secretary of DAFF or delegate. Before an export establishment can be registered by DAFF for export it is the responsibility of the food business operator to develop, implement, maintain, and have approved their arrangement to ensure ongoing compliance with food safety and hygienic requirements.

The systems for controlling export certification are described in Ch 8 The Australian Export System – wholesomeness and integrity. The intention in this section is to describe, in general terms, some of the more important hygienic practices as performed in Australia.

2.2 Construction

Australia no longer has prescriptive standards for construction, or even guidelines that are up-to-date with currently available materials and practices. However, a 1988 guideline is available on the Meat Export website for reference.[224]

While construction standards are important to the hygiene of the product, the impact on safety and suitability of product would probably be the criterion that would be used to judge construction standards. There is a balance between the quality of the construction and the efforts that need to be made on a daily basis to maintain it; a poorly constructed or poorly maintained facility may require more effort to achieve the same standards of hygiene, as judged by monitoring activities.

2.3 Pre-operational cleaning and sanitation

Pre-operational sanitation is considered critical to the operation of establishments. Cleaning at the end of each day, before the commencement of operations and between shifts are prescribed in AS4696, 4.2. Detailed checklists of requirements are provided in the Approved Arrangements Guidelines[225]

[223] DAFF (2019) Guidelines. Approved Arrangement – Meat ELMER3 https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/export/approved-arrangements-guidelines-meat.pdf

[224] DAFF (2015) Construction and equipment guidelines for export meat establishments. Construction and equipment guidelines for export meat establishments - DAFF (agriculture.gov.au)

[225] DAFF (2019) Guidelines. Approved Arrangement – Meat ELMER3 approved-arrangements-guidelines-meat.pdf (agriculture.gov.au)

2.4 Personal hygiene

Personal hygiene, relating to the health of the meat worker, protective clothing, and handwashing are prescribed by the AS4696, 4.16 and Schedule 1. Handwashing facility requirements are described in AS4696, 20.7

2.5 Equipment sanitation

Implements used in meat processing need to be sanitized with potable water at no less than 82°C (AS4696 20.5). Alternative processes producing an equivalent outcome are permitted, but very few deviations from the text of the standard have been explored.

This is usually understood to mean that knives and other equipment are dipped into water of the required temperature between animals (prior to post-mortem inspection, after which only when knives become contaminated or to prevent a build-up of residues). Viscera trays are also treated this way. It is notable that no duration is specified for sanitization process, so no microbiological outcome can be inferred. The process is not scientifically designed or validated, but has become standard practice (Eustace, Midgley, Small, Jenson, & Sumner, 2008).

Some points in the slaughter process transfer very few bacteria to knives (Eustace et al., 2007; Eustace et al., 2008). The AS4696 allows alternative processes, which have been investigated in Australia. Longer times with lower temperature water can be effective (Eustace et al., 2007; Eustace et al., 2008; Goulter, Dykes, & Small, 2008) and provide a basis for alternative processes.

2.6 Operational practices contributing to good carcase hygiene

There are several practices in Australia that are believed to contribute to the hygienic quality of carcases. It is difficult to collect data to prove that these practices are effective, and under all circumstances.

Hide cleanliness

The hides of Australian cattle coming to slaughter are considered to be much cleaner than cattle in some places, such as North America, where many animals come to slaughter from feedlots. A study scored the cleanliness of cattle in Australia[226] which allowed comparison with North American cattle.[227]

Worker training

The National Meat Industry Training Advisory Council (MINTRAC)[228] role is to improve the skills of workers in the industry through the provision of recognized and accredited training. There is a system of training workers in individual tasks to a high standard.

Hide removal

Care during the hide removal process, both in making the opening cuts through the hide, and the actual removal process, reduce the transfer of bacteria from the hide to the carcase. Some carcase contamination appears to originate from the mouth (saliva, rumen) of the animal during hide

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[226] Jordan, D. (2003). Pilot study on the use and usefulness of tag scores at Australian cattle abattoirs. MLA Project PRMS.042. North Sydney, NSW, Australia.

[227] Sumner, J et al. (2018) Microbiological food safety and storage life of Australian red meat. AMPC Report project 2018-1086 Australian Meat Processor Corporation - Supporting the red meat processing industry throughout Australia (ampc.com.au)

[228] Meat Industry Training Advisory Council MINTRAC

removal[229] A study of carcase hygiene (using large area sampling) found aerobic plate count after hide removal of 0.69 log_{10}CFU/cm^2 (Horchner, Huynh, Sumner, Vanderlinde, & Jenson, 2020).

Removal of the Gastrointestinal tract

Sealing both the oesophagus and rectum (and enclosing the rectal end in a bag) prior to evisceration minimizes opportunities for the contents to contaminate the carcase.

Trimming

Trimming of carcases occurs to ensure that no faeces, urine, milk or ingesta are visible. Also, hairs, wool, dust, grease, bruising etc. must be removed (AS4696 9.18). There is a commercial standard beef carcase trim[230]. A study of carcase trimming (using large area sampling) demonstrated a reduction in aerobic plate count of 0.38 log_{10} CFU/cm^2) and reduction in the presence of *E. coli* and coliforms bacteria by 49% and 33% respectively (Horchner et al., 2020).

Chilling

Australian requirements for chilling (Chapter 13) contribute to the hygienic quality of Australian meat.

2.7 Foreign matter control

Foreign matter is difficult to control. It may originate from the animal or from the production environment and can be difficult to detect.

Foreign matter originating from the animal can include: incorrectly placed HGP implants, broken injection needles, pieces of wire from when an animal may have come into contact with fencing, barium selenate nodules from intramuscular injection of barium supplements, shot gun pellets. Within the production environment, pieces of equipment, and tools may find their way into product.

Methods of detection include visual, metal detection and X-rays. Not all foreign matter is observable, even with careful attention. Metal detectors, relying on the magnetic properties of the metal, are less effective when applied to large pieces of meat, or cartons, than on small pieces of meat. X rays can be effective but are not always employed.

2.8 Removal of contamination

To be considered wholesome (chapter 8) meat must be free of obvious contamination. In general, obvious contamination consists of visible faeces, ingesta, and milk which are considered to be 'zero tolerance' defects by the US FSIS.[231] Contamination also addressed includes urine, hair, wool, dust, grease. All of these types of contamination may be removed by trimming of the visible defect with a margin to allow for removal of associated invisible contamination.

The effectiveness of sanitary dressing and removal of contamination is assessed through Meat Hygiene Assessment on carcases and cartoned product (4.5 below)

[229] Chandry, P. Scott (2016) Metagenomic analysis to explore the mechanisms of carcass contamination. MLA Report G.MFS.0327 Metagenomic analysis to explore the mechanisms of carcass | Meat & Livestock Australia (mla.com.au)

[230] AUS-MEAT Limited (2010) AUS-MEAT Language Changes – Beef standard Carcase trim. Advice 05/10

[231] FSIS Directive 6420.2 Verification of Procedures for Controlling Fecal Material, Ingesta, and Milk in Livestock Slaughter Operations - Revision 2 | Food Safety and Inspection Service (usda.gov)

2.9 Removal of defects

To be considered wholesome (chapter 8) meat must be free of defects that may be considered objectionable to consumers. Such defects may include bruising, abscesses, injection site lesions etc.

The effectiveness of sanitary dressing and removal of contamination is assessed through Meat Hygiene Assessment on carcases and cartoned product (4.5 below)

2.10 Research and data on good practices in Australia

Investigation of routine hygiene data collected from processing establishments, lead to the question of why some establishments had different results than others. Criteria had been developed to identify establishments that had significantly different results in the hope of determining (and correcting) the reasons why hygiene was not as good (P. Vanderlinde, Jenson, & Sumner, 2005).

For beef processing, a study of a number of processing establishments grouped variables influencing contamination under two categories: contamination on incoming livestock (Problem variables) together with the ability of the plant's process to deal with such contamination (Process variables). The analysis prompted two main conclusions. Firstly, plants with a large incoming problem with livestock (long travel distance, high tag (dags) (poor cleanliness) score and high proportion of cows/bulls slaughtered) plus “poor” processes had higher than average *E. coli* prevalence. Secondly, plants with hot water decontamination systems had low *E. coli* prevalence even when there was a substantial incoming problem with livestock, such as a relatively high proportion of cows/bulls (Kiermeier et al., 2006).

A similar approach taken with sheep processors also defined the incoming problem score and the process score and finding a relationship between these scores and the microbiological quality of carcases(Kiermeier, Jenson, & Sumner, 2009).

The industry has continued to identify steps in their process that lead to poor hygiene and corrective actions that can be taken. In the period soon after the US implemented new rules for testing for STEC in manufacturing beef, the quality of processing of cows and bulls, previously noted as worse than steers and heifers (Kiermeier et al., 2006) made significant improvements (Sumner, Kiermeier, & Jenson, 2011). Several publications have reported on investigations performed in slaughter establishments to choose better practices. The *Processor’s Guide to Improving Microbiological Quality and Shelf Life of Meat*, 3rd edition[232], contains investigations along the slaughter line for beef and sheep processing as models for investigation and improvement in processing standards.

3. Hazard Analysis and Critical Control Points (HACCP)

Hazard Analysis and Critical Control Points (HACCP) is, at its heart a concept, which has been developed into a system, that has developed and now exists in different forms which is not usually explicitly acknowledged.

HACCP developed in the late 1960s and early 1970s as the optimal control method for manufacturing ‘zero-defect’ food products for use in the US space programme. It was first presented at the 1971 National Conference on Food Protection. HACCP has since been transferred to many other industries and regulatory bodies as the method of choice for controlling and preventing hazards of many kinds (Adams, 1994).

[232] Meat & Livestock Australia. Processor’s Guide to Improving Microbiological Quality and Shelf Life of Meat. 3rd edition .Processors guide 3rd edition - 1st Draftij (mla.com.au)

The United States Department of Agriculture (USDA) began considering the use of HACCP for meat processing in the 1980s (Adams, 1994) and published the pathogen reduction/HACCP rule in 1996 (Hulebak & Schlosser, 2002). In parallel, Codex Alimentarius was including HACCP as an annex, and then a chapter, in the GPFH.

The 2003 Codex definition of a CCP was: “A step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level.”

At about this time, USDA Food Safety and Inspection Service (FSIS) employees published this explanation of a CCP, presumably in line with their concept of HACCP:

> For example, the intestinal tracts of animals can harbor large populations of enteric pathogens, such as Salmonella…. As the slaughtered animals are eviscerated, there is potential for spreading the Salmonella from the intestinal tract to the carcass, operator, or equipment. Therefore, evisceration would be considered a CCP in a HACCP plan for beef slaughter. Critical limits for the evisceration CCP might be 0% occurrence of the following defects for a single carcass: fecal material, ingesta, urine, or abscesses (Hulebak & Schlosser, 2002).

This formulation of a CCP could be criticized because, as a CCP preventing contamination, it is relying on visual assessment of absence of a pathogen, and urine, abscesses and ingesta may be unlikely to contain a foodborne pathogen at all.

A review of process performance standards notes:

> In the USA, to comply with the requirement by the Food Safety and Inspection Service (FSIS) that a Critical Control Point (CCP) for *E. coli* O157 be operated on the slaughter floor, processors have evaluated the inactivation conferred by various interventions. A wide range of interventions is used in series including hide sanitization, acid rinsing of carcases and pieces of meat, plus thermal pasteurization of carcases. The additive effect of a sequence of interventions, which are typical for USA slaughter operations, should be sufficient to comprise a CCP for *E. coli* O157 by eliminating it. Yet despite this plethora of inactivation, recalls of large quantities of meat are relatively common and are sometimes associated with illness and death (I. Jenson & Sumner, 2012).

The Codex 2003 decision tree for determining whether a step in the process is a CCP is “not specific to all food operations, e.g., slaughter, and therefore it should be used in conjunction with professional judgement, and modified in some cases.”

The 2020 definition of CCP:

> “A step at which a control measure or control measures, essential to control a significant hazard, is/are applied in a HACCP system”

and, control measure:

> “Any action or activity that can be used to prevent or eliminate a hazard or reduce it to an acceptable level.”

allows more flexibility to determine the need for a CCP and how it is defined. A decision tree to assist in identifying CCPs has been added to the GPFH in line with the requirements of HACCP step 7 – Principle 2 – determine the critical control points (CCPs).[233] The decision tree first asks whether good hygienic practices are sufficient to control the hazard to an acceptable level, and later asks whether subsequent steps may eliminate or reduce the hazard to an acceptable level. Additionally, a step must ‘specifically prevent or eliminate the identified significant hazard or reduce it to an acceptable

[233] CAC. 2022. General Principles of Food Hygiene CXC1-1969 (revised in 2022). fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B1-1969%252FCXC_001e.pdf

level'. This decision tree will minimise the number of CCPs identified to those essential for controlling significant hazards.

3.1 Identifying CCPs in meat processing

As noted above, some regulators, such as FSIS mandate a CCP on the slaughter floor, whilst the Codex decision tree (2003) specifically warns against applying HACCP to meat processing in the same way as it might be applied to other foods.

Amongst the food safety community in the Australian meat industry there is generally a belief that CCPs do not exist in meat processing but rather a set of controls, many good hygienic practices, contribute to meat being safe for human consumption (after cooking) (I Jenson, Maguire, & Sumner, 2004).

3.2 Validation of CCPs in meat processing

Codex definition (GPFH, 2020), Validation of control measures:

> Obtaining evidence that a control measure or combination of control measures, if properly implemented, is capable of controlling the hazard to a specified outcome.

The Codex Validation guidelines[234] allow the validation of a whole process:

> Collection of data during operating conditions in the whole food operation. When this approach is used, biological, chemical or physical data relating to the hazards of concern are collected for a specified period (e.g., 3-6 weeks of full-scale production) during operating conditions representative of the whole food operation, including periods where production is increased, e.g., holiday rush. For example, when the food safety control system is contingent upon the use of good veterinary or agricultural practices in the field or good hygienic practices in the processing establishment, it may be necessary to validate these measures through the use of intermediate/finished product and/or environmental sampling and testing. Sampling should be based on the use of appropriate sampling techniques, sampling plans and testing methodology. Data collected should be sufficient for the statistical analyses required.

The ability to validate a whole process avoids the whole issue of what is, or is not, a CCP, and whether HACCP is applicable to meat processing.

4. Monitoring and verification

Ongoing verification of the implementation of good hygienic practices and other control measures are required.

Codex definitions (GPFH, 2020)

Monitor:

> The act of conducting a planned sequence of observations or measurements of control parameters to assess whether a control measure is under control.

Verification:

> The application of methods, procedures, tests and other evaluations, in addition to monitoring, to determine whether a control measure is or has been operating as intended.

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[234] Codex Alimentarius Commission. PROPOSED DRAFT GUIDELINES FOR THE VALIDATION OF FOOD SAFETY CONTROL MEASURES (fao.org) CXG 69-2008 (edited 2013)

The following sections will describe the monitoring and verification that occurs to demonstrate that the slaughter process is operating as intended., and the data analysis system that provides verification that the Australian system, as a whole, is operating as intended.

4.1 Standards for microbiological testing

Monitoring data must be reliable. In the case of microbiological data, this is achieved through control of the standards of the laboratory and the specification of acceptable test methods.

Laboratories testing meat and meat products relevant to export certification are accredited by the National Association of Testing Authorities (NATA) to undertake such testing and as meeting ISO/IEC 17025 *General requirement for the competence of testing and calibraton laboratories*.[235] Laboratories not accredited by NATA may also be recognised as approved laboratories by the department to undertake specific testing if they comply with similar requirements imposed by the department. NATA is a private, not-for-profit company, governed by its members including representatives from government, professional bodies and industry. The department recognises NATA as the Australian authority for accrediting laboratories for testing. NATA represents Australia in the International Laboratory Accreditation Cooperation (ILAC), the Asia Pacific Laboratory Accreditation Cooperation (APLAC) and the Good Laboratory Practice (GLP) compliance monitoring authority representing Australia on the OECD GLP Working Group.

Test methods used must be approved by the department. These methods, in general, are those specified by importing countries (sometimes their own in-house method, or an ISO method) and those demonstrated to be equivalent to a standard method though a validation process specified by AOAC, AFNOR or the relevant part of ISO16140.[236]

4.2 Pre-operational microbiological monitoring

Monitoring: Three types of monitoring occur: visual, tactile, and microbiological. After cleaning and sanitation is completed, and before processing operations commences, a visual and tactile inspection is made of equipment and machinery to ensure that all meat and material from previous production has been removed and all surfaces cleaned. In an operational context a clean surface will be both visually clean and free of detectable residues (i.e., fat) to touch. Any defects are noted, and the area is re-cleaned. Samples are collected for microbiological analysis to confirm that the visual assessment of surfaces indicates acceptable microbiological standards. Visual inspection occurs every day and microbiological sampling and testing occurs once per week, rotating through each operational day.

The Meat Standards Committee (now Australian Meat Regulators Group) developed guidelines for microbiological testing for the purpose of demonstrating control of cleaning and sanitation. [237]

Verification: The department conducts weekly independent verification of pre-operational hygiene monitoring, check-the-checker (CTC) verification of contact surface and personal gear swabbing with all records documented on department systems including any non-compliance management.

4.3 Pre-operational personnel and personal equipment monitoring

Monitoring: Company quality assurance staff monitor personnel and personal equipment upon entry to processing areas. All staff not following the documented work instructions for sanitising

[235] DAFF. ELMER 3 Approved laboratory program. Approved laboratory program - DAFF (agriculture.gov.au)
[236] DAFF. ELMER3. Approved methods for microbiological testing of meat and meat products. August 2022. Approved methods for microbiological testing of meat and meat products - DAFF (agriculture.gov.au)
[237] Meat Standards Committee (2002) *"Microbiological Testing for Process Monitoring in the Meat Industry"* (2002)

equipment, fitting personal protecting equipment (PPE), and preparing for operations are directed to re-clean and correctly apply PPE prior to entry. Equipment testing is undertaken weekly and covers workers personal equipment across all operational areas. Systems vary across establishments, but the objective is that random sampling will cover a representative number of staff and equipment over the course of the monitoring period.

Verification: Quality Assurance (QA) managers undertake check-the-checker (CTC) verification of QA Officers undertaking daily inspections.

The department conducts weekly independent verification of pre-operational hygiene monitoring, CTC verification of contact surface and personal gear swabbing with all records documented on department systems including any non-compliance management.

4.4 Visual – process Meat Hygiene Assessment[238]

Meat Hygiene Assessment (MHA) was devised by DAFF as a means of visual monitoring that processes are being performed as well as possible, and therefore, likely minimizing microbiological contamination. The first part of MHA relates to process controls in the production of the meat utilising standard methods to assure consistency in the outputs from monitoring and to provide an objective approach to assessing meat hygiene.

Monitoring: The process monitoring system assesses the efficiency of operations on the slaughter floor, in the offal room and the boning room and during refrigeration and storage of product, with a view to minimising microbiological contamination. It requires the routine examination of the procedures used in each task and at each process step in the production areas.

Procedures at each process step are described in work instructions which include “best practice” techniques for tasks and sanitation. These procedures collectively represent the control measures to minimise the risk from hazards, such as contamination, during processing. The process monitoring system measures compliance with procedures in work instructions against their limits.

The system specifies a minimum sample size and frequency of monitoring and employs pass / fail criteria as targets. The Conformity Index provides an overall picture of the process control and corrective action occurs when the Conformity Index falls below the target level.

4.5 Visual -- carcase/carton Meat Hygiene Assessment[239]

MHA was devised by DAFF as a means of visual monitoring that processes are being performed as well as possible, and therefore, likely minimizing microbiological contamination. The second part of MHA relates to the physical condition of meat utilising standard methods to assure consistency in the outputs from monitoring and to provide an objective approach to assessing meat hygiene.

Monitoring: The product monitoring system includes the monitoring and control of faeces, ingesta, , and milk contamination (the “zero tolerance” defects) and gives guidance to what is expected of corrective and preventive action.

The product monitoring system assesses the level of macro-contamination on carcases, offal and cartoned meat. Representative samples are routinely examined using a consistent methodology, including a defined classification for defects and their respective tolerances. It provides a minimum sample size and frequency of monitoring and employs pass / fail criteria as targets.

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[238] DAFF (2002) ELMER 3 Meat Hygiene Assessment 3. Meat Hygiene Assessment (MHA) - DAFF (agriculture.gov.au)
[239] DAFF (2002) ELMER 3 Meat Hygiene Assessment 3 Meat Hygiene Assessment (MHA) - DAFF (agriculture.gov.au)

Weightings are applied to defects according to their public health risk and severity. This information is then condensed to a single value called a Defect Rating. The Defect Rating provides an overall picture of the hygienic condition of meat and verifies the adequacy of process controls associated with its production. Corrective action is specified when the Defect Rating falls below a target value or when zero tolerance detections are made.

4.5.1 Small stock port of entry product hygiene verification

In response to a number of Port-of-Entry rejections for zero tolerance defects (faecal matter) in skin-on goat in the USA, materials were produced[240] to explain the skin-on goat processing system and appearance of skin-on goat carcases (for example, naturally occurring pigmented spots, and singed hairs from the firing process). The materials were designed to assist in adequate processing and inspection in Australia and have materials available so that DAFF could intervene on behalf of Australian exporters.

4.6 Carcase microbiological monitoring[241]

Monitoring: All export registered slaughtering establishments participate in the National Carcase Microbiology Monitoring Program (NCMMP) (formerly known as ESAM) which requires Aerobic Plate Count (APC) and *E. coli*, and *Salmonella* testing, of chilled carcases to monitor slaughtering and chilling operations.

In most instances, the number of carcases tested is proportional to the production volume. Carcases from different shifts, slaughter chains, species, class and/or chillers are sampled and tested independently based on the production volume for each shift, chain, species, class, or chiller. Carcases are selected randomly from those available for sampling.

One of the key elements of the microbiological testing is to assess and monitor chiller performance. Therefore, all chillers are included in the sampling frame for the selection of sample carcases.

Where sampling frequencies, by using the formula do not achieve a minimum of one test per day for indicators of process control i.e., *E. coli* and APC, establishments should test one carcase.

Methods are prescribed and are equivalent to the US FSIS requirements[242]. They are also considered equivalent to the EU requirements (European Food Safety Authority, 2010).

This testing is an integral part of an establishment's QA program. Ongoing adverse *E. coli* testing trends, and/or detection of *Salmonella* above acceptable limits may be indicative that an establishment's system has failed at one or several points which should be investigated and if required, necessary corrective action taken.

Verification: The Department conducts a weekly CTC verification of microbial sampling of carcase and carton meat with all records documented on department systems including any non-compliance management.

[240] MLA. R&D – processing productivity report. Guidelines for visual inspection of skin-on goat | Meat & Livestock Australia (mla.com.au)

[241] DAFF (2021) ELMER 3. Microbiological manual for sampling and testing of export meat and meat products. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products - DAFF (agriculture.gov.au)

[242] USDA. FSIS Equivalence. Equivalence | Food Safety and Inspection Service (usda.gov)

4.7 Carton meat microbiological monitoring

Monitoring: To monitor the application of hygienic standards through the boning room to packed products, all establishments producing carton or bulk packed meat for export must collect and analyse tissue samples from final product for APC, and many establishments also test for coliforms.

Samples must be collected as close to final carton closure as possible. Where boned product is produced in other than a carton (e.g., production of 'combos' for export), equivalent arrangements with regards to the testing of final product must be undertaken and approved by the department. Cartons from different shifts, boning and/or species must be sampled and tested independently.

4.8 Product Hygiene Indicators[243]

The Product Hygiene Indicators (PHI) Program identifies a number of key performance indicators (KPIs) which when combined produce an index, the Product Hygiene Index, which is a measure of hygienic meat production at individual export establishments. The KPIs can be used within an establishment to monitor and assess the effectiveness of process control and can be used across establishments to compare performance against other similar slaughter and boning operations.

The focus of the PHI Program is on preventing contamination by enteric pathogens and on the application of good refrigeration to ensure that there is minimal growth of microorganisms in the event of undetected contamination. KPIs have been selected or developed based on their ability to address hazards identified through an industry wide whole-of-chain risk assessment of the Australian red meat production system against the requirements of AS4696. Data from the previously mentioned monitoring activities are included as KPIs. Refrigeration is monitored through the application of the Refrigeration Index (RI).

5. External evidence for the outcomes of process hygiene

Baseline studies are an attempt to assess the quality of product across the country, in a statistically relevant way. They collect data independently of the monitoring conducted by establishments and are able to address a wider variety of microorganisms than routinely collected.

5.1 Carcase baselines

5.1.1 Beef

The most recent carcase baseline conducted using standard methods, was conducted in 2004. Carcasses (n=1,155) sampled at 27 slaughter establishments had a mean APC (at 25°C) of 1.3 log CFU/cm^2. *Escherichia coli* was isolated from 8.0% of the carcasses, with a mean count of -0.8 log CFU/cm^2 for samples above the detection limit. *Salmonella* was isolated from 0 of 1,155 carcasses. No *Campylobacter* spp. were isolated from carcasses. Coagulase-positive staphylococci were isolated from 28.7% of beef carcasses, and samples above the limit of detection had a mean count of 0.3 log CFU/cm^2 (Phillips, Jordan, Morris, Jenson, & Sumner, 2006b).

A baseline survey to examine hygienic control of the slaughter and dressing process for beef carcases, sampled using a non-standard method (large area sampling) has been conducted (Horchner et al., 2020). Samples were collected at the completion of dressing before the commencement of chilling. Hindquarter and forequarter samples were collected from 24 establishments. The overall contamination level on carcass sides was low. The concentration and

[243] DAFF. ELMER 3. Product Hygiene Indicators Program Product Hygiene Indicators Program - DAFF (agriculture.gov.au)

prevalence of indicator bacteria were higher on samples from hindquarters than on samples from forequarters. Salmonellae were isolated from 0.56% of carcases.

5.1.2 Sheep meat

The most recent baseline survey of sheep carcases was conducted in 2004. Carcases (*n* =1117) sampled at 20 slaughter establishments were found to have a mean log Total Viable Count (TVC, 25 C) of 2.28 cfu/cm^2 and *Escherichia coli* was isolated from 43.0% carcases with a mean log 0.03 cfu/cm^2 on samples above the limit of detection. *Salmonella* was isolated from 0/1117 carcases. *Campylobacter* sp. were isolated from 4/1117 carcases. Coagulase positive staphylococci were isolated from 23.4% of carcases, with samples above the limit of detection having a mean log count of 0.93 cfu/cm^2 (Phillips, Jordan, Morris, Jenson, & Sumner, 2006a).

5.2 Primal baselines

5.2.1 Beef

The fourth national baseline microbiological survey of Australian beef was conducted in 2011, including samples from selected beef primal cuts. Cartons of primals were sampled at 29 boning (fabrication) plants. The mean TVC for striploins (longissimus dorsi, n=572) and outsides (biceps femoris, n=572) were 1.3 and 1.5 log CFU/cm^2 respectively. *E. coli* isolates were obtained from 10.7 and 25.2% of striploins and outsides, respectively, with mean counts of 20.5 and 20.3 log CFU/cm^2 on samples above the limit of detection. *E. coli* O157:H7, *Salmonella*, and *Campylobacter* were not isolated from any primal cut samples, and *Salmonella* was not isolated from any of the boneless product (*E. coli* O157:H7 and *Campylobacter* were not tested). *Listeria* spp. was obtained on 1 (0.2%) of 572 striploin samples. Coagulase-positive staphylococci were isolated from 7.7% of beef striploins, and 8.4% of beef outsides, with samples above the limit of detection having mean log counts of 0.2 CFU/cm^2, and 0.2 CFU/cm^2, respectively (Phillips, Bridger, Jenson, & Sumner, 2012).

5.2.2 Sheep meat

The fourth national baseline microbiological survey of Australian sheep meat was conducted in 2011 including for the first time samples from selected sheep meat primal cuts. Sheep and lamb legs (n= 613) and shoulders (n = 613) sampled at 12 meat processing establishments were found to have mean TVC (25°C) of 2.02 and 2.29 $\log_{10}$ cfu/cm^2 respectively; *Escherichia coli* was isolated from 42.9% of legs and 34.6% of shoulders with respective mean counts of -0.44 and -0.63 $\log_{10}$ cfu/cm^2 on samples above the limit of detection. *E. coli* O157:H7 was isolated from 2/613 leg and 1/613 shoulder samples. *Salmonella* was isolated from 17/613 leg samples, 5/613 shoulders. *Campylobacter* spp. were isolated from 1/613 shoulder samples. *Listeria* spp. was isolated from 1/613 leg samples. Coagulase positive staphylococci were isolated from 4.2%, and 5.2% of leg, shoulder and frozen boneless sheep meat samples respectively, with samples above the limit of detection having a mean $\log_{10}$ count of -0.21 cfu/cm^2, and 0.34 cfu/cm^2 respectively. (Phillips, Tholath, Jenson, & Sumner, 2013).

5.3 Manufacturing (boneless meat) baselines

5.3.1 Beef

The fourth national baseline microbiological survey of Australian beef was conducted in 2011, including frozen boneless beef. Cartons of frozen boneless beef (n=1,165) sampled at 29 boning (fabrication) plants were found to have a mean TVC of 2.2 log CFU/g, and the mean count for the 2.1% of samples with detectable *Escherichia coli* was 1.3 log CFU/g. *Salmonella* was not isolated from any of the boneless product. *Listeria* spp. were not detected in any of the boneless product.

Coagulase-positive staphylococci were isolated from 3.4% of boneless beef samples, with positive samples having mean log counts of 1.9 CFU/g (Phillips et al., 2012).

5.3.2 Sheep meat

The fourth national baseline microbiological survey of Australian sheep meat was conducted in 2011. For samples of frozen boneless sheep meat (n = 551) the mean TVC was 2.80 log_{10} cfu/g and the mean count for the 12.5% of samples with detectable *E. coli* was 1.51 log_{10} cfu/g. *Salmonella* was isolated from 17/551 samples of frozen boneless product. *Listeria* spp. were not detected in any of the frozen boneless product. Coagulase positive staphylococci were isolated from 1.8% of samples, with samples above the limit of detection having a mean log_{10} count of 1.66 cfu/g respectively. Extreme weather patterns may have led to elevated levels of indicator organisms (APC and *E. coli* prevalence) on frozen trim compared with previous Australian baseline surveys (Phillips et al., 2013).

5.4 Offal baselines

A national baseline study of offal hygiene was undertaken at 17 Australian export establishments in 2018-19. A total of 1756 samples of different offal types were analysed for APC, generic *Escherichia coli*, and coliform bacteria. Average APC values varied from 1.51 to 5.26 Log_{10} CFU/g, depending on species and offal type. The average APC on beef, sheep, lamb, and goat offal was 3.25, 3.38, 3.70, and 2.97 Log_{10} CFU/g, respectively. There is a small but significant difference in APC on offal sampled frozen (3.26 Log_{10} CFU/g) and offal sampled fresh (3.73 Log_{10} CFU/g). *Escherichia coli* prevalence on beef, sheep, lamb, and goat offal was 15.4%, 28.1%, 17.5%, and 39.3%, respectively. The number of *E. coli* on offal samples above the limit of detection ranged from 1.42 to 1.82 Log_{10} CFU/g. While the quality of some offal approach that of muscle meat, the hygienic quality of red meat offal can be understood by considering the anatomical site from which it is harvested, the usual bacterial levels found at that site, the difficulty in hygienically removing the offal from the carcase, the process prior to packing, and the chilling method used (Paul Vanderlinde, Horchner, Huynh, & Jenson, 2022).

6. Microbiological testing – primer on sampling, testing, and understanding results

This section will attempt to provide a basic understanding of the processes of sampling and testing, so that the results of microbiological testing can be understood. A useful source for further explanation can be found in the a JEMRA publication (FAO/WHO [Food and Agriculture Organization of the United Nations/World Health Organization], 2016), though the scope of this document is not the same as this section.

6.1 Sampling

Microorganisms are frequently found to be unevenly distributed through a lot of food or ingredient. When we think about meat processing, this becomes very obvious: each carcase on a slaughter chain comes from an animal that has a variable number of bacteria on its hide and in its gastro-intestinal tract, which becomes uneven distributed over the carcase during processing, with the variable addition/removal of bacteria through the steps of processing and human handling.

Sampling of a carcase most often uses a sponge to remove bacteria from the surface of a defined area of meat. The removal of bacteria is highly variable between operators, and even after repeated attempts, bacteria remain on the surface (Seager, Tamplin, Lorimer, Jenson, & Sumner, 2010). Excision sampling, where the surface tissue is physically removed probably does not result in removal of all bacteria into the test medium.

Sampling of trimmings presents an additional source of non-uniformity: some surfaces may be external carcase surfaces, and therefore probably have more bacteria than internal surfaces that become exposed relatively late in processing. There is some evidence that belts in boning rooms 'distribute' contamination on meat pieces, and lead to a more unform level of contamination after running for a short while.[244] Some tests (e.g., STEC for the USA market) require the collection of surface slices for analysis[245] but there is some evidence that small pieces of trim will do as well as a surface slice (Kiermeier, Holds, Lorimer, Jenson, & Sumner, 2007). Much less surface will be sampled when collecting material from frozen blocks, as occurs at import inspection for cartons of frozen manufacturing beef[246] but this difference does not appear to be of concern to the regulator.

Samples are collected with sterile tools and placed in sterile sample containers and are transported to the laboratory in a way that minimizes changes to the bacterial levels in the sample. This usually requires sending samples to the laboratory with ice packs and testing within 24 hours. There may be specifications for time and temperature for the samples to be accepted for testing in the laboratory.

6.2 Testing

The first decision that is made by the laboratory is whether the test is quantitative or qualitative. Quantitative tests yield a result which is a concentration: number of colony forming units (cfu) per gram or mL. Colonies (lumps of bacteria growing on an agar plate, or equivalent) are considered to have arisen from a single bacterial cell (though this may not always be true), so a count of the number of colonies on an agar plate (after incubation) can be converted to the number of cfu in the original sample. Qualitative tests yield a result which is whether the bacterium being tested for was detected or not detected in a sample of a certain size after being incubated in an enrichment broth (which allows their concentration to increase, making detection possible). Sometimes this is incorrectly referred to as 'positive' or 'negative' result, but the laboratory can only report on what it detected, or not. Sample sizes often range between 25g and 375g, but also may be 300cm^2 carcase sponge sample.

In a quantitative test, a sample (which may be a sponge, representing a surface area) is weighed, and then diluted with sterile diluent to reach a countable number on an agar plate (or equivalent). The lab can make an estimate of the dilutions to use based on previous experience. In meat testing laboratories results of 'less than the limit of detection' are not uncommon because no colonies were present on the plate (it is incorrect to call these 0 cfu), even at the lowest possible dilution.

In both quantitative and qualitative tests, the test procedure may progress through several stages. Typically, in a quantitative test the laboratory is able to count colonies that grow (not all bacteria will grow, particularly when the agar is selective for a particular group or species of bacteria) and have the right appearance (because the agar is formulated to be differential) for the bacterium being tested for. This is often called a presumptive count, which is then sometimes confirmed by additional testing. In qualitative tests, the enrichment broth grows the target bacterium (if present) but also other bacteria, so the target organism needs to be detected on an agar or using rapid test methods, often based on a specific DNA sequence using a polymerase chain reaction (PCR) test to amplify the target DNA to detectable levels. Again, these results are often presumptive and require

[244] Meat & Livestock Australia. Processor's Guide to Improving Microbiological Quality and Shelf Life of Meat. 3rd edition Processors guide 3rd edition - 1st Draftij (mla.com.au) page 115-123, 169-174

[245] FSIS. Directive 10010.1 Sampling verification activities for Shiga toxin-producing Escherichia coli (STEC) in raw beef products. FSIS Directive 10010.1 Rev 5 Sampling Verification Activities for Shiga Toxin-Producing Escherichia Coli (STEC) in Raw Beef Products (usda.gov)

[246] FSIS. Directive 10010.1 Sampling verification activities for Shiga toxin-producing Escherichia coli (STEC) in raw beef products. FSIS Directive 10010.1 Rev 5 Sampling Verification Activities for Shiga Toxin-Producing Escherichia Coli (STEC) in Raw Beef Products (usda.gov) Attachment 5

additional PCR and culture (agar) tests to yield a definite result. Some methods even have a 'potential' stage prior to the 'presumptive' stage.

6.3 Interpreting results

Laboratories usually report the results of the tests for the sample 'as received by the laboratory', since they are rarely responsible for the collection of samples or their transportation to the laboratory.

Quantitative test results are reported as (presumptive/confirmed) concentration per gram/mL of the original sample. The test method will also be specified in the report, because that is a key to understanding the significance of the result. In many ways, the result is a product of the method used. For example,

> Standard Plate Count (SPC) is the result of following a standard method for counting bacteria in a sample, for example, Australian Standard, "AS 5013.5:2016 Food microbiology. Microbiology of the food chain - Horizontal method for the enumeration of microorganisms - Colony count at 30°C by the pour plate technique", which requires incubation for 72 hours.
>
> Total Bacterial Count, or Total Viable Count (TVC, term commonly used in the Australian meat industry) does not count the total number of bacteria, or the total number of living bacteria. It counts the number of bacteria that are capable of forming visible colonies under the conditions of the test (as does the SPC). Incubation is usually at 25°C for 4 days.
>
> Aerobic Plate Count (APC) is often specified in the USA and requires incubation at 35°C for 48h.

These methods are not interchangeable, even though they all use very similar agars, and are measures of the number of bacteria present because different bacteria will grow at the temperatures specified and the time allowed for incubation.

Qualitative test results are reported as (potential, presumptive, confirmed) detected (or not detected) in x grams/mL/cm^2 of the original sample.

Often when test results are used in calculations and reports, the log_{10} of the count is used (so 100 cfu/g = log_{10} 2.0) because taking the log_{10} more likely results in a statistically normal distribution which is assumed for many statistical tests, and average (mean) counts.

Bacteria multiply by binary fission (1 becomes 2, becomes 4), and 1 cycle of doubling results in a number of cells that is always 0.301 log_{10} higher than the number before doubling. While double the number of bacteria may sound like a large increase, that may be accomplished in only 20 minutes to an hour, depending on the bacterium and the conditions. Given the sources of variation in the sampling and testing process, it is often considered that results that are less than 0.5 log_{10} or even 1.0 log_{10} different do not have practical significance, irrespective of statistical test results).

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10. Stunning

Summary

The stunning and slaughter of animals for food is a process that is highly sensitive to Australian consumers and regulators, international export markets, and religious markets, both domestic and export.

The foremost consideration in the stunning and slaughter of animals in Australia is to ensure all animal welfare requirements have been addressed through the stunning and slaughter process, resulting in good animal welfare outcomes.

Two forms of stunning operate across Australian jurisdictions, irreversible stunning where there is no possibility of the animal regaining consciousness, and reversible stunning where the animal may regain consciousness unless effectively bled. Both these stunning methods are extremely effective at delivering strong animal welfare outcomes.

Many of Australia’s export markets, and a large component of the domestic market require meat from animals that have been subject to religious slaughter. Australian industry and government have worked extremely closely with our religious export markets to ensure that Australia’s reversible stun techniques meets both Australia’ strong animal welfare standards and regulation outcomes, and religious requirements. Australia has continued through R&D to improve the effectiveness of this process while continuing to ensure alignment with all importing country requirements.

As with food safety outcomes, Australia’s commitment to animal welfare begins through its undertaking to the World Trade Organization (WTO) and to the World Organisation for Animal Health (WOAH). Australian standards for animal welfare are harmonised with these international standards as we are obliged to do as part of our WTO undertaking. Australia has been deeply involved in leading animal health and welfare through WOAH and involvement in numerous agriculture capacity building projects internationally, particularly regarding providing capacity building and technology to assist the stunning of animals in developing countries.

Australia has had a focus on continual improvement in stunning practices since the 1980s, with the development of Codes of Practice, developing legal frameworks, and welfare science to support best practices. All slaughter requires the application of stunning to minimise pain and distress to the animal. Some form of research on cattle and/or sheep stunning has been conducted in Australia continuously since the early 2000s.

Stunning, as part of animal welfare policy, is primarily a state responsibility backed by legislation, robust standards, and industry systems to demonstrate compliance with government or additional standards. Auditing occurs by both government and third-party auditors. The Commonwealth Department of Agriculture, Fisheries and Forestry closely supervises stunning at export slaughter establishments to ensure that Australian requirements, and agreed international specific market requirements are met.

The animal welfare concerns of stunning and slaughter of animals are taken very seriously not only in Australia but also by our exporting partners. Australian export establishments are audited regularly by importing country auditors, who include stunning in their audits and issue public reports of their findings, usually with no animal welfare concerns. Australian and international purchasers of Australian meat also have stunning standards and these requirements are audited.

Contents

1. Definitions and approaches to stunning

The 'five freedoms' paradigm for animal welfare has been influential since formulation in the early 1990s and consists of freedom:

- from thirst, hunger and malnutrition
- from discomfort and exposure
- from pain, injury, and disease
- from fear and distress
- to express normal behaviour (Mellor, 2016).

Despite further developments in concepts of animal welfare (Ch 7), in the few minutes surrounding the stunning and exsanguination (stun and stick) of animals, the freedoms from fear, distress, and pain (EFSA Panel on Animal Health Welfare et al., 2020) become critical and observable/measurable using Animal Based Measures (ABMs). ABMs are simply measuring the outcome in the animal (rather than the input measures associated with equipment etc.).

The following definitions are from the World Organisation for Animal Health (WOAH), *Terrestrial Animal Health Code*[247]:

Stunning: (current in 2023) means any mechanical, electrical, chemical or other procedure that causes immediate loss of consciousness; when used before slaughter, the loss of consciousness lasts until death from the slaughter process; in the absence of slaughter, the procedure would allow the animal to recover consciousness.
(proposed in 2023): means any procedure that causes loss of consciousness for the purpose of killing without avoidable distress, fear and pain.

Slaughter: (current in 2023) means any procedure that causes the death of an animal by bleeding; (proposed in 2023) means the killing of an animal using a method that causes a rapid and irreversible loss of consciousness with minimum pain and distress.

Killing: means any procedure that causes the death of an animal.

2. International (WOAH) standards

The WOAH *Terrestrial Animal Health Code* covers the slaughter of animals (Chapter 7.5[248]) and is being revised in 2023.

3. Australian Government standards

3.1 Australian Meat Standard

The Australian Meat Standard*, Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS 4696)[249] provides the legal standards for animal welfare in processing establishments. The desired outcome of the animal welfare

[247] World Organisation for Animal Health. Terrestrial Animal Health Code. Glossary. Terrestrial Code Online Access - WOAH - World Organisation for Animal Health
[248] World Organisation for Animal Health. Terrestrial Animal Health Code. Terrestrial Code Online Access - WOAH - World Organisation for Animal Health
[249] AS4696 Australian Standard for the Hygienic Production and Slaughter of meat and meat products for human consumption 5553 (csiro.au)

requirements is the minimisation of the risk of injury, pain and suffering and the least practical disturbance to animals. The *Standard* requires attention to the handling of animals, especially young, injured, sick or stress susceptible animals, and stunning prior to severing of the large blood vessels.

3.2 Australian Animal Welfare Standard

The Australian Government together with states and territories is developing and implementing nationally consistent standards and guidelines for farm animal welfare. The *Australian Animal Welfare Standards and Guidelines* update and replace the *Model Code of Practice for the Welfare of Animals*, for particular animal industries. Consideration of contemporary animal welfare science, costs to industry, practicalities, community standards, and international expectations are utilised to support an evidence-based approach. The standards are accompanied by voluntary guidelines that set out recommended practice for the care and husbandry and animals.

The Australian Animal Welfare Standards have both Standards and Guidelines relating to stunning and exsanguination of cattle[250], sheep[251] and goats[252] when that occurs on a farm but in processing establishments, the *Model Code of Practice for the welfare of animals; Livestock at slaughtering establishments*[253], 2001 is applicable. The *Australian Animal Welfare Standards and Guidelines for Slaughter Establishments* is expected to be released during 2024.[254]

The standards are designed to be implemented in state and territory legislation. The standards provide the basis for developing and implementing consistent legislation and enforcement across Australia. Australia's state and territory governments have primary responsibility for animal welfare and laws to prevent cruelty.

4. Acceptability of methods by importing countries

4.1 EU

Council Regulation (EC) No 1099/2009 of 24 September 2009 *on the protection of animals at the time of killing* [255]contains requirements for the welfare of animals during slaughter processes.

Definitions: 'stunning' means any intentionally induced process which causes loss of consciousness and sensibility without pain, including any process resulting in instantaneous death.

"Simple stunning" [reversible stunning] methods are those that require a secondary step (e.g., exsanguination) to ensure the death of the animal.

The following methods of stunning are approved for ruminants (Annex I):

- Penetrative captive bolt

[250] Animal Health Australia.2016. Australian Animal Welfare Standards and Guidelines for Cattle. Edition 1 version 1Cattle : Animal Welfare Standards

[251] Animal Health Australia. 2016. Australian Animal Welfare Standards and Guidelines for sheep. Edition 1 version 1. Sheep : Animal Welfare Standards

[252] Animal Health Australia. 2020. Australian Animal Welfare Standards and Guidelines - Goats Goat : Animal Welfare Standards

[253] Primary Industries Standing Committee. 2020. Model Code of Practice for the Welfare of Animals. Livestock at Slaughtering Establishments. SCARM Report 79. Scarm 79 Text (csiro.au)

[254] DAFF. Australian Animal Welfare Standards and Guidelines. Australian Animal Welfare Standards and Guidelines - DAFF (agriculture.gov.au)

[255] EU. Council Regulation (EC) No 1099/2009 of 24 September 2009 on the protection of animals at the time of killing (Text with EEA relevance) EUR-Lex - 32009R1099 - EN - EUR-Lex (europa.eu)

- Non-penetrative captive bolt [potentially reversible]
- Firearm with free projectile
- Head-only electrical stunning [potentially reversible]
- Head-to-body electrical stunning

There is a specific requirement that non-penetrative captive bolt device needs to avoid fracture of the skull and may only be used for ruminants of less than 10kg live weight (Annex I, chapter II) clause 1). (The use of non-penetrative captive bolt continues, however, because of the lack of suitable alternatives).

Specific requirements for the parameters of electrical stunning are given.

There is an allowance for equivalent methods to be proposed and approved.

4.2 USA

Humane slaughter of livestock is the concern of the Food Safety and Inspection Service (FSIS) with no change in the regulations in recent times[256]. There are general requirements for construction of pens, driveways, and ramps, and for handling of livestock. Several methods of stunning are approved:

Species	Method
Sheep, calves,	Carbon dioxide gas
Sheep, goats, calves, cattle,	Mechanical; captive bolt (either skull penetrating or nonpenetrating)
cattle, calves, sheep, goats,	Mechanical; gunshot
sheep, calves, cattle, and goats	Electrical; stunning or slaughtering

Two Guidelines are helpful to processors seeking to meet the standards enforced by FSIS: The American Veterinary Medicine Association’s *Guidelines for the Humane Slaughter of Animals*[257], and the North American Meat Institute’s *Recommended animal handling guidelines & audit guide: A systematic approach to animal welfare.*[258] A new edition of the AVMA *Guideline* is expected in 2023, and the NAMI recommendations are likely to be revised as a result.

5. Underlying science and approved techniques

Public demands for improved animal welfare, the science to determine animal welfare outcomes in an objective manner, the practical drivers for practice change, and the technological means of ensuring successful animal welfare outcomes have not developed at a steady pace or been coordinated in a manner to allow simple or smooth transitions. The variable definitions used by various standard-setting bodies, the different terminology used for stunning methods, the multiple ways that insensibility is determined even in the same species, makes this an extremely complicated area to understand.

[256] USDA FSIS Code of Federal Regulations Humane Slaughter of Livestock. eCFR :: 9 CFR Part 313 -- Humane Slaughter of Livestock

[257] American Veterinary Medicine Association. 2016. Guidelines for the humane slaughter of animals. Guidelines for the humane slaughter of animals | American Veterinary Medical Association (avma.org)

[258] North American Meat Institute. 2021. Recommended Animal Handling Guidelines & Audit Guide: A systematic approach to animal welfare. Guidelines and Audits | North American Meat Institute

A basic textbook for reference is Gregory and Grandin's (2007) *Animal Welfare and Meat Production*.

An extensive scientific review was prepared as part of an EU-funded project, Dialogue on Religious Slaughter.[259]

An extensive review[260] was prepared to inform the work to prepare the *Australian Animal Welfare Standards and Guidelines for Slaughter Establishments.*

The European Food Standards Agency (EFSA Panel on Animal Health Welfare et al., 2020) have prepared an extensive review on the potential issues associated with all aspects of stunning by all methods and found that the human factors involved in implementing methods are the most likely causes of failure of animal welfare.

5.1 Training

All guidelines and regulations emphasise the importance of trained operators to adequately manage the entry of animals into the area where slaughter tasks are performed.

5.2 A classification of stunning methods

Various stunning methods are approved for production animal species in different countries (Table 1).

Table 1: A classification of stunning methods

Classification / Description			Power Source	Result
Mechanical	Gunshot		Explosive charge	Kill
	Captive Bolt	Penetrating	Explosive charge Pneumatic	Kill
		Non-penetrating	Explosive charge	Stun
			Pneumatic	Stun
Electrical		Head-only	Electric	Stun
		Head-to-body	Electric	Stun or kill
Gas	Carbon dioxide			Stun or kill
Microwave			Electric	Stun or kill

5.3 Stun effectiveness/ insensibility

The effectiveness of stunning is measured by objective observations or tests (ABMs) that differ according to stunning method, but include: eye movement; sensitivity to pain; breathing; movement etc. Since stunning methods are not always 100% successful, the frequency of successful first (attempt to) stun is an important measure of animal welfare in practice.

Of critical importance is the length of time for which the stun is effective (for methods in which the stun is not intended to immediately kill the animal). This time is available for processing staff to

[259] VON HOLLEBEN, K., VON WENZLAWOWICZ, M., GREGORY, N., ANIL, H., VELARDE, A., RODRIGUEZ, P., CENCI-GOGA, B., CATANESE, B. & LAMBOOIJ, B. 2010. Report on good and adverse practices - Animal welfare concerns in relation to slaughter practices from the viewpoint of veterinary sciences. Deliverable 1.3. Available: https://www.dialrel.net/dialrel/images/veterinary-concerns.pdf

[260] Hewitt, L and Small, A (2022) An independent scientific review of processing establishment practices for livestock welfare. An Independent Scientific Review of Processing Establishment Practices for Livestock Welfare. (agriculture.gov.au)

move the animal into a position where it can be bled (stuck, cut) so that the animal dies from exsanguination prior to recovery from the stun.

5.4 Bleeding methods

Cutting of large blood vessels of the neck or of the thorax ensures rapid loss of blood and death. Religious requirements may specify how and what vessels are cut, and by whom.

5.5 Confirming death

Death is confirmed in practice using ABMs: cessation of breathing; eye fixed and staring; pupils dilated. In the immediate post-death period, small muscle twitches may still be seen as part of the rigor mortis process.

6. Control of stunning in processing establishments

The Australian Government has animal welfare responsibilities for export abattoirs. Industry-based certification against standards ensures compliance with legislated requirements.

6.1 Department of Agriculture, Fisheries and Forestry

The Department of Agriculture, Fisheries and Forestry (DAFF) will ensure that all export registered abattoirs meet the minimum animal welfare requirements as described in the *Australian Standard for the hygienic production and transportation of meat and meat products for human consumption* (AS4696) (Australian Meat Standard- see below). It will also ensure that market access requirements over and above the Australian Meat Standard are also maintained at export registered abattoirs.

In recognition of the Australian livestock processing industry Australian Animal Welfare Certification System (AAWCS)(see below), the department will accept AAWCS certified establishments, which. are certified and audited by AUS-MEAT, as equivalent to its own regulatory audit program, and accordingly will reduce the audit scope of its animal welfare audits during its monthly or six-monthly audit programs. The department will audit non-certified establishments against the Australian Meat Standard requirements for animal welfare and importing country requirements for animal welfare.

6.2 Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS)

The Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS) system[261] and the *Industry Animal Welfare Standard for Livestock Processing Establishments Preparing Meat for Human Consumption* was developed to reflect the expectations of both the Australian meat processing industry and the community regarding the management of livestock at Australian livestock processing establishments. The Standard and System is intended for incorporation into existing livestock processing industry quality assurance programs and to provide support towards demonstrating existing regulatory requirements in the industry. The development of the first edition was described by Edge and Barnett (2008). The third edition of the industry standard was approved December 2020 and took effect from 1 January 2022

[261] Australian Meat Industry Council (2021) Industry Animal Welfare Standard for Livestock Processing Establishments Preparing eat for Human Consumption AMIC-Ed3-Industry-Animal-Welfare-Standard_effective-1-Jan-2022.pdf (aawcs.com.au)

An implementation Guide accompanies the Standard and provides examples of the evidence that is required to meet the Standard and explain how the Standard may be achieved.[262]

The objectives of the Standard are to enable establishments to demonstrate fulfilment of the regulatory requirements covering the welfare of livestock and ensure good animal welfare outcomes. The Standard sets out requirements for the welfare of livestock during processing including stunning, sticking, and humane killing (excerpts):

> 7 Humane stunning and sticking processes
>
> 7.1 Restraint
> 7.1.1 Livestock shall be restrained for stunning using a method that:
> a) is designed and operated effectively for the species and type of livestock processed.
> b) allows the animal to be positioned for effective stunning; and
> c) does not involve the use of unacceptable practices and procedures….
> 7.1.2 The establishment shall ensure that:
> a) livestock are not left in restraint, single file races or without access to water during scheduled breaks in processing; and
> b) during delays, the welfare of livestock is monitored and action is taken if welfare is compromised.
> 7.1.3 When adult cattle or pigs are being moved into restraint for stunning, the establishment shall monitor vocalisation and use of electric goads in accordance with 6.2.2 and 6.2.3 as appropriate.
> 7.1.4 After effective restraint, the animal shall be stunned without delay.
>
> 7.2 Stunning procedures
> 7.2.1 Livestock shall be effectively stunned prior to sticking, using a permitted method…
> 7.2.2 The establishment shall ensure that monitoring of stunning effectiveness is performed in accordance with a documented procedure….
> 7.2.3 Where the first application is not effective or the animal shows signs of recovery before death, the animal shall be re-stunned immediately, using a back-up method if required.
> 7.2.4 The establishment shall ensure that:
> a) effective stunning is confirmed before hoisting or sticking commences;
> b) livestock remain unconscious during the period between stunning and death; and
> c) bleedline insensibility is monitored in accordance with a documented procedure …, where 100% of animals remain unconscious from stunning until death.
>
> 7.3 Sticking procedures
> 7.3.1 Sticking shall be performed using:
> a) throat cut severing both carotid arteries; or
> b) thoracic sticking severing the major blood vessels close to the heart.
> 7.3.2 In cattle and buffalo (including calves), where an initial throat cut is used, a thoracic stick shall be performed after cutting the throat in accordance with compliance requirements.
> 7.3.3 Dressing procedures shall not be performed before the animal is confirmed as dead.

The methods of stunning permitted under the AAWCS are described in Table 2.

[262] Australian Meat Industry Council (2021) Industry Animal Welfare Standard for Livestock Processing Establishments Preparing eat for Human Consumption. Implementation Guide. AMIC-Industry-Animal-Welfare-Guidance_effective-1-Jan-2022.pdf (aawcs.com.au)

Table 2: Permitted methods of stunning in AAWCS

Method	Species	Parameters
Non-penetrating percussive stunning device	Cattle	Equipment to be applied according to manufacturer's recommendations for appropriate position and power (charge, air-pressure, etc.)
	Sheep and goats	Equipment to be applied according to manufacturer's recommendations for appropriate position and power (charge, air-pressure, etc.)
Penetrating captive bolt stunning	All species	Equipment to be applied according to manufacturer's recommendations for appropriate position and power (charge, air-pressure, etc.)
Free bullet	All species	Equipment to be applied in the correct position with appropriate gauge used. Suitable as an emergency method as local laws allow
Head-only electrical stun	Cattle and buffalo	Electrode shall span the brain. Minimum current to produce and immediate stun
	Sheep and goats	Electrode shall span the brain. Minimum current to produce and immediate stun
Head to body electrical stun / kill	Cattle and buffalo	Electrode shall span the brain and the heart. Minimum current to produce an immediate stun.
	Sheep and goats	Electrode shall span the brain and the heart. Minimum current to produce an immediate stun.

7. Animal welfare performance

7.1 Department

DAFF verifies animal welfare on all export registered abattoirs. With respect to stunning, monthly activities include Check-the-checker process monitoring verification of animal handling (load-in to the knocking box) and Check-the-checker process monitoring verification of slaughter floor or skinning room operations. The latter check covers animal welfare elements that relate to stunning and sticking.

7.2 Industry

Training

The National Meat Industry Training Advisory Council (MINTRAC)[263] facilitates the development of training standards (units of competency) in the Certificate III Meat Processing:

- AMPA3000 stun animal
- AMPA3001 stick and bleed animal
- AMPA3003 assess effective stunning and bleeding

and produce training materials for delivery by Registered Training Organisations.

[263] Meat Industry Training Advisory Council. MINTRAC

Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS)
AAWCS is independently audited[264] to demonstrate compliance with the industry best practice animal welfare standards.

Processors are required to monitor animal welfare - include the following stunning targets as a minimum:

- when, penetrating captive bolt and non-penetrating percussive devices are used, at least 96% of animals are stunned effectively with the first application of the stunning method;
- when electrical stunning is used, at least 99% of animals have the electrodes applied in the optimum position and 98% or more of the animals show no sign of starting the process of return of consciousness

References

Edge, M. K., & Barnett, J. L. (2008). Development and integration of animal welfare standards into company quality assurance programs in the Australian livestock (meat) processing industry. *Australian Journal of Experimental Agriculture*, *48*(7), 1009-1013. https://doi.org/10.1071/EA08024

EFSA Panel on Animal Health Welfare, Nielsen, S. S., Alvarez, J., Bicout, D. J., Calistri, P., Depner, K., Drewe, J. A., Garin-Bastuji, B., Gonzales Rojas, J. L., Schmidt, C. G., Michel, V., Miranda Chueca, M. Á., Roberts, H. C., Sihvonen, L. H., Spoolder, H., Stahl, K., Velarde, A., Viltrop, A., Candiani, D., . . . Winckler, C. (2020). Welfare of cattle at slaughter. *EFSA Journal*, *18*(11), e06275. https://doi.org/10.2903/j.efsa.2020.6275

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[264] AUS-MEAT Australian Animal Welfare Certification System. AAWCS | AUS-MEAT (ausmeat.com.au)

11. Managing traceability and product identity in processing

Summary

The Australian system heavily relies on traceability, from individual animal identification (commenced in 2004) through saleyards, feedlots, processors, boning rooms, cold stores, freight forwarders, non-packer exporters and our export certification system. It is reflected across the total supply chain and within each of its various components are the traceability tools that enables the flow of animals and product to be identified, recorded, and managed to ensure any or all the system requirements are met. This traceability capability continues to evolve to keep pace with new technologies, emerging risks, user requirements, and customer expectations.

Like the Codex Alimentarius Commission standards, Australia has ensured strong traceability systems to ensure it has the best tools in place to protect its national animal health status through to a fundamental underpinning of food safety as reflected in the Australian Meat Standard (AS 4696).

For export establishments, the requirement for strong traceability systems is further enhanced due to importing country requirements. The Department of Agriculture, Fisheries and Forestry (DAFF), the competent authority for export certification, can only ensure certificate attestations are accurate, which address such issues as animal health, processing controls, religious slaughter, organic certification, product age, date of slaughter, sex, and other label claims, if the processing/export establishment has clearly documented procedures outlining its traceability systems as reflected in its Approved Arrangement. It is only when all these traceability elements align that the DAFF, post its verification, can issue export certificates confidently.

An export establishment will need to demonstrate and document how its traceability system operates relevant to the various system requirements, AS4696, and importing country requirements before its arrangement can be approved by the Department and pre its export registration.

Contents

1. Objective of traceability and product identification through processing

1.1 Requirement for identification and traceability of meat

1.1.1 International

Traceability of meat, from the animal on farm through to product being sold to consumers is a tool necessary for the efficient control of animal diseases, managing food safety, and ensuring fair trade. Identification is a prerequisite to traceability.

The World Organisation for Animal Health (WOAH) has developed principles on identification and traceability of animals[265] which are reflected in Australia's own systems (chapter 3, Identification of animals).

Codex Alimentarius Commission has developed principles for traceability of food products[266] recognising its role in contributing to consumer protection against foodborne hazards, deceptive marketing practices, and the facilitation of trade through accurate product description.

Codex defines traceability as: the ability to follow the movement of a food through specified stage(s) of production, processing, and distribution. In Codex, and generally accepted, traceability tools should be able to identify where food came from (one step back) and where the food is going (one step forward).

Sometimes a distinction is made between tracking (forward through the chain) and tracing (backwards through the chain), but this distinction is not found frequently, probably as it is liable to cause confusion.

There is much discussion about the need for more sophisticated systems for traceability, particularly the need to traceback to the start of a supply chain quickly to be able to investigate and curtail outbreaks of foodborne disease. While these systems are being developed commercially, there is not yet regulatory demand, or demand from large commercial interests.

1.1.2 National

The *Australian Standard for hygienic production and transportation of meat and meat products for human consumption*, AS4696 has a general requirement:

> 16.1 Meat businesses have a documented system that provides for the accurate identification of, and the ability to trace and recall, meat and meat products produced by the business.

The requirement is then further specified to apply to

- The source of animals (16.3)
- The species and date of slaughter (16.2)
- Operational details of the meat business, including size of batch (16.4)
- The consignee of the meat (16.4)

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[265] World Organisation for Animal Health. 2007.General Principles on identification and traceability of live animals. Terrestrial Animal Health Code. Chapter 4.2 Terrestrial Code Online Access - WOAH - World Organisation for Animal Health

[266] Codex Alimentarius Commission. 2006. Principles for traceability/product tracing as a tool within a food inspection and certification system. CAC/GL 60-2007. PRINCIPLES FOR TRACEABILITY/PRODUCT TRACING AS A TOOL WITHIN A FOOD INSPECTION AND CERTIFICATION SYSTEM (fao.org)

The responsibility is clearly with the occupant of the meat processing establishment (meat business), and oversight and certification by the Department of Agriculture, Fisheries and Forestry (DAFF). Through an agreed arrangement, AUS-MEAT (on behalf of the department) manages the day-to-day operational responsibilities for trade description at eligible AUS-MEAT accredited registered establishments. To meet the requirements of export markets (countries and customers) description of the animals and products extends beyond the requirements of the Australian Meat Standard.

1.2 Department role[267,268]

DAFF:

a. Maintains regulatory oversight for trade descriptions and trade description language
b. Ensures meat and meat products have a correctly applied trade description
c. Ensures trade description is accurate
d. Assumes responsibility for description of the following:
    - Species
        - Bovine
        - Ovine
        - Caprine
    - Basic Categories (meat)
        - Rosé Veal, Veal, bull, beef[269]
        - Lamb, mutton, ram
        - goat
    - Basic Categories (offal)
        - Bovine
        - Ovine
        - Caprine
    - Other compulsory health/hygiene/trade description aspects
        - Date of Packaging
        - Net weight
        - Identity of batch
        - Customer Country Markings
        - AI [Australia Inspected] Stamp (security and monitoring of application)
        - Refrigeration Statement (e.g., 'Keep Frozen')
        - Bilingual Trade Description Approvals
        - Trade Description Alteration/Interference
        - Trade Description Other than in the Rules
        - Ingredients Statement
        - Permanently Affixed Prescribed Tag Approvals
        - Identification of Product 'For Further Processing Before Export'
        - Trade Description Requirements for Meat Fractions, mechanically separated meat (MSM), Pharmaceutical Products, Animal Food.

[267] DAFF. 2016. Reminder of AUS-MEAT's responsibilities for accuracy of trade descriptions as they relate to export meat. Meat Notice 2016/2. Meat Notice 2016-02 - Reminder of AUS-MEAT's responsibilities for accuracy of trade descriptions as they relate to export meat - DAFF (agriculture.gov.au)

[268] DAFF. (2023) Export Meat Operational Guidelines 3.12 Trade descriptions. https://www.agriculture.gov.au/biosecurity-trade/export/controlled-goods/meat/elmer-3/guideline-trade-descriptions

[269] Beef – female OR castrate or entire male bovine that show no evidence of secondary sexual characteristics. Dentition range is 0-8 permanent incisor teeth.

Some aspects relate to the processing establishment, the order (destination country), and others relate to the animal, its source, and characteristics.

1.3 AUS-MEAT role [270,271]

The role of verifying truth-in-labelling rests with DAFF. An agreement between the Department and AUS-MEAT outlines that this obligation can be met through a verification process whereby AUS-MEAT takes day-to-day operational responsibility, including for corrective action, for all trade descriptions other than basic descriptions that importing country authorities may require the Department, as the government regulating authority, to oversight. Verification of the trade description system and relevant functions by the Department and its approved third-party auditors ensures the legislative requirements for trade descriptions are met.

AUS-MEAT Limited is a not-for-profit industry owned company set up in 1998 operating under an arrangement with DAFF. AUS-MEAT has responsibility for the operation of the Australian Meat Industry Classification System, a national meat trading language for both domestic and export meat. This language, which is based on the objective trade descriptions for export meat.

AUS-MEAT is responsible for recommending approval of the parts of an establishment's Approved Arrangement that relate to trade description, verifying compliance with the arrangement and Export Control (meat and meat products) Rules, ensuring corrective action is taken in the event of a particular management's failure to adhere to requirements, and providing reports back to the Department. The Department verifies the activities of AUS-MEAT are in compliance with the agreement established between both parties.

AUS-MEAT (through arrangements with the Department):

a. Fulfils requirements of agreed delegated responsibility for trade descriptions and trade description language.
b. Assumes responsibility for trade description of the following:
   - Alternative Categories (meat)
     - Bovine: various descriptions including steer, cow, ox, yearling, young, prime
     - Ovine: various descriptions including young lamb, hogget, ewe
     - Caprine: various descriptions including kid, wether, buck
   - Alternative Categories (offal)
     - Bovine: veal/calf, bull
     - Ovine: lamb, ram, mutton
   - Compulsory commercial/marketing aspects
     - 'Product of Australia'
     - Establishment Number
     - Name and Address
     - Bone-in/Boneless
     - Chiller Assessment (Fat/Meat Exclusion Colour)
     - Location of Trade Description on Carton/Bag
     - Size of Print
     - Logos
     - Contrast and Obscured Printing
     - Tolerances

[270] DAFF. 2016. Reminder of AUS-MEAT's responsibilities for accuracy of trade descriptions as they relate to export meat. Meat Notice 2016/2. Meat Notice 2016-02 - Reminder of AUS-MEAT's responsibilities for accuracy of trade descriptions as they relate to export meat - DAFF (agriculture.gov.au)
[271] AUS-MEAT. 2021. AUS-MEAT Accreditation – abattoirs / boning rooms. Accreditation_-_Meat_Processors.pdf (ausmeat.com.au)

    - Net Weight (enforced by National Measurement Institute)
- Customer/additional commercial/marketing aspects
    - Fat Depth Range
    - Weight Range
    - Fat Class
    - Weight Class
    - CL Content
    - Cut/Item Description (including Common Code Cipher)
    - Number of Cuts or Portions
    - Type of Packaging
    - Original Untrimmed Fat Class
    - Original Weight Class
    - Weight Related Fat Class
    - Expiry Date/Shelf Life
    - Temperature Statement in Conjunction with Refrigeration Statement e.g., 'Store at 0°C'
    - Animal raising claims[272]
- Supplementary specifications/Minimum Standards
    - Grain Fed Beef, lamb/hogget
    - Accelerated Conditioning
    - Skin-on (Goats)

Some elements of trade description relate to the processing establishment, the order (destination country), and others relate to the animal, its source, and characteristics. AUS-MEAT maintains and publishes the Australian Meat Industry Classification System[273] which is overseen by the Australian Meat Industry Language and Standards Committee (AMILSC) which includes departmental representation.

1.4 Processor role

The processor's role is to accurately assess the characteristics that are compulsory or are voluntarily applied to an animal, carcase, or piece of meat, and to accurately associate that information with the product at the time of packing.

2. Identification of product characteristics

2.1 Product characteristics

AUS-MEAT define the Language (Australian Meat Industry Classification System) and produce a guide for producers of beef[274] and sheepmeat[275] that explains the meaning of terms in the language.

[272] DAFF. (2023) Export Meat Operational Guidelines 3.12 Trade descriptions. https://www.agriculture.gov.au/biosecurity-trade/export/controlled-goods/meat/elmer-3/guideline-trade-descriptions

[273] AUS-MEAT. Australian Meat Industry Classification System. Australian Meat Industry Classification System – AUS-MEAT Limited (ausmeat.com.au)

[274] AUS-MEAT. 2021. Handbook of Australian Beef Processing. The AUS-MEAT Language. Producer_HAP_Beef_Small.pdf (ausmeat.com.au)

[275] AUS-MEAT. 2021. Handbook of Australian Sheepmeat Processing. The AUS-MEAT Language. Producer_HAP_Sheepmeat_Small.pdf (ausmeat.com.au)

More recently *National Bovine Livestock Language Guidelines*[276] have been agreed that deal with description of the live animal (age, sex, breed, dentition, fat, muscle score etc.).

Many elements of the AUS-MEAT language are accepted internationally through the work of the United Nations Economic Commission for Europe (UNECE) Working Party of Agricultural Quality Standards (WP.7)[277] Specialized Section on Standardization of Meat (GE.11) which has developed numerous standards for description of carcases and cuts.[278]

2.2 Product label

Carton labels provide detailed data about the product that has been packed in the carton:

1. GENERIC: Bone-in or boneless statement as well as species identification.
2. CARCASE IDENTIFICATION: Category cipher which identifies carcase age and sex.
3. PRODUCT NAME: Primal cut description as shown in the Handbook of Australian Meat.
4. GRAINFED DESCRIPTION: Identifies the product as meeting Grainfed requirements.
5. MSA DESCRIPTION: Identifies the product as MSA graded with eating quality outcomes. MSA (Meat Standards Australia) is a voluntary eating quality designation[279]
6. NET WEIGHT: The meat content of the carton minus the carton weight.
7. AI STAMP: Australian Federal Government Inspected stamp.
8. REFRIGERATION STATEMENT: Indicates the product has been held in controlled chilling.
9. COMPANY DETAILS: Indicates the name of the packer of the product.

3. Tracing animals through processing to cartons

3.1 Traceability infrastructure

There are several sources of information and standards that contribute to the conformance infrastructure concerning meat traceability. These guidance documents are not necessarily used by the industry but are models for good practice and are likely to become more significant in future.

GS1[280] is a not-for-profit organisation collaborating with stakeholder communities to develop and implement a robust system of standards which enable the unique identification, accurate capture, and automatic sharing of authentic information about products, locations, and events. They are best known for commercial product barcodes. Almost all Australian export processors use the GS1 barcode system for carton identification.

The Implementing Food Traceability program at Deakin University's Food Traceability Lab[281] has published a guide to implementing food traceability, including a red meat specific guide.

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[276] Meat & Livestock Australia. 2022. National Bovine Livestock Language Guidelines. national-livestock-guidelines-2022-web_final_291122.pdf (ausmeat.com.au)

[277] United Nations Economic Commission for Europe Working Party of Agricultural Quality Standards (WP.7) Specialized Section on Standardization of Meat (GE.11) Working Party on Agricultural Quality Standards (WP.7) | UNECE

[278] United Nations Economic Commission for Europe Working Party of Agricultural Quality Standards (WP.7) Specialized Section of Standardization of Meat (GE.11) UNECE Standards for Meat | UNECE

[279] Meat & Livestock Australia. Marketing beef & lamb. Meat Standards Australia. Meat Standards Australia | Meat & Livestock Australia (mla.com.au)

[280] GS1 Australia. Home - GS1 Australia

[281] Deakin University. The National Implementing Food Traceability Program. Implementing Food Traceability Program (deakin.edu.au)

The Red Meat Supply Chain Committee[282] , which makes suggestions to the Australian Meat Industry Language and Standards Committee, has also produced a number of guidance documents.

3.2 Admission of animals to slaughter through to carcase

Animals arriving at slaughter are accompanied by one, or more, documents (chapter 3, 3.3) such as the National Vendor Declaration. An example of possible production stages and product identification:[283]

	Livestock Receival	Lairage	Slaughter and Dressing	Chilled carcase	Offal preparation
identification	NLIS tag	NLIS tag	NLIS tag Body number Carcase ticket	Body number Carcase ticket	Carton label
records	NVD Post sale summary Delivery records	NLIS tag scan reports Daily kill agenda	NLIS tag scan reports Kill production summary	Chiller inventory	Production summary

Towards the end of the slaughter process, each carcase is issued a carcase ticket with a unique serialised identifier. This identifier allows the forward and backward traceability of the carcase through the value chain, being correlated to the live animal National Livestock Identification System (NLIS) tag number and remaining with the carcase until it is boned into cartoned product and receives a serialised carton label.

The carcase ticket and the information it contains are illustrated in the AUS-MEAT Language document.[284]

If animals have particular claims associated with them, there is a need to effectively segregate these animals and products from other animals.[285]

3.3 Carcase to packed product

Traceability for cartoned and palletised product is limited to the carcases that have entered the boning room for the production run of cartons that are created. For example, 200 carcases (400 sides) individually identified with unique carcase tickets enter the boning room for a specific boning run. These carcase tickets are linked to the specific boning run. From these carcases, 3,200 cartons of primal cuts and 1,000 cartons of trim and other highly mixed products are created. While all

[282] AUS-MEAT. Red Meat Supply Chain Committee Red Meat Supply Chain Committee (rmscc.org)
[283] DAFF. 2013. Product Integrity and Certification requirements. Meat Notice 2013/02. mn2013-02.pdf (agriculture.gov.au)
[284] AUS-MEAT. 2021. Handbook of Australian Beef Processing. The AUS-MEAT Language. Producer_HAP_Beef_Small.pdf (ausmeat.com.au)
[285] DAFF. (2023) Export Meat Operational Guidelines 3.12 Trade descriptions. https://www.agriculture.gov.au/biosecurity-trade/export/controlled-goods/meat/elmer-3/guideline-trade-descriptions

cartons are identified with unique serialised carton labels, including a GS1 meat industry barcode, linked to the boning run (and may be packaged into pallets containing unique serialised pallet labels including a GS1 SSCC barcode), it is not readily possible to identify which carcases are in which cartons as the cartons will contain meat products from different carcases. If the carcases were sourced from several different properties, the resulting carton can only be traced to a number of possible carcases and source properties. The precision of traceability is defined by the Approved Arrangement, which could be less than an hour to a whole day; the processor accepts the risk of a larger recall should the traceability be less precise.

An example of possible production stages and product identification[286]:

	Chilled carcase	Boning	Cold storage	Load out
identification	Body number Carcase ticket	Carcase ticket Carton labels	Carton labels	Carton labels
records	Chiller inventory	Product inventory Carcase input Production summary	Product inventory MTCs	Product inventory MTC Load out report Carton scan report

The carton label and the information it contains are illustrated in the AUS-MEAT Language document.

3.4 Transfer of meat between establishments[287,288]

Export legislation (Export Control (Meat and Meat Products) Rules, (5-38)), requires the transfer of meat and meat product between establishments to be accompanied by a Meat Transfer Certificate (MTC), which can be either manual or electronic.

The message carries the information required:

(a) a full description of the meat or meat products;
(b) information about storage conditions (that is, whether the meat or meat products are chilled, frozen or shelf-stable);
(c) the name, address and registration number of the transferring establishment;
(d) the date or dates when operations to prepare the meat or meat products (other than storing, handling or loading) were last carried out before the transfer;
(e) the quantity of meat or meat products in the consignment;
(f) if the meat or meat products are in packages—the number and kind of packages;
(g) the identification of the conveyance used to transport the meat or meat products;
(h) a description of any means of security applied to the meat or meat products;

[286] DAFF. 2013. Product Integrity and Certification requirements. Meat Notice 2013/02. mn2013-02.pdf (agriculture.gov.au)
[287] DAFF. 2013. Product Integrity and Certification requirements. Meat Notice 2013/02 Meat Notice 13-02 - Product Integrity and Certification Requirements - DAFF (agriculture.gov.au)
[288] DAFF. 2021. Electronic Meat Transfer Certificates (eMTC) Electronic Meat Transfer Certificates (eMTC) (agriculture.gov.au)

(i) the name, address and registration number of the receiving establishment;
(j) if operations to prepare the meat or meat products were carried out to meet importing country requirements of one or more countries—the name of each country;
(k) a declaration stating that, at the date the declaration is made: (i) the prescribed export conditions, and any other conditions that apply in relation to the meat or meat products under the Act, have been complied with; and (ii) importing country requirements relating to the meat or meat products are met;
(l) a declaration stating that all of the information given in relation to the consignment is true and complete.

4. Verification and auditing

4.1 By AUS-MEAT

AUS-MEAT conducts audits and provides summary reports of accreditation audits and language issues to the AMILSC. The department is a member of the AMILSC.

4.2 By the Department

The department's Certification and Integrity Unit (CIU) audits AUS-MEAT on an annual basis to assess compliance with the agreed arrangements for managing trade description assessment of goods inspection requirements.

The department is responsible for species testing at all meat commodity registered establishments.

12. Microbiological standards and criteria

Summary

Microbiological criteria, if properly constructed, allow a food to be tested at a point in the supply chain, and the criteria will be one method to determine whether the food is safe and suitable for human consumption. Australia utilises these criteria and has had deep involvement in Codex Alimentarius Commission, various ad hoc technical groups, and the International Commission on Microbiological Criteria for Foods.

When microbiological criteria were first proposed in the 1960s, there was little information available in international trade, and frequently product arriving in a country needed to be judged for safety based on microbiological data alone. A system for setting criteria was developed taking into account the likely use of the food after the point of testing, and whether an increase in risk was likely. Since the 1960s there have been great increases in the volume and availability of data, the understanding of microbiological hazards, and development of paradigms for the quantitative assessment of risk.

Australia and the international scientific community recognise that the application of controls through the chain (Good Hygienic Practice (GHP), Hazard Analysis and Critical Control Points (HACCP)) will ensure optimal food safety outcomes, and these have been developed and applied in Australia, and accepted by our trading partners. Microbiological testing and the application of microbiological criteria form a key part of the control systems and monitoring applied in Australia. Monitoring of indicator bacterial levels (e.g., aerobic plate count or equivalent, *Escherichia coli*) at the time of production are the best indicators of quality and safety. There is little to be gained by random testing of product at the point-of-entry into an importing country.

Since around 2010, microbiological criteria should have been set based on WTO agreements, an understanding of risk, and how the food supply chain could modify that risk through to the time of consumption. Australia also recognises that for many countries without strong through chain systems and standards that microbiological criteria provide a ready tool to help in protecting consumers, particularly in some developing countries. Unfortunately, many criteria exist that have not been the product of the application of internationally accepted principles.

Contents

1. Microbiological criteria

Microbiological criteria are at the heart of testing meat and meat products for acceptance by import authorities (both in Australia, and other countries) and more generally, in trade. Criteria are easily set and expressed using an arcane code and may cause considerable disruption and cost to international trade without being understood, adequately justified, or of value to the importing country. Sometimes they are seen as evidence of safety, though the adage 'you cannot inspect quality into a product' remains true. The International Commission on Microbiological Specifications for Foods (ICMSF) and the Codex Alimentarius Commission (CAC) have been the defining bodies for microbiological criteria.

A brief explanation of microbiological testing and the expression of the results of microbiological tests is provided in Chapter 9 Process Hygiene 6. Microbiological testing – primer on sampling, testing. and understanding results.

The ICMSF was established in 1962 as concerns about foodborne disease greatly increased microbiological testing of foods. Increased testing, in turn, created widespread practical and regulatory problems in the international food trade (Roberts, 1997). ICMSF was founded to assemble, correlate, and evaluate evidence about the microbiological safety and quality of foods; to consider whether microbiological criteria would improve and ensure the microbiologic safety of particular foods; to propose, where appropriate, such criteria; and to recommend methods of sampling and examination. The long-term objective of enhancing the microbiological safety of foods in international commerce was addressed initially in books recommending uniform analytical methods, and sound sampling plans and criteria. At an early stage, the Commission concluded that no food sampling plan could ensure the absence of a pathogen. Testing foods at ports of entry (PoE), or end-product testing elsewhere in the food chain, cannot guarantee food safety.

The first ICMSF publication to deal with microbiological criteria, *Microorganisms in Foods 2: Sampling for Microbiological Analysis: Principles and Specific Applications* (1st ed. 1974, 2nd ed. 1986) was published at a time when the control of food safety was largely by inspection and compliance with hygiene regulations, together with end product testing. *Microorganisms in Foods 2* put such testing on a sounder statistical basis through sampling plans, which remain useful at PoE when there is no information on the conditions under which a food has been produced or processed. The successor, *Microorganisms in Foods 7: The Role of Microbiological Testing in Systems Managing Food Safety* (1st ed. 2001, 2nd ed. 2018) illustrates how systems such as Hazard Analysis and Critical Control Points (HACCP) and Good Hygienic Practices (GHP) provide greater assurance of safety than microbiological testing but also identifies circumstances where microbiological testing still plays a useful role in systems to manage food safety (International Commission on Microbiological Specifications for Foods, 2018).

The CAC has brought the concepts of microbiological criteria into international texts; there is a strong association of ICMSF in the work of the CAC Committee on Food Hygiene and the work of the FAO/WHO Joint Expert Meetings on Microbiological Risk Assessment (JEMRA).

1.1 Brief definition

A microbiological criterion is a risk management metric which indicates the acceptability of a food, or the performance of either a process or a food safety control system following the outcome of sampling and testing for microorganisms at a specified point of the food chain.[289]

[289] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

Microbiological criteria are an example of a lot-by-lot acceptance based on an attribute sampling plan (the attribute being ‘pass’ or ‘fail’). The statistical basis and implications have been explored in detail by an FAO/WHO Joint Meeting on Microbiological Risk Assessment.[290]

Criteria may be used as.

- Standards: a requirement that is in a law, or referenced by a law. A standard must be met.
- Guideline: a suggestion, by some government or non-government body, of the characteristics that should be achieved
- Specification: a commercial requirement that is agreed between the supplier and a customer (International Commission on Microbiological Specifications for Foods, 2018)

1.2 Sampling plans

Microbiological criteria and sampling plans were developed for many foods in international trade (ICMSF *Microorganisms in Foods 2*) based on a broad concept of the degree of hazard, and comprising two components:

- Severity of adverse effects, ranging from no effect, to serious, life-threatening illness
- Whether subsequent processes would increase or decrease the level of hazard

Five levels of adverse effects and three levels of impact of subsequent processing were defined, creating a matrix of 15 ‘cases’, from case 1 for bacteria causing only reduced shelf life or spoilage under conditions that would be expected to reduce the risk, to case 15 for severe hazards under conditions that would be expected to increase the risk with increasingly stringent sampling plans and criteria (International Commission on Microbiological Specifications for Foods, 2011).

There are two types of attribute sampling plans: 3 class and 2 class plans. Three-class attributes plans were devised for situations where the quality of the product can be divided into three attribute classes, depending upon the concentration of microorganisms within the sample units: acceptable, marginal, and unacceptable. Three class plans usually are applied to microorganisms that are indicators or pose moderate hazard. A two-class plan is usually applied to more severe hazards and tests for the presence (detected, positive result) or absence (not detected, negative result) of a microorganism.

The acceptable concentration of microorganisms is based on the degree of hazard posed by the microorganism. For more serious hazards (cases 10-15), 2 class plans are usually prescribed often with m = 0/25g (not detected in 25g) (but see the following sections for examples). n varies between 5 and 60, depending upon the case.

[290] FAO/WHO [Food and Agriculture Organization of the United Nations/World Health Organization]. (2016). *Statistical Aspects of Microbiological Criteria Related to Foods. A Risk Managers Guide.* (Microbiological Risk Assessment Series, no. 24. Statistical aspects of microbiological criteria related to foods: a risk managers guide (who.int)

The sampling plan is described using several parameters[291,292]

parameter	2 class plan	3 class plan
n (sample size)	the number of sample units	the number of sample units
c (acceptance number)	the maximum number of unacceptable analytical units	the maximum number of marginally acceptable analytical units
m (microbiological limit)	differentiates acceptable from unacceptable microbial concentrations	differentiates acceptable from marginally acceptable microbial concentrations
M (microbiological limit)		differentiates marginally acceptable from unacceptable microbial concentrations

1.3 Role in public health

At an early stage, the ICMSF concluded that no food sampling plan could ensure the absence of a pathogen. Testing foods at PoE, or end-product testing elsewhere in the food chain, cannot guarantee food safety (Roberts, 1997).

The microbiological safety of foods is managed by the effective implementation of control measures that have been validated, where appropriate, throughout the food chain to minimise contamination and improve food safety. This preventative approach offers more advantages than sole reliance on microbiological testing through acceptance sampling of individual lots of the final product to be placed on the market. However, the establishment of microbiological criteria may be appropriate for verifying that food safety control systems are implemented correctly.[293]

In some cases, microbiological testing of the end product may be used if no prior history of the product is available (e.g., at PoE). Consistent with previous ICMSF considerations (*Microorganisms in Foods 7*), testing should be required only when the following two conditions exist:

> 1. The product group has been implicated in foodborne disease or may have an inadequate shelf life or other microbiological issues if effective controls are not applied.
> 2. The application of testing will reduce the health risk or quality issues associated with a food or will effectively assess adherence to microbiological control measure or process controls. (International Commission on Microbiological Specifications for Foods, 2011, p. 63)

[291] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

[292] FAO/WHO [Food and Agriculture Organization of the United Nations/World Health Organization]. (2016). *Statistical Aspects of Microbiological Criteria Related to Foods. A Risk Managers Guide.* (Microbiological Risk Assessment Series, no. 24. Statistical aspects of microbiological criteria related to foods: a risk managers guide (who.int)

[293] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

1.4 Microbiological criteria for lot acceptance

According to the Codex Alimentarius Guidelines on Microbiological Criteria[294], a microbiological criterion consists of the following components:

- The purpose of the microbiological criterion;
- The food, process or food safety control system to which the microbiological criterion applies;
- The specified point in the food chain where the microbiological criterion applies;
- The microorganism(s) and the reason for its selection;
- The microbiological limits (*m, M;* …) or other limits (e.g., a level of risk);
- A sampling plan defining the number of sample units to be taken (*n),* the size of the analytical unit and where appropriate, the acceptance number (*c);*
- Depending on its purpose, an indication of the statistical performance of the sampling plan; and
- Analytical methods and their performance parameters.

An example:[295]:

Codex microbiological criteria for ready-to-eat (RTE) foods in which growth of *L. monocytogenes* will not occur:
For RTE foods in which the growth of *L. monocytogenes* will not occur, various factors such as the pH and a_w, were considered in developing the rationale for the policy. Growth limits for *L. monocytogenes* were stated as being a pH value < 4.4, an [water activity] a_w value of < 0.92, or a combination of factors (pH, a_w), e.g., the combination of a pH < 5.0 and an a_w < 0.94. In addition, frozen products fall into the category of foods that do not support growth of the organism.

Point of Application	Microorganism	n	c	m	Class Plan
Ready-to-eat foods from the end of manufacture or port of entry (for imported products), to the point of sale	*Listeria monocytogenes*	5[a]	0	100 cfu/g[b]	2[c]

Where n=number of samples that must conform to the criterion;
c=the maximum allowable number of defective sample units in a 2-class plan;
m=a microbiological limit which, in a 2-class plan separates acceptable lots from unacceptable lots.
[a] National government(s) should provide or support the provision of guidance on how samples should be collected and handled, and the degree to which compositing of samples can be employed.
[b] This criterion is based on the use of the ISO 11290-2 method. Other methods that provide equivalent sensitivity, reproducibility, and reliability can be employed if they have been appropriately validated, e.g., based on ISO 16140 (ISO, 2017)
[c] Assuming a log- normal distribution, this sampling plan would provide 95% confidence that a lot of food containing a geometric mean concentration of 93.3 cfu/g and an analytical standard deviation of 0.25 log cfu/g would be detected and rejected if any of the five samples exceeding 100 cfu/g *L. monocytogenes*. Such a lot may consist of 55% of the samples being below 100 cfu/g and up to 45% of the samples being above 100 cfu/g, whereas 0.002 % of the samples from this lot could be above 1000 cfu/g.
The typical actions to be taken where there is a failure to meet the above criterion would be to (1) prevent the affected lot from being released for human consumption, (2) recall the product if it has been released for human consumption, or (3) determine and correct the root cause of the failure.

[294] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)
[295] Codex Alimentarius Commission. (2007). Guidelines on the Application of General Principles of Food Hygiene to the Control of *Listeria monocytogenes* in Foods. In (adopted 2009 ed., Vol. CAC/GL 61-2007). Rome: FAO. untitled (fao.org)

1.5 Microbiological criteria for process monitoring

Codex clearly defined how a 'moving window' can be used for monitoring of a process.[296]:

> In a moving window approach a sufficient number of sample units (n) is collected for a defined period of time (the "window"). The results of the latest n sample units are compared with the microbiological limit(s) (m, M) using the acceptance number c. Each time a new result from the sampling period is available, it is added to the window while the oldest result is removed, creating the "moving window". This approach can also be applied to a set of results, e.g., results obtained during a week. The window, always consisting of n results, moves one result or set of results forward in time. In determining the size of the moving window consideration should be given to the combination of the production frequency and sample frequency necessary to obtain a sufficient number of results that enables appropriate verification of performance of a process or a food safety control system.
>
> The moving window approach is a practical and cost beneficial way of checking continuous microbiological performance of a process or a food safety control system. As in the traditional point-in-time approach commonly used in connection with microbiological criteria, the moving window determines the acceptability of the performance so that appropriate interventions can be made in case of unacceptable shifts in control.

In Australia, moving window criteria for carcase microbiological testing were developed (Vanderlinde, Jenson, & Sumner, 2005) and the approach has continued to be used in Product Hygiene Indicators (PHI) Program. The approach was to set performance criteria which prompt individual plants to investigate, in the event that the criteria cannot be met, and thus improve the overall performance of the country's system. Accordingly, a 95% level was selected because it was considered that this level would be likely to identify establishments with realisable opportunities for improvement and would offer an incentive for them to improve performance. The criteria were set based on data collected over an 18-month period in 2000–2001 and does not reflect the current performance.

Performance criteria set based on the 2000-2001 data (Vanderlinde et al., 2005), and modified over time, are set in the National Carcase Microbiology Monitoring Program[297] for *E. coli* counts (per cm^2) on species processed at export establishments and sampled under defined conditions. These criteria may be modified from time to time, based on available data, risk management objectives, and equivalence with other systems.

2. Setting microbiological criteria

2.1 Codex Alimentarius Commission (CAC)

The CAC[298] has agreed principles and guidelines for setting microbiological criteria.

The CAC is clear about the role of criteria, compared to other food safety approaches (emphasis added):

> 1.5 The **microbiological safety of foods is managed by the effective implementation of control measures that have been validated, where appropriate, throughout the food chain to minimise**

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[296] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997).Para 4.9 PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

[297] DAFF. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (agriculture.gov.au)

[298] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

contamination and improve food safety. **This preventative approach offers more advantages than sole reliance on microbiological testing** through acceptance sampling of individual lots of the final product to be placed on the market. However, the establishment of **microbiological criteria may be appropriate for verifying that food safety control systems are implemented correctly.**

1.6. **Codex Alimentarius has a role in recommending microbiological criteria at the international level**. National governments may choose to adopt Codex microbiological criteria into their national systems or use them as a starting point for addressing their intended public health goals. **National governments also may establish and apply their own microbiological criteria.** Food business operators may establish and apply microbiological criteria within the context of their food safety control systems.

The principles set out by CAC set a high bar for setting criteria:

- A microbiological criterion should be appropriate to protect the health of the consumer and where appropriate, also ensure fair practices in food trade.
- A microbiological criterion should be practical and feasible and established only when necessary.
- The purpose of establishing and applying a microbiological criterion should be clearly articulated.
- The establishment of microbiological criteria should be based on scientific information and analysis and follow a structured and transparent approach.
- Microbiological criteria should be established based on knowledge of the microorganisms and their occurrence and behaviour along the food chain.
- The intended as well as the actual use of the final product by consumers needs to be considered when setting a microbiological criterion.
- The required stringency of a microbiological criterion used should be appropriate to its intended purpose.
- Periodic reviews of microbiological criteria should be conducted, as appropriate, in order to ensure that microbiological criteria continue to be relevant to the stated purpose under current conditions and practices.

The Codex Alimentarius *Code of Practice for Hygienic Meat*[299] does not deal with microbiological criteria for the purpose of judging the acceptability of a product (Annex II 1.4) but does provide principles for microbiological performance objectives[300] or performance criteria[301] for verification of process control. Performance objectives and performance criteria have not become widely used largely because the concept of Food Safety Objective is understandable and appealing as a public health metric, but extremely difficult to define in practise.

2.2 International Commission on Microbiological Specifications for Foods (ICMSF)

The International Commission on Microbiological Specifications for Foods (2011) makes the following recommendations for useful testing for fresh (chilled and frozen) meat products (excluding comminuted meats):

[299] Codex Alimentarius Commission. (2005). *Code of hygienic practice for meat* (CAC/RCP 58-2005). https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXC%2B58-2005%252FCXP_058e.pdf

[300] The maximum frequency and/or concentration of a hazard in a food at a specified step in the food chain before the time of consumption that provides or contributes to a Food Safety Objective or Acceptable Level Of Protection, as applicable (Codex Procedural Manual)

[301] The effect in frequency and/or concentration of a hazard in a food that must be achieved by the application of one or more control measures to provide or contribute to a Performance Objective or a Food Safety Objective (Codex Procedural Manual)

<table>
<tr><th>Stage</th><th>Relative importance</th><th>Useful testing</th></tr>
<tr><td>In-process</td><td>Medium</td><td>Swab, sponge or tissue samples from carcasses before or after entering the chiller, or tissue samples from cut portions can be useful to assess hygiene process control and conditions that affect microbial levels of subsequent product (ISO 17604).
Typical levels encountered in operations that apply multiple hurdles during slaughter are an aerobic colony count of$<10^3$ CFU/cm^2 carcass surface, or $<10^4$ CFU/g of tissue from cut meat when plates are incubated at 35°C. These counts can vary considerably depending on the temperature of incubation and the processing methods used in the region. Because of this, regional or internal company standards will vary and specific recommendations are not possible for this category of products.</td></tr>
<tr><td>Processing environment</td><td>Medium</td><td>Sample equipment surfaces before start-up to verify efficacy of cleaning and disinfecting.
Analysis for aerobic colony counts is commonly used, but other tests, coliforms, Enterobacteriaceae, occasionally staphylococci may provide useful information. A typical level encountered on thoroughly cleaned, disinfected stainless tells is an aerobic colony count of <500 CFU/cm^2.</td></tr>
<tr><td>Shelf life</td><td>Low</td><td>Routine shelf life testing of refrigerated raw meat is not recommended. Shelf life testing may be useful to validate code dates of new retail products or when new packaging systems are implemented.
<table>
<tr><th>Product</th><th>Microorganism</th><th>Analytical method</th><th>case</th><th colspan="4">Sampling plan and limits</th></tr>
<tr><th></th><th></th><th></th><th></th><th>n</th><th>c</th><th>m</th><th>M</th></tr>
<tr><td>Raw, noncomminuted meat</td><td>E. coli</td><td>ISO 16649-2</td><td>4</td><td>5</td><td>3</td><td>10</td><td>10^2</td></tr>
</table></td></tr>
<tr><td>End product</td><td>Medium</td><td>Test for indicators or utility organisms for on-going process control and trend analysis of freshly packaged product using internally developed guidelines. Level developed for processing do not apply during distribution or at retail.
Typical levels encountered in operations that apply multiple hurdles during slaughter are an aerobic colony count (incubated at 35°C) of $<10^4$ CFU/g and generic E. coli of <10 CFU/g. These counts can vary considerably depending on the temperature of incubation and the processing methods used or allowed in the region. Because of this, regional or internal company standards will vary and specific recommendations are not possible for this category of products.</td></tr>
<tr><td></td><td>Medium</td><td>Routine lot acceptance sample is not recommended for salmonellae on raw meat products. In countries or regions that have established performance criteria for salmonellae use the required sampling plan and tests. Test in regions where ground beef is a continuing source of E. coli O157:H7 illness.
<table>
<tr><th>Product</th><th>Microorganism</th><th>Analytical method</th><th>case</th><th colspan="4">Sampling plan and limits</th></tr>
<tr><th></th><th></th><th></th><th></th><th>n</th><th>c</th><th>m</th><th>M</th></tr>
<tr><td>Beef trimmings used in ground beef</td><td>E. coli O157:H7</td><td>ISO 16654</td><td>14</td><td>30</td><td>0</td><td>0</td><td>-</td></tr>
</table></td></tr>
</table>

The testing required by the Department of Agriculture, Fisheries and Forestry (DAFF) for export meat (see 3.1 and 3.2 below) addresses the testing considered to be of medium importance by the ICMSF. Testing of low importance is a commercial arrangement conducted by most exporters.

3. Australian criteria

Domestic Australian Food Regulations (Australia New Zealand Food Standards Code, Standard 1.6.1 – Microbiological limits in food)[302] do not have any microbiological criteria for raw meat products (but there are criteria for ready-to-eat meat products).

DAFF sets criteria for export meat addressing the testing considered to be of medium importance by the ICMSF (2.2 above) covering both process and end-product monitoring.

3.1 Process

There are two components of process monitoring:

1. Monitoring hygiene of surfaces
2. Monitoring of carcase hygiene

Monitoring of the hygiene of work surfaces and personal equipment (knives, gloves etc.) is performed according to Meat Standards Committee (now the Australian Meat Regulators Group) Guidelines: *Microbiological testing for process monitoring in the meat industry*[303] as specified in DAFF documents.[304] Pre-operational personal hygiene microbiology results and pre-operational contact surface microbiology results are entered into Export Meat Data Collection (MEDC) and contribute to a Product Hygiene Indicator (PHI).[305] These data provide an assessment of the effectiveness of cleaning. The criterion for both sample types is that acceptable results are ≤ 5 CFU/cm^2 with higher counts resulting in demerit points being applied. The ICMSF notes that a typical level encountered on thoroughly cleaned, disinfected stainless tells is an aerobic colony count of <500 CFU/cm^2.

As noted above (1.5) process monitoring criteria exist in Australian export establishments for *E. coli*, *Salmonella*, and Aerobic Plate Count in the National Carcase Microbiology Monitoring Program.[306] The purpose of these criteria is to ensure that process hygiene is effective. The ICMSF suggests that typical levels encountered in operations that apply multiple hurdles during slaughter are an aerobic colony count of $<10^3$ CFU/cm^2 carcass surface. The criteria applied by DAFF[307] for Aerobic Plate Count are defined and may be modified from time to time based on available data, risk management objectives and equivalence with other systems.

3.2 End product

The National Carton Meat Microbiology Testing Program[308] requires sampling and testing for Aerobic Plate Count. There are no criteria for this test, but an establishments results are compared to all other establishments and reported as terciles (top, middle, bottom thirds) and contribute to an

[302] Food Standards Australia New Zealand. Australia New Zealand Food Standards Code, standard 1.6.1 – microbiological limits in food. Federal Register of Legislation - Australian Government

[303] Meat Standards Committee (2002). Microbiological testing for process monitoring in the meat industry. Guidelines. Microbiological Guidelines_Meat.pdf (primesafe.vic.gov.au)

[304] DAFF. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (agriculture.gov.au)

[305] DAFF Guidelines. Interpretation of KPIs using the MEDC System Dashboard. interpretation-monthly-national-kpi-data.doc (live.com)

[306] DAFF. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (agriculture.gov.au)

[307] DAFF. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (agriculture.gov.au)

[308] DAFF. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products. Microbiological Manual for Sampling and Testing of Export Meat and Meat Products (agriculture.gov.au)

overall ranking of establishments in the PHI Program. The ICMSF suggest that typical levels encountered in operations that apply multiple hurdles during slaughter are an aerobic colony count (incubated at 35°C) of <10^4 colony forming units (CFU)/g and generic *E. coli* of <10 CFU/g. As noted, DAFF does not apply criteria to this parameter. Phillips, Bridger, Jenson, and Sumner (2012) and Phillips, Tholath, Jenson, and Sumner (2013) surveyed beef and lamb in 2011 from multiple export processors. For beef primals, more than 95% met the APC criterion and greater than 90% met the *E. coli* criterion. For frozen boneless beef, 95% met the APC criterion, and the mean count of *E. coli* in the 2% of samples in which it could be detected was 20 CFU/g. For sheep meat primals between 90 and 95% met the ICMSF APC criterion and 95% of frozen boneless product did so. More than 95% of primals met the ICMSF *E. coli* criterion, and the median was 20 CFU/g for the 12.5% of samples in which *E. coli* was detected. These data provide confidence that Australian product meets the specifications suggested by the ICMSF, especially considering that improvements (especially in beef processing) have occurred since that time.

4. Importing country criteria

Importing countries sometimes employ microbiological criteria, usually at the point of entry (PoE). As noted above, the ICMSF initially proposed criteria if no prior history of the product is available, such as at PoE (International Commission on Microbiological Specifications for Foods, 2011) but no food sampling plan could ensure the absence of a pathogen. Testing foods at PoE, or end-product testing elsewhere in the food chain, cannot guarantee food safety (Roberts, 1997).

Consistent with previous ICMSF considerations (International Commission on Microbiological Specifications for Foods, 2018) testing should be required only when the following two conditions exist:

1. The product group has been implicated in foodborne disease or may have an inadequate shelf life or other microbiological issues if effective controls are not applied.

2. The application of testing will reduce the health risk or quality issues associated with a food or will effectively assess adherence to microbiological control measure or process controls. (International Commission on Microbiological Specifications for Foods, 2011, p. 63)

Codex Guidelines[309] suggest that criteria are only set in particular circumstances when particular criteria are met, as noted above.

This section will list, and critique microbiological criteria set by certain importing countries. It is not intended to suggest that these criteria represent the entirety of an importing country's standards, or documentation on the subject, or that they are current; they are simply provided as examples.

4.1 Gulf Standards Organisation

The Gulf Standards Organisation standard GSO 1016/2010 'Microbiological criteria for foodstuffs -

Part 1. (since updated) applies criteria for the following:

Product type	Microbe	n	c	m	M
Fresh whole meat (chilled / frozen)	Total bacteria (APC)	5	3	10^6	10^7
	Salmonella	5	0	0	

[309] Codex Alimentarius Commission. (2013). Principles and Guidelines for the establishment and application of microbiological criteria related to foods. In (Vol. CAC/GL 21 -1997). PRINCIPLES AND GUIDELINES FOR THE ESTABLISHMENT AND APPLICATION OF MICROBIOLOGICAL CRITERIA RELATED TO FOODS (fao.org)

Escherichia coli O157	5	0	0

The United Arab Emirates applies the Aerobic Plate Count (APC) (35°C, 48h) criterion to all chilled meat at PoE. Bacteria (particularly lactic acid bacteria) grow in vacuum-packed, chilled meat products while stored, so this criterion indicates nothing about the hygiene applied during production (MEDC is more useful to determine that). The shelf life is affected by the growth of bacteria, but the end of practical (acceptable quality) shelf life occurs after the APC has reached its maximum (around 10^8 CFU). This criterion possibly provides assurance that the product has not been severely temperature abused during transit (which would cause the APC to increase faster) and that there is a reasonable shelf life remaining on the product, however, no known data exists to validate the significance of this criterion.

The value of 0 for *Salmonella* almost certainly means 'not detected in 25g', which might be confirmed by reference to the laboratory testing method. Criteria for *Salmonella* are common, though specifically not recommended by the ICMSF. Historically, criteria were easily applied to a product, and *Salmonella* was associated with raw meat, so this criterion was easily applied, and less easily removed.

The criterion for *E. coli* O157 should only apply if justified on public health grounds, as part of a control program, and if applied, then only to certain products, in which case, ICMSF would recommend a more stringent sampling plan.

4.2 Egypt

According to the Egyptian Standard for chilled meat (3602/2008):

- *Salmonella* shall be absent in 25 gram of chilled meat
- *Shigella* shall be absent in 25 gram of chilled meat
- Total bacteria <1,000,000/cm^2 of surface
- Chilled meat shall be free of *Clostridium* and *Listeria monocytogenes*
- Chilled meat shall be free of *Staphylococcus aureus*

Criteria for *Salmonella* are common, though specifically not recommended by the ICMSF. *Shigella* species are not found in ruminants and are not commonly recognised foodborne pathogens, though they may be waterborne. There is little value in applying this criterion at PoE, though there is very little risk of failure to meet the specification.

Bacteria (particularly lactic acid bacteria) grow in vacuum-packed, chilled meat products while stored, so this criterion indicates nothing about the hygiene applied during production (MEDC is more useful to determine that). The shelf life is affected by the growth of bacteria, but the end of practical (acceptable quality) shelf life occurs after the APC has reached its maximum (around 10^8 CFU). This criterion possibly provides assurance that the product has not been severely temperature abused during transit (which would cause the APC to increase faster) and that there is a reasonable shelf life remaining on the product, however, no known data exists to validate the significance of this criterion.

Some *Clostridium* species may cause foodborne illness (*Clostridium perfringens*). The genus is very diverse, so without knowing the method it is difficult to know what is being measured, or what the disposition of the product is likely to be. No mass or surface area is provided, making this a meaningless requirement. *Clostridium perfringens* most frequently results in foodborne illness in prepared foods that are temperature abused (such as stews or curries on a buffet that are held at the wrong temperature for a long time). There is no need to set a microbiological criterion for fresh meat. Testing of fresh meat samples in Australia has rarely found *Cl. perfringens* (see Chapter 1).

Listeria monocytogenes is a foodborne pathogen, frequently associated with processed, ready-to-eat meats and rarely isolated from Australian fresh meat (see Chapter 1). Again, since no mass or surface area is provided, this requirement is meaningless. There is no need to set a microbiological criterion for *L. monocytogenes* in fresh meat.

Staphylococcus aureus is a significant foodborne pathogen, but meat is not accepted as a significant source of illness (see Chapter 1). No mass or surface area is provided, making this a meaningless requirement. There is no need to set a microbiological criterion for *S. aureus* in fresh meat.

4.3 EU monitoring requirement and criteria for STEC

EU criteria can be found in Commission Regulation (EC) No 1441/2007 of 5 December 2007 amending Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs. This regulation has criteria for carcases for APC/SPC and *E. coli* as process control criteria calculated on a daily basis, for *Salmonella* using a moving window and for minced meat, mechanically separated meat and meat preparations intended to be eaten raw – but not for primals, beef trim and meat intended to be cooked.

These criteria are for the purpose of monitoring processing hygiene, as in the Australian carcase and carton meat monitoring programs and require adjustments to process if the criteria are exceeded.

Some EU member states apply microbiological criteria to Shiga toxin-producing *Escherichia coli* (STECs), at their discretion. A working document describes the approach that member states should apply if they choose to impose criteria for STEC.[310] The definition of STEC is much broader than the US FSIS (which is equivalent to the Australian) definition, encompassing all *E. coli* that possess an *stx* and an *eae* gene. Withdrawal from the market, or recall is recommended for all food if an STEC is detected unless it will be treated to eliminate STEC (e.g., roast beef). In the case of foods which will be treated to eliminate STEC, recall can still occur if particular serogroups (O26, O103, O104, O111, O145, or O157) are detected.

These STEC criteria are extremely stringent because they apply to a wide group of bacteria, that may not have been associated with human illness, and meat (sheep meats as well as beef) destined for a wide range of applications.

4.4 USA

The Jack in the Box outbreak became of prime importance to Australian processors when USA authorities imposed the Pathogen Reduction Hazard Analysis and Critical Control Point (HACCP) systems final rule in 1996. The rule required that all establishments implement a HACCP plan supported by sanitation standard operating procedures (SSOPs) and good manufacturing practices (GMPs); a zero-tolerance was mandated for visible contamination with faeces and ingesta. Microbiological testing was introduced for both contact surfaces and products, in the latter case, both for indicator organisms and *Salmonella*. Later, the USA declared *E. coli* O157:H7 an adulterant and, later added six additional serotypes of STECs. The declaration has resulted in testing of manufacturing beef for the presence of STECs becoming the significant measure of the control of this pathogen in the beef supply chain. The establishment's testing program has become a 'disposition CCP' under which a unit (lot) of production cannot be released to the trade until there is confirmation that the pathogen has not been detected in the sampled units.

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[310] European Commission, Health and Consumers Directorate-General (?2013/2014) GUIDANCE DOCUMENT ON THE APPLICATION OF ARTICLE 14 OF REGULATION (EC) N°178/2002 AS REGARDS FOOD CONTAMINATED WITH SHIGA TOXIN-PRODUCING ESCHERICHIA COLI (STEC). working document [draft] https://www.ceirsa.org/fd.php?path=201708/Draft_VTEC_guidance_document_on_application_Art_14_GFL_REV_3-3.pdf

The US testing program has the support of the ICMSF, on the basis that this kind of microbiological criterion helps to control the incidence of a foodborne disease in that jurisdiction. As risk assessment demonstrates (Kiermeier, Jenson, & Sumner, 2015), cooking temperature is the most significant means of controlling STEC in the beef supply, however, forcing this means of control was shut off by US Courts, so microbiological criteria for meat destined for risky products has become the cornerstone of control.

4.5 *Salmonella* in Finland/Sweden

Commission Regulation (EC) No 1441/2007 of 5 December 2007 on microbiological criteria for foodstuffs applies some microbiological criteria for *Salmonella* on carcases as a process control criterion. However, product being shipped to Sweden and Finland[311] requires *Salmonella* sampling and testing to be applied to carcases, quarters, cuts etc. and certified for each shipment.

In other European Union countries, rejection of product appears to occur without the application of these criteria. Possibly, the justification is the application of general provisions of European food law, allowing foods deemed unsafe by consideration of it being injurious to health or unfit for human consumption[312].

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International Commission on Microbiological Specifications for Foods. (2011). *Microorganisms in Foods 8: Use of Data for Assessing Process Control and Product Acceptance*. New York: Springer.

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[311] COMMISSION REGULATION (EC) No 1688/2005 of 14 October 2005 implementing Regulation (EC) No 853/2004 of the European Parliament and of the Council as regards special guarantees concerning salmonella for consignments to Finland and Sweden of certain meat and eggs. LexUriServ.do (europa.eu)

[312] REGULATION (EC) No 178/2002 OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 28 January2002 laying down the general principles and requirements of food law, establishing the European Food Safety Authority and laying down procedures in matters of food safety. EUR-Lex - 32002R0178 - EN - EUR-Lex (europa.eu)

13. Chilling and temperature control during processing

Summary

Chilling of carcases and carcase parts (primals and offal) is a key step for ensuring the safety and suitability of meat with a long shelf life. Chilling minimises the microbiological changes that occur after the application of good hygienic practices employed during processing. Initial carcase chilling is also the commencement of the shelf life of the product. Chilling must occur at a rate which does not interfere with the changes that occur in the carcase post-mortem, otherwise eating quality can be affected.

Australia's system is based on science to ensure strong food safety outcomes. Our system has been designed to allow different commercial operations to be able to calculate a range of time and temperature controls ensuring wholesomeness of red meat products, and safe food outcomes. The Refrigeration Index is an outcome-based, predictive microbiology measure that allows the effectiveness of different chilling protocols to be compared. Chilling requirements are regulated by the Australian Government Department of Agriculture, Fisheries and Forestry through its export legislation, that requires temperature controls and chilling requirements to be verified and documented in the export establishment's Approved Arrangement, that forms part of the company's Quality Assurance system that is audited regularly by government official auditors.

Australia is a producer of high value red meat products that supply a range of global high-end restaurants and hotels. Our most sought-after product is chilled product, that, through our food safety systems and controls of the chilling process, achieves the very best shelf life and eating quality. Australian red meat initially chilled and controlled through requirements in Australian regulations will result in product that is not only proven very safe to eat after more than 120 days (beef) and 90 days (lamb) but has also the finest eating quality.

The success of the combination of good hygienic practices in processing, and effective chilling of carcases and carcase parts, results in microbiological quality of chilled product that is exceptional by international standards.

Contents

1. Importance of chilling

1.1 Safety

The outcome of refrigeration is defined in *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* AS 4696 as:

> The chilling and freezing of meat maintains and does not jeopardise its wholesomeness

Wholesome (in AS 4696) means that the meat and meat products may be passed for human consumption, by meeting criteria including that the meat and meat products are not likely to cause food-borne disease or intoxication when properly stored, handled, and prepared for their intended use and that the meat is free of objectionable defects.

Refrigeration is applied to reduce the temperature of product to a desired endpoint. In the case of food safety this end point is generally considered to be ≤ 7°C. To ensure wholesomeness, lower temperatures may be required to supress the growth of spoilage bacteria (see below). All raw meat and meat products will eventually spoil at temperatures above the freezing point of meat. Meat generally begins to freeze below -1.5°C, although high pH meat can start to freeze at higher temperatures, i.e., above -1°C.

The effect of refrigeration is measured by achieving the required temperature at the site of microbiological concern, which is defined (AS4696) as the site on the meat or meat product where microorganisms of concern are likely to be located or the thermal centre (slowest cooling part). For example, for a carcase, this is the surface of the carcase, and in meat packed in a carton, it is at the thermal centre of the carton.

Refrigeration is sometimes designated as a critical control point (CCP) in the processing of meat for human consumption. While refrigeration does not prevent or eliminate biological hazards on meat it may result in a reduction in the hazard compared to the storage without refrigeration.

1.2 Eating quality

The control of carcase temperature during chilling is important because it also affects the rate of pH decline in muscle. The pH decline is the rate at which the carcase pH level falls from 7.10 (live animal pH) to the level at which it will not fall any further (which is known as the ultimate pH). The specification for good eating quality (Meat Standards Australia) requires the carcase pH to pass through pH 6.0 at a temperature between 15°C and 35°C. If the rate of pH–temperature decline does not result in meeting this specification, then eating quality can be severely compromised.[313]

1.3 Shelf life

Temperature control of meat after the initial chilling of the carcase or carcase part is important to shelf life.

The practical shelf life (PSL) can be defined as “the greatest length of time for which the bulk of the produce may be stored either with maximum commercially acceptable loss of quality and nutritive value or with maximum acceptable wastage by spoilage” (International Institute of Refrigeration, 2006).

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[313] Meat & Livestock Australia (2018) Meat Standards Australia, Tips & Tools. The effect of the pH-temperature decline on beef eating quality. msa10-beef-tt_the-effect-of-the-ph-temperature-decline-on-beef-eating-quality-lr.pdf (mla.com.au)

There is no correlation between bacterial concentrations (e.g., maximum bacterial populations) of vacuum-packed beef and lamb and their sensory characteristics (odour and colour) (Mills et al., 2014; Sumner et al., 2021). At usual storage temperatures, the maximum bacterial concentration is reached weeks before deterioration of product quality is significant. The PSL of vacuum-packed (VP) products therefore cannot be determined based on bacterial numbers (microbiological criteria) despite that spoilage is typically due to the activity of microorganisms because bacterial metabolism results in spoilage by continued activity after the maximum population is reached. The acceptability of product, therefore, should be based on its organoleptic characteristics (i.e., odour and colour).

The PSL of VP red meat is affected by the degree of bacterial contamination at packing (because that determines how soon the maximum bacterial population is reached), and the conditions for growth relevant to these bacterial contaminants. Such conditions include temperature, pH (as a function of muscle glycogen, and glycolysis during post-mortem processing) and oxygen (controlled by permeability of the packaging film). Among these conditions, temperature is considered the most important factor affecting the PSL. Gill and Jones (1992)), state the optimum temperature for storage of VP meat as -1.5 ± 0.5°C, and showed that small rises in temperature reduce shelf life significantly.

2. Safety

2.1 Carcase chilling

According to the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS 4696), refrigeration processes in Australia are considered effective if they can reduce the temperature of the surface of carcases, sides, quarters, or bone-in major separated cuts to no more than 7°C and other carcase parts at the site of microbiological concern to no more than 5°C, within 24h of stunning. In some cases, these requirements may be overly prescriptive, and allowance is made in the *Standard* for alternate time and temperature regimes.

Carcases are chilled in air to prevent the growth of enteric bacteria such as *Salmonella* and to limit the growth of spoilage bacteria. Control of growth is achieved by reducing the surface temperature and by drying of the surface tissue. In the initial stages of chilling the carcase surface is hotter than the surrounding air resulting in evaporation of water from the carcase surface and its subsequent removal through condensation onto the coils of the refrigeration equipment. In the initial phases of chilling the rate of migration of moisture from underlying tissue to the carcase surface is slower than the evaporative loss, resulting in a lowering of the water activity (see 2.6 below) at the carcase surface. The lower water activity inhibits bacterial growth in the early stages of chilling when the surface temperature is high enough to support growth. When the air temperature and carcase temperature equilibrate the water activity of the surface rises and growth is controlled largely by temperature alone. Growth of enteric bacteria may occur during the early stages of chilling if surface drying is prevented or impeded. The amount of drying that occurs at the carcase surface is affected by carcases touching, shrouding of carcases, spray chilling, increasing humidity etc. When drying occurs, microbial growth is easily controlled for the first 18-24h of chilling even with relatively slow cooling regimes. Carcases are generally boned when their internal temperature has fallen below 20°C (cold boning). This places less burden on subsequent carton chilling/freezing for control of microbial growth.

Carcases may sometimes be held in the chiller for extended periods (e.g., over a weekend) which impacts both the relative numbers of the types of bacteria present, and the total number of bacteria on a carcase. Holding meat at low temperature allows the growth of psychrotrophs (bacteria that are able to grow at low temperatures), and in many cases are unable to grow at 30°C or 35°C, which are the incubation temperatures used in most standard laboratory tests. Simmons, Tamplin, Jenson, and Sumner (2008) found that incubating a laboratory test at 35°C rather than 25°C (the temperature recommended for shelf life studies for chilled products) resulted in a count around 0.2 log_{10} cfu/cm^2 lower 24 hours after slaughter and up to 1-1.5 log_{10}/cfu/cm^2 lower after holding beef carcases for 4-5 days. For sheep carcases the different after 24 hours was around 0.7 log_{10} cfu/cm^2 and sometimes in excess of 1.5 log_{10} cfu/cm^2 after 4-5 days. Additionally, counts performed by the pour plate method resulted in lower counts than by the popular Petrifilm™ method, consistent with the adverse effect of heat from molten agar on psychrotrophs. This work helps to explain why establishments may obtain higher carcase plate counts after weekend chilling, and the reason why results from an apparently simple laboratory test can be so dependent on the conditions employed in the test procedure.

2.2 Carcase freezing

Some carcases and/or carcase parts are frozen immediately after exiting the slaughter floor; this is particularly true for small-stock. Bacterial growth is controlled in the initial stages of freezing in much the same way as for chilled carcases. Most frozen carcases are shrouded prior to freezing, limiting surface drying, with bacterial growth controlled by a rapid reduction in the surface temperature.

2.3 Carton chilling and freezing

Carton product is either chilled or frozen. Generally, primals are chilled (either vacuum packed or individually wrapped) while offal, lower grade cuts and manufacturing meat are usually frozen. Control of bacterial growth during carton chilling/freezing is dependent on the initial temperature of the product and the rate of cooling achieved when refrigeration is applied. The rate of temperature reduction in blast chillers or freezers is dependent on the type of carton used, air velocity and set temperature. Solid fibreboard cartons are more efficient in allowing heat transfer than fluted cartons and higher air velocities help remove heat from cartons more effectively. For a given set temperature, blast freezers are less effective in reducing the temperature of product than plate freezers. Once product has been placed into cartons there is no longer an opportunity for the surfaces to dry and therefore microbial growth is essentially controlled by temperature alone. The type of system used will depend on the individual process and will need to balance cost against the rate of temperature reduction required to meet food safety requirements.

2.4 Hot boning

In hot boning, (where carcases are boned before reaching a deep muscle temperature of 20°C), meat is removed from the carcase prior to any chilling when the temperature of the hottest part of the carcase may be 37°C or higher. The deep temperature of carcases immediately after slaughter may rise to above 40°C as a result of continuing metabolic activity without blood flow to remove heat from the cells. Some processors cool carcases for several hours before boning (warm boning) when the meat deep muscle temperature is between 20 to 25°C. The initial stages of refrigeration of hot boned product, when product temperatures at > 25°C, are critical in minimising growth of enteric bacteria such as *Salmonella.* Hot boning processors have difficulty meeting the prescriptive time-temperature specifications of AS4696.

In general, microbiological counts are higher on hot boned meat. In the analysis of the national microbiological database Vanderlinde et al. (2005) noted that hot boning establishments detected *E. coli* at consistently higher rates than other establishments. Of necessity, hot-boning plants undertake microbiological testing of the hot carcase which leads to a greater recovery of *E. coli* than occurs from carcases which have been chilled overnight. Lower recovery of *E. coli*, post-chill may reflect the fact that the cells may have become attached to the carcases surface and/or undergone inactivation during chilling, and during the drying process which accompanies it (Mellefont, Kocharunchitt, & Ross, 2015; Ware, Kain, Sofos, Belk, & Smith, 1999).

2.5 Offal

Offal can be considered “hot boned” as it is usually packed into cartons directly from the slaughter floor. Some offal are of more concern than others (i.e., livers, hearts, tripe) as they are bulky leaving no space between them when packed in a carton and have relatively high starting temperatures (≥37°C). Offal such as hot scalded tripe may have a very high starting temperature, although it is not clear what effect scalding has on bacterial counts or on subsequent microbial growth.

2.6 Behaviour of microorganisms

On a carcase surface (the site of microbiological concern) the temperature is decreasing as heat is removed from the carcase by the action of cooled air, and in some cases, chilled water sprays (spray-chilling). The surface of the carcase is also drying (water sprays during chilling are only used for the first few hours, and the weight of the carcase leaving the chiller is not allowed to exceed the weight of the carcase entering the chiller, so drying of the surface also occurs on spray chilled carcases). Drying does not occur with hot-boned meat which is being chilled within cartons. The pH of muscle is also decreasing, though this factor is not important for most of the carcase because it is largely covered with fat.

Temperature has a significant effect on the growth of bacteria. For each species (or group of strains within a species) a minimum, maximum, and optimum temperature can be defined, but often depend on the availability of nutrients (growth medium) and the time over which the measurements are taken. The optimum temperature is much closer to the maximum growth temperature than to the minimum growth temperature. The minimum growth temperature can be difficult to determine, in part because growth becomes very slow and therefore difficult to measure, but also because the behaviour of the bacteria can change, for example, cells becoming much longer, but not dividing, which makes the result dependent on the method used. The minimum growth temperature is most significant for chilling and subsequent storage of meat.

Food microbiologists usually measure dryness in terms of the availability of water for microbial growth and activity. This measure is called water activity (a_w). A solution of salt, or sugar appears to be liquid, but some of the water is not available to microorganisms because it is keeping the sugar or salt in solution. Concentrated salt or sugar acts as a preservative, at least partly because it prevents water being available for microbial growth. Freezing acts as a preservative, because, similarly, water is no longer available for microbial activity. The rate of water activity reduction of the surface tissues depends on the difference between the rate of evaporation at the surface and diffusion of moisture from the deeper layers of tissue. Drying of the carcase surface occurs mainly during the early part of chilling when the surface is warmer than the air. During storage, moisture will diffuse through to the surface from deeper tissues at a rate exceeding that of evaporation and, thus, the surface water activity increases again over time. Salter (1998) mapped the water activity of the carcase surface at different stages during chilling and reported that carcases appeared to follow a similar pattern of large fluctuations over the first 20 h of chilling, with a_w falling as low as 0.929 at the rib site and 0.942 at the brisket site, and thereafter returning to, and stabilising at, levels in the range of 0.98 to 0.99. The increase in water activity after 20 h coincides with carcase surfaces reaching temperatures similar to that of the air in the chiller. (reviewed by (Mellefont et al., 2015).

pH also exerts an effect on bacterial growth, though less than temperature and water activity under most circumstances. In meat, pH may be significant because of differences in the pH of fat and muscle, the pH differences between species and carcases which have undergone a large amount of glycolysis post-mortem and those that have not (affected by muscle glycogen levels at the time of slaughter and speed of chilling). pH of fat is higher than muscle and is less limiting the growth of *E. coli*. Higher pH muscle is more susceptible to spoilage bacteria (e.g., *Shewanella putrefaciens*).

The minimum temperature, pH and water activity for growth may be found in Table 1, but these should be taken as a rough guide only, since the factors interact. Predictive models are now widely used to predict the effect of combinations of factors on the growth (and death) of bacteria in foods.[314]

Table1 : Minimum growth conditions for bacteria that may be of concern in meat (FSANZ[315] and (Hocking, 2003)).

	Minimum growth temperature	Minimum pH	Minimum water activity	comment
Campylobacter sp.	30°C	5.5	0.987	Unable to grow in foods due to the high levels of oxygen
Clostridium perfringens	15	5.5	0.97	Grows anaerobically only
Listeria monocytogenes	<0	4.4	0.92	
Salmonella enterica	7 (most)	3.8	0.93	
Escherichia coli	7	4.4	0.95	
Staphylococcus aureus	7	4.0	0.83	
Yersinia enterocolitica	-5	4.6		
Aeromonas sp.	<5	5.5		

Predictive microbiology is based upon the premise that the responses of populations of microorganisms to environmental factors are reproducible, and that by considering environments in terms of the environmental factors having the largest effect on those responses it is possible, from past observations, to predict the responses of those microorganisms. The responses of microorganisms to environmental conditions such as temperature, pH, and water activity (a measure of the availability of water to the microorganism) are the most significant. Predictive microbiology utilises mathematical models (developed with data from laboratory testing) to describe these responses. It is possible to measure the lag time (time before growth commences) and growth rate of different bacteria under different conditions of temperature, pH, and water activity in the laboratory. Such measurements can be made in artificial media or on meat. Measurement on meat is preferred but is the more difficult of the two methods. Under the same conditions the lag and growth rate should be constant. If enough measurements under varying conditions are made then it is possible to develop predictive models that can be used to estimate the lag and growth rate over a range of temperatures, pH, and water activities.

There is ample evidence that enteric bacteria such as *E. coli* and *Salmonella* will not grow on meat at temperatures ≤7°C (Chapter 18 Salmonella 1.5 minimum growth temperature, Chapter 19 E. coli 1.6 minimum and maximum growth temperature). Growth at higher temperatures can be restricted on carcases by surface drying as previously mentioned. This, in combination with a rapid temperature drop, ensures that little if any growth of enteric bacteria occurs in the first 24h of carcase chilling. Growth of enteric bacteria in carton product (either hot boned or conventionally boned) is basically

[314] University of Tasmania Centre for Food Safety and Innovation, US Department of Agriculture. ComBase Home (combase.cc)
[315] Food Standards Australia New Zealand. 2022. Compendium of microbiological criteria for food. Compendium March 2022 (foodstandards.gov.au)

controlled by temperature, although product pH will have some effect. Other pathogenic bacteria such as *Listeria monocytogenes*, *Yersinia enterocolitica* and *Aeromonas* spp. may be able to grow on fresh meat at temperatures of ≤7°C. However, there is no epidemiological evidence linking raw meat and meat products to human disease associated with these bacteria. Also, these bacteria are unable to compete with spoilage bacteria, and raw meat and meat products will spoil before the numbers of these bacteria can increase to levels where they could be any concern to human health. Growth of bacteria on carcase surfaces during chilling will generally be aerobic i.e., in the presence of air. Growth in cartons or on vacuum package meat will generally be anaerobic (without oxygen). The enteric bacteria we are most concerned with will grow both aerobically and anaerobically on meat, although they will grow a little slower anaerobically.

A number of studies, in Australia have observed that the *E. coli* count on a chilled carcase is lower than on a hot (pre-chill) carcase. Eustace et al. 2004[316] measured reductions of around 0.4 $\log_{10}$ cfu/cm^2 in Australian chilling and similar and greater reductions have been observed in the USA and in Ireland (reviewed by (Mellefont et al., 2015)). Greig et al. (2012), based on an extensive analysis of the available literature on carcase chilling, concluded that chilling alone can cause inactivation of *E. coli*. As much as these studies suggest that numbers of enteric bacteria decrease during chilling by around 1-$\log_{10}$, it is not clear if this decrease is real or just an artefact of cells entering a viable but non-culturable state. Mellefont et al. (2015) compared observed *E. coli* counts during laboratory-simulated chilling and compared observed counts with the predictions of an *E. coli* growth model that had been validated with data collected from meat. There were periods during some chilling treatments in which transient deviations from predicted population behaviour occurred. Deviations from model predictions were extreme, however, when *E. coli* was exposed to combined chilling and water activity conditions. The observed cell numbers eventually returned to the levels predicted by the model. One interpretation of the observed population kinetics is that the decrease in (culturable) cell numbers in both cases was not due to cell death but, instead, a temporary loss of the ability to produce colonies on agar plates. To elaborate, it is possible that the population is responding as predicted by the model but that some (e.g., injured) cells in the population fail to produce colonies on the culture medium. Depending on the proportion of cells that are unable to be cultured, deviation from the predicted growth could be observed as slower than expected growth or as inactivation. The putative non-culturable proportion of cells may then stabilise and, after 20.5h the fraction of nonculturable cells could progressively decrease, resulting in the observed phase of anomalously rapid increase in culturable cell numbers. The authors suggest that this phase of rapid population increase reflects the combination of cells recovering from the inability to produce colonies on agar plates and contributing again to the viable count as well as some 'true' growth, which is still predicted to occur during that period (Mellefont et al., 2015).

2.7 Refrigeration Index

When considering the impact of refrigeration on bacterial numbers on a freshly contaminated carcase or piece of meat, prediction of behaviour depends on the lag phase, as the bacterial population adjusts to its environment and the log (or exponential) phase when the population is actively dividing, as permitted by the environment (temperature, pH, water activity).

The period of the lag phase and the rate of growth (growth rate) during the log phase are controlled by both external and internal factors. Generally, bacterial contamination of carcases is from the hide or intestinal tract of the animal or its companions. These bacteria require time to adapt to conditions on the carcase surface; this time is known as the lag phase. The duration of the lag phase depends on the condition of the bacteria at the time of contamination and the conditions on the carcase. The greater the magnitude of the difference in the conditions on the carcase and the ideal at the time of

[316] Eustace, I., McPhail, N., Knox, D., 2004. Carcase Chilling Survey Final Report PRMS.043B. Meat and Livestock Australia, North Sydney

contamination, the longer the lag phase. Once bacteria have adapted to the conditions on the carcase they begin to grow.

The rate of growth is determined by the type of bacteria and the conditions on the carcase surface. If the conditions on the carcase surface remain constant the growth rate remains constant until the stationary phase (maximum bacterial count) is reached. For carton product, contamination is a result of transfer of bacteria from the carcase surface to the meat during boning, or through cross-contamination from the environment during boning. Bacteria transferred to meat during boning may not have a significant lag as they may already have adapted to growing on meat.

The RI is a measure of the potential growth of generic *E. coli* at the monitored site. It is not a count of the number of *E. coli* at that site. The RI is used to measure the performance of the refrigeration process from the time chilling or freezing commences until all the sites of microbiological concern are at or below 7°C.This reflects temperature at which enteric pathogens such as Shiga toxin-producing *E. coli* (STEC) and *Salmonella* stop growing on meat. Since they will only grow at or above 7°C, the RI will not accumulate below that temperature. The RI is used to validate both existing and alternative refrigeration processes and is an ongoing process verification measure used by meat processors.

Generic *E. coli* (i.e., non-pathogenic) is considered a surrogate for pathogenic bacteria such as STEC and *Salmonella*. It has a similar lag and growth rate to *Salmonella* when grown on meat and has been extensively used to model growth of enteric bacteria on meat. Researchers at the University of Tasmania developed a model for the growth of *E. coli* on meat that combined terms for high and low temperature, high and low water activity, high and low pH and dissociated and undissociated lactic acid (Ross, Ratkowsky, Mellefont, & McMeekin, 2003). The model was then validated (Mellefont, McMeekin, & Ross, 2003) against a large number of observations of the behaviour of *E. coli* in meat and meat products under a range of conditions and found to provide a reliable prediction of *E. coli* growth. The model is available as the Refrigeration Index Calculator (RI Calculator)[317]

The RI is an expression of the potential growth of *E. coli* at the site of microbiological concern, calculated through the RI calculator, expressed in $\log_{10}$ units. The choice of acceptable RI criteria was based upon:

- The existence and application of a microbiological monitoring program for carcase chilling and microbiological criteria for acceptable results
- An understanding that the outcome of refrigeration processes could be variable from day to day
- Criteria being applied in the New Zealand system
- An intention to maintain the hygienic quality of product, and conformity to existing microbiological criteria
- An intention to ensure that refrigeration processes were applied in a way that ensured the hygienic quality of all products

The following RI criteria are specified in both AS 4696 (for hot boned carcases and carcase parts) and Export Control (Meat and Meat Products) Rules 2021 (5-13 Assessing the effectiveness of refrigeration) (for all refrigeration programs) in $\log_{10}$ units:

i) The refrigeration index average is to be no more than 1.5; and
ii) 80% of refrigeration indices are to be no more than 2.0; and
iii) No refrigeration index above 2.5

[317] Meat & Livestock Australia. Tools and calculators. Refrigeration Index Calculator | Meat & Livestock Australia (mla.com.au)

3. Shelf life

Control of temperature through carcase chilling, boning, and carton chilling is critical to the shelf life of meat. The previous section concentrated on the effect of chilling on pathogens, or surrogates, which has implications for the control of pathogens, and therefore, the safety of meat.

Time and temperature also have an impact on the shelf life of meat, though the atmosphere (packed in air, or under vacuum) also has a significant effect. Chapter 16 on chilled shelf life discusses these impacts in detail.

4. Temperature controls in production and transport

AS4696 provides prescriptive temperature requirements (below) and also provides for an alternative time and temperature controls that will not adversely affect the microbiological safety of the meat. The *Standard* makes an allowance for alternative techniques that are assessed to be equivalent (Preface to AS 4696:2007).

4.1 Carcase chilling

In AS4696 carcases, sides, quarters, or bone-in cuts are required, within 24 hours of stunning, to be no warmer than 7°C on all surfaces (AS 4696, 11.6(a)(i)).

If the carcase is to be frozen, then it must be hard frozen without delay after the initial reduction below 7°C (AS4696, 11.6(d)).

Carcases need to be stored at or below 7°C unless being processed. (AS 4696, 11.8).

4.2 Boning and carton chilling

Boning processes, when conducted on a chilled carcase are performed in a room no warmer than 10°C (AS4696 12.4).

In AS4696 cuts are required, within 24 hours of stunning, to be no warmer than 5°C at the slowest cooling site where microorganisms are likely to be present (the surface of a cut; the centre of a carton) (AS 4696, 11.6(a)(ii)).

Cut product is maintained at a temperature of no warmer than 5°C (AS4696, 15.2(a)(ii)).

4.3 Load out and transportation

Meat must be at the required storage temperature prior to removal from a chiller for transport (AS 4696, 15.6) and transported in a vehicle that can maintain the required temperature (AS4696, 15.10).

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14. Managing environmental sustainability in processing

Summary

This chapter overviews the extensive work that is progressing on Australian abattoirs both in response to ensuring an internationally competitive processing sector, but also seeking to ensure the industry meets the 30% carbon reduction target by 2030. The key areas flagged in this chapter include waste, carbon capture, energy generation and use, and water.

Aside from the government's carbon reduction commitments for 2030; the key challenges for processing establishments operating in Australia for the next decade are energy costs, water access and costs, eliminating all waste, and labour costs. Embedded in the energy costs are minimization of energy costs through plant and equipment design e.g., highly efficient heat pump technology, minimizing freezing capacity through logistics control and developing chilled product lines with long shelf life, developing a culture of no waste, where every component of an animal is used and adds value, and packaging waste minimised. Plants will also seek to offset energy costs through solar panels and large battery storage, gasification, green hydrogen power generator, with minimal baseline energy drawn from grid power. As energy costs keep increases and new green technology becomes available, the business viability of these alternatives is improving.

Due to extreme weather events, reliable access to water is essential for Australian abattoirs, particularly those in regional areas that can be substantially impacted by drought. This chapter highlights some of the food safety and market access challenges in using recycled water. Strategically, this is an area in which industry and government need to progress aligned pathways of what is commercially practicable and create opportunities to move some of the international food safety benchmarks and market access requirements that may be outdated and limit progress in this regard.

As export markets continue to progress towards their own carbon reduction targets there is some likelihood that their respective consumer groups will also seek similar assurance from Australian exporters. This chapter identifies key focus areas for the Australian processing sector as it evolves to reduce its carbon exposure as plant move towards more formal carbon technical assessments and ultimately accreditation.

Processor environmental performance will be a rapidly evolving area that starts with the fundamental components as outlined within it, to being one that is significantly more advanced in coming years. The challenge for both industry and government in this regard is what "holistic good" looks like and ensuring that R&D, regulations, and export requirements supports this progression.

Contents

1. Environmental concepts and definitions

The most often quoted definition of sustainability comes from the UN World Commission on Environment and Development: "sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Sustainable practices support ecological, human, and economic health and vitality. Sustainability presumes that resources are finite and should be used conservatively and wisely with a view to long-term priorities and consequences of the ways in which resources are used.[318]

The red meat processing industry makes an important contribution to rural and regional Australia, being the largest food manufacturing sector as well as the largest food exporting sector. Energy, water use, and waste efficiency are connected and impact on production costs, profitability, competitiveness, and future business continuity. In some regions water availability is a potential constraint on industry operations and future expansion. In addition, the industry must meet community expectations about environmental sustainability, which includes limiting greenhouse gas (GHG), odour, and noise emissions and progressing towards the broad industry goal of carbon neutrality by 2030 (CN30). Reporting of environmental performance is also a requirement of some supply chain partners and is emerging in some export markets.[319]

Environmental performance assessment in the Australian red meat processing industry is not new. Individual red meat processing plants work actively to improve resource use efficiency and environmental performance. Industry-wide environmental performance reviews have been undertaken since 1998 at approximately 5 year intervals, with key reports published in 2011, 2015 and 2017. These industry-wide reviews have been widely used for benchmarking individual plant performance and the data have also been used to assess performance change over time, to support the development of industry policies, as well as for communication and training purposes.[320]

1.1 Definitions

Sustainability vs environmental performance
The environmental aspects of sustainability have been of greatest interest to the meat processing sector. Environmental aspects have been concerned with the inputs of water and energy, and the outputs of GHG, wastewater, and waste for disposal. Until now, reviews have been concerned with environmental performance; other factors contributing to the broader concept of sustainability, including economic, social, and animal welfare issues have been excluded from sustainability performance assessments.[321] The sector engages in work to improve employment prospects for school leavers, training to provide a career pathway, worker safety and evaluation of the benefits of meat processing to regional communities, but this work does not include measurements that are included in sustainability reporting.

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[318] University of California at Los Angeles. Sustainability. What is Sustainability? | UCLA Sustainability

[319] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[320] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[321] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

Types of metrics to measure environmental performance
Three types of metrics are used in the measurement of environmental performance[322]:

> **Resource Use Efficiency**: quantitative indicators that describe the technical efficiency of operations, e.g., energy use efficiency, water use efficiency, waste production. The performance result is largely within the sphere of control of the business depending on technology adoption and operating practices. The major issue is that the importance of achieving a high level of efficiency may vary from one location to another, e.g., locations may differ in terms of local water stress and is likely to be limited by scale i.e., larger plants have greater capacity to take advantage of economies of scale when implementing projects.
>
> **Environmental Impact**: quantitative indicators that describe potential environmental impact: For example, global warming potential associated with energy and non-energy based GHG emissions. These indicators more closely reflect actual concern (i.e., environmental performance), but may be impacted by factors outside the direct control of the business (e.g., emissions intensity of grid electricity).
>
> **Practices / targets**: indicators describing the rate of adoption of good environmental management practices. The advantage is that these indicators describe concrete actions. However, their link to actual environmental impacts may be weak.

Intensity
In some cases, the total input or output is of interest, in other cases, an 'intensity measure' is made.

Intensity ratios[323] express GHG impact per unit of physical activity or unit of economic value (e.g., tonnes of CO_2 emissions per unit of electricity generated). Intensity ratios are the inverse of productivity/efficiency ratios.

For processing, the intensity measure is often in terms of tonnes of Hot Standard Carcase Weight (tHSCW). The resulting measure will be affected by the type of livestock being processed at an establishment.

Scope
Three 'Scopes' are used to define the operational boundaries in relation to indirect and direct GHG emissions[324] and are sometimes used for other environmental reporting purposes.

> **Scope 1 inventory** - organisation's direct GHG emissions.
>
> **Scope 2 inventory** - organisation's emissions associated with the generation of electricity, heating/ cooling, or steam purchased for own consumption.
>
> **Scope 3 inventory** - organisation's indirect emissions other than those covered in scope 2.

1.2 Water

Red meat processing facilities critically depend on water for their operation. As with all industrial facilities, there is a need to use water more efficiently, especially in regions where water scarcity is

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[322] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[323] World Resources Institute, World Business Council for Sustainable Development. The Greenhouse Gas Protocol: A corporate accounting and reporting Standard. Revised edition. World Business Council for Sustainable Development / World Resources Institute [?2004] Corporate Standard | Greenhouse Gas Protocol (ghgprotocol.org)

[324] World Business Council for Sustainable Development / World Resources Institute [?2004] Corporate Standard | Greenhouse Gas Protocol (ghgprotocol.org)

high. Water recycling can be used to reduce water demand, subject to food safety and other regulations. Water is primarily consumed in washdown of live animals, yards, boning and slicing floors, slaughter floor, hides and offal processing, rendering, and hand washing and sterilization.

Water intake may be from town, bore, dam, water body (e.g., lake or river), and rainwater, or water recycling. Processors usually are concerned with direct water consumption, and "indirect" water use (analogous to scope 3 GHG emissions), associated with the production of feed commodities, and purchased cattle is reported by producer metrics (see 2. below)

Metrics may include:

- Water consumption kL/tHSCW
- Demand met by recycling water %

1.3 Wastewater

Red meat processing facilities can generate wastewater streams rich in nutrients and organic matter. Good operating practices can limit wastewater contamination and treatment can be used to limit harmful and costly (if discharged as trade waste) emissions to the environment.[325]

The volumes and destination of treated and untreated wastewater is of primary concern. Where possible, nutrient analyses on wastewater used to quantify nutrients (Phosphorus (P), Nitrogen (N), Biological/Chemical Oxygen Demand (BOD, COD), Fats Oils and Grease (FOG) etc) discharged by red meat processing.

Wastewater is often treated onsite, so the generated and captured methane, sludge production and assay, non-energy emissions become relevant)

Metrics may include:

- Untreated quality P, N, BOD, FOG mg/L
- Emissions to environment P and N mg/L

1.4 Energy use

Red meat processing facilities can be significant energy users, associated particularly with refrigeration, production of steam and hot water, and rendering. Energy consumption is associated with a range of environmental impacts and is an important cost of production. Energy consumption in meat processing establishments ranges from grid power, diesel for stationary energy and transport, coal (bituminous, sub-bituminous, and brown), natural gas for thermal and stationary energy, LPG for thermal and transport, fuel oil, unleaded petrol, biomass, biogas, and solar photovoltaic. Energy assessment is made by determining energy content (in megajoules – MJ) of all energy sources used[326]. Energy used may be reported separately for fossil and renewable sources.[327]

Metrics may include:

- Electrical kWh/tHSCW
- Thermal GJ/tHSCW

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[325] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[326] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[327] Wiedemann and Fowler (2021). Developing a sustainability assessment framework and strategy. Project 2022-1035. AMPC 2021 Developing a sustainability assessment framework and strategy for the US supply chain - 2022-1035

1.5 Greenhouse gas emissions

Reducing greenhouse gas emissions is a major global challenge. Red meat processing facilities can play an important role in limiting direct emissions (Scope 1) as well as emissions associated with the use of electricity on site (Scope 2). Scope 3 emissions, can be difficult to measure with the most relevant examples being transporting and distribution of product in trucks / ships not owned by the processing company, business travel and commuting, and leased assets.[328]

The established metric for GHG is tCO_2 equivalent tHSCW.

The *Greenhouse Gas Protocol*[329] is a widely accepted means of calculating this metric. Carbon dioxide (CO_2) equivalents (CO_2 e) converts the Global Warming Potential (GWP)of other gases to a carbon dioxide equivalent (CO2-e) by multiplying the quantity of the gas by its GWP. The GWP for methane is 28[330] and the GWP of other gases can also be determined.

1.6 Waste to landfill

Red meat processing facilities can generate large quantities of organic wastes which have the potential to be beneficially recycled into new products. In addition, the production of other miscellaneous solid waste can be limited to reduce demand for new materials and the environmental impacts associated with solid waste disposal (i.e., via landfilling).

The production of recyclable and non-recyclable wastes including carcasses, hides, cardboard/paper, pond crust and sludge, paunch, manure, rubber, ash, plastic, scrap metal, oil, and general waste. It is possible to assign waste streams to either landfill, compost/recycling, or other management methods.[331]

The metrics for Waste to landfill are t/tHSCW and a recycling fraction % can also be calculated.

1.7 Local amenity

Red meat processing facilities have the potential to emit odours and noise which can impact the amenity of the surrounding community. Local amenity issues include odour and noise complaints from residential, commercial, industrial, or rural sources.[332]

The metrics can include:

- Odour complaints (number/site/year) and source of complaints (residential, commercial, industrial, rural)
- Noise complaints (number/site/year) and source of complaints (residential, commercial, industrial, rural)

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[328] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

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[331] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

[332] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

2. Processors as part of the whole supply chain sustainability

2.1 Value chain sustainability frameworks

The Australian Beef Sustainability Framework (ABSF)[333] sets out the key indicators of performance in sustainability for the beef industry. Sustainability includes the production of livestock in a way that is environmentally, socially, and financially responsible, with respect for people, animals, and natural resources, today and for future generations. The reporting boundary covers the actions of the entire Australian beef value chain, including farms, saleyards, feedlots, transport, processing, and live export (see Ch 6). The sustainability indicators relevant to processing included in the ABSF include[334]:

- Animal welfare certified by Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS) certified processor
- CO_2e emitted per tonne HSCW
- Percentage CO_2e captured and reused
- water use per tonne HSCW
- solid waste per tonne HSCW
- food waste recovered along the supply chain
- participation by women in processing businesses

The Sheep Sustainability Framework (SSF)[335] encompasses the value chain for Australian sheep meat and wool – from farm to fork and sheep to shelf. Sustainability includes the production of livestock in a way that is environmentally, socially, and financially responsible, with respect for our people, our animals, and our natural resources, today and for future generations. The role of the Sheep Sustainability Framework (SSF) is to monitor, measure, and report industry performance against sustainability priorities (see Chapter 6).

The sustainability indicators relevant to sheep processing in the SSF[336] include

- Animal welfare certified by Australian Livestock Processing Industry Animal Welfare Certification System (AAWCS) certified processor
- water use per tonne HSCW
- solid waste per tonne HSCW
- CO_2e emitted per tonne HSCW

2.2 Post-processor supply chain

There are other components of sustainability that are not associated with on-farm activities, or with the processing operation itself. Examples are transport (especially chilled transport), packaging materials etc.

2.2.1 Packaging

The Australian Packaging Covenant is a national regulatory framework under the National Environment Protection (Used Packaging Materials) Measure 2011 (NEPM) that sets out how

[333] The Australian Beef Sustainability Framework. Home | The Australian Beef Sustainability Framework (sustainableaustralianbeef.com.au)
[334] The Australian Beef Sustainability Framework absf-indicator-summary-2023-web.pdf (sustainableaustralianbeef.com.au)
[335] Sheep Sustainability Framework. Home | Sheep Sustainability (sheepsustainabilityframework.com.au)
[336] Sheep Sustainability Framework. 2023. Annual Report. sheep-sustainability-framework-2023-annual-report_updated-nov-23_web.pdf (sheepsustainabilityframework.com.au)

governments and businesses across Australia share the responsibility for managing the environmental impacts of packaging.[337]

The Covenant aims to reduce the environmental impacts of Consumer Packaging by supporting two goals:

- Optimising resource recovery of Consumer Packaging through the supply chain by:
    - adopting approaches that make changes in the way packaging is designed, used, and purchased and packaged so that packaging uses less resources and is more easily recycled, and
    - enabling packaging materials to be returned to the economy thereby minimising waste associated with the generation and consumption of consumer packaging across the supply chain.
- Preventing the impacts of fugitive packaging on the environment by adopting approaches that support new innovations and find solutions to capture packaging materials or waste before it enters the environment or support the adoption of new or alternative types of packaging.

Key Performance Indicators for packaging may be added to a future processor environmental performance review.

2.2.2 Transport

Greenhouse gas emissions from transcontinental transport are a significant part of the post-farmgate emissions when considering product delivered to the supermarket shelf.[338]

3. Processing sector environmental performance

This section reports the results of the 2020 industry-wide environmental performance review (EPR),[339] the fifth undertaken since 1998 at approximately 5 year intervals, with key reports published in 2011, 2015 and 2017.

3.1 2020 survey response

Of the approximately 150 red meat processing facilities operating in Australia over all scales and species, 26 responses were received representing 17.3% of the total number of businesses and contribute 41.3% of the 3,464,022 tHSCW for all red meat production reported from July 2019 to June 2020.

3.2 Water

Water use intensity was 7.9 kL/tHSCW. Compared to the previous report (2015), where a result of 8.6 kL / t HSCW was reported, a reduction of water use intensity of 7.9% or 0.7 kL/t HSCW. Considering the 2008/2009 FY EPR where 8.7 kL/tHSCW was reported, this shows that the Australian red meat processing industry is continuing to achieve reductions in water intake.

3.3 Wastewater

The average site wastewater discharge volume calculated was 6.5 kL/tHSCW, a significant improvement of 2 kL/t HSCW on the 2015 figure of 8.5 kL/tHSCW, or 23.5%. Relative to the intake,

[337] Australian Packaging Covenant Organisation. APCO. APCO

[338] Wiedemann, S et al. 2021. Developing a sustainability assessment framework and strategy. AMPC report. Project code 2022-1035 AMPC 2021 Developing a sustainability assessment framework and strategy for the US supply chain - 2022-1035

[339] All Energy (2020) 2020 Environmental Performance Review (EPR) for the Red Meat Processing (RMP) Industry. MLA Project Code V.MFS.0448 AMPC 2020 Environmental performance review for the red meat processing industry Project V.MFS.0448

this survey calculated 83% of water intake being discharged, compared to 99% in 2015. This suggests significant improvements in in-plant water usage.

3.4 Energy use

The energy use intensity calculated in this survey was 3316.2 MJ/tHSCW, or a total increase of 10.4% compared to the 2015 value. The energy value associated with rendering was 1,223 MJ/tHSCW, meaning that for this sample size and excluding rendering the energy use intensity is 2092.9 MJ/tHSCW, or a 43% increase on the 2015 figure.

This figure should be considered in the context of energy performance over time, where 2008/2009 energy intensity was 4,108 MJ/tHSCW. In addition, if the 2020 reduction in wastewater discharges are partly attributable to improvements in wastewater management, this may come at a cost to energy intensity.

3.5 Greenhouse gas emissions

On average, total site GHG emissions were 397 kg CO2-e/tHSCW, an 8.1% reduction compared to the 2015 value of 432 kg CO2-e/tHSCW.

Emissions from red meat processing have been declining for over a decade. Analysis of previous surveys has found that the emissions intensity of red meat processing has fallen from 554 kg CO2e/tHSCW in 2008-9 to 432 kg CO2e/tHSCW in 2011, and research by CSIRO for Meat & Livestock Australia calculated that the sector's total emissions have fallen from 1.45 million tCO_2e in 2005 to 1.39 million in 2015. These emissions represent 2% of the whole-of-industry emissions.[340]

3.6 Waste to landfill

The average figure for waste sent to landfill in this EPR was 11.9 kg/tHSCW, a very large increase of 102% compared to the 2015 value of 5.9 kg/tHSCW. Sites in this EPR reported a wider scope of wastes sent to landfill, whereas the 2015 figure was calculated for only solid waste sent to landfill. Sites did not break down the components of their general waste, however large volumes of liquids (e.g., waste oil, non-renderable blood, un-dewatered paunch) sent to landfill are believed to have skewed these results. Due to increases in state-based landfill levies, it is not consistent with expectation that the processing sector has increased tonnages of wastes disposed to landfill.

3.7 Local amenity

Noise complaints were reported to be comparatively rare, at far below 1 per site per year. Of the 25 sites, only one reported receiving two noise complaints from a residential source. This continues the positive trend observed in the 2015 EPR of receiving very few noise complaints.

Odour complaints are relatively more common than noise complaints, with on average 3.8 per site per year reported, however a 46% reduction for 2019/20 was achieved compared to 2015, where 7.1 odour complaints per site per year were recorded, showing that the processing sector is making good progress in reducing odours.

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[340] Meat & Livestock Australia, 2018. Greenhouse gas mitigation potential of the Australian red meat production and processing sectors | Meat & Livestock Australia (mla.com.au) report B.CCH.7714

15. Maintaining integrity from processor to importer

Summary

Maintaining integrity from the processor to the importer is probably the most critically important element in the export supply chain. It is within this segment that verification of the integrity of a consignment is confirmed that then directly underpins the issuance of export documentation to the exporter. Without this documentation, being an export permit and export certificate, the consignment will not be allowed to depart Australia, nor will it be accepted by most importing authorities around the world. The competent authority (CA) in Australia for the issuance of export documentation is the Department of Agriculture, Fisheries and Forestry (DAFF).

An export certificate is an official assurance provided by the exporting country CA to the importing country CA attesting to a range of declarations contained thereon. This document must be 100% accurate. These declarations will cover both elements of food safety, product origins, and animal health, and other information relating to product description and any additional product claims that are provided or specifically required by the importing CA. In order to facilitate official validation of the exporter's information prior to the issuance of official documentation, the exporter must show the system that supports the accuracy of details entered. The integrity at this point of any consignment presented for validation can only be made based on a pre-approved system that ensures traceability of the product back to farm, verifies health and treatment of each animal prior to slaughter, that traceability (and information) of product is maintained through potentially a long process (slaughter establishment, independent boning room, colds store, further manufacturing and packing, cold store, freight forwarder and export). Organic and Halal certification will also dictate a range of traceability and segregation requirements which is also part of pre-approved arrangement that ensure the integrity of claims that are made, or assurances provided.

The pre-approved arrangement is part of the Approved Arrangement that is the official approval by DAFF for a documented system in the exporting establishment, which is then subject to ongoing audit and verification. The export chain, particularly from processor to import authority is highly regulated by DAFF. Without these strong regulatory controls, Australian exporters would not have the global access to export markets they currently enjoy. Australia's export certification system is recognised internationally as world leading and is audited regularly by international import authorities to ensure its integrity is maintained.

The additional cornerstone of integrity is ensuring that only competent well-trained persons that are fit and proper are in positions of control within our export sector. Again, this is particularly the case from the export processor through to the import authority, which is underpinned by the Export Control Act 2020 and the associated Rules.

The Australian red meat industry, processors, exporters, and the Australian Government seek to ensure the highest standard of integrity to our export certification system understanding its importance in continuing to maintain trust and confidence of both our export customers and import authorities. This chapter expands on the above and identifies some of the critical regulatory and industry elements that supports the integrity of our export chain.

Contents

1. Objective

1.1 Definition

Maintaining integrity contributes to product wholesomeness. As explained, in the Preface to AS4696:

> "This Standard incorporates other objectives so that wholesomeness can be assured. These objectives include the need for systems to be in place for the accurate identification, traceability, effective recall and integrity of meat and meat products."

Identification, traceability, and integrity are dealt with in the standards together in Section 16. The outcome is that "meat and meat products are accurately identified. Meat and meat products that should be recalled can be recalled."

Further discussed in Chapter 8, Managing integrity during processing and Chapter 11 Managing traceability and product identity in processing, maintaining the integrity of product also provides a level of protection from fraud which will undermine international confidence in our integrity at both the import Government level and importantly, the customer.

2. Preparing to export

The Australian Government through the Department of Agriculture, Fisheries and Forestry (DAFF) who administers the Export Control Act (ECA) 2020, ensures that every carcase and carton of red meat produced for export meets all the requirements of the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696); and importing country requirements.

2.1 Export Control Act (2020)

DAFF regulates exports of agricultural product to assure trading partners that Australian agricultural products meet their import requirements. The department's responsibilities and powers are defined in the Export Control Act 2020.[341]

Export commodities controlled by the department are listed or 'prescribed' in the legislation. This includes live animal exports, red meat and meat products, seafood, dairy, etc. The legislation sets out the list of requirements that must be met by an exporter before prescribed goods can be exported from Australia.

The objective of the legislation is to enable trade by ensuring that export commodities meet importing country requirements and are fit for purpose. Exported meat products must be:

- fit for human consumption,
- accurately described and labelled,
- fully traceable, if necessary.

All premises where prescribed goods are prepared for export must be registered to undertake those operations by the DAFF under the Export Control Act 2020.

Preparation for export includes:

- slaughter of animals and dressing of carcasses
- processing, packing or storage of goods

[341] Australian Government. Export Control Act 2020 Export Control Act 2020 (legislation.gov.au)

- pre-export quarantine or isolation, treatment, and testing of livestock
- treatment of goods
- handling or loading of goods

People participating in Australia's export industry are subject to an integrity test called the fit and proper person test when applying for export licences and other regulatory approvals. The Fit and Proper Person (FPP) Test is where the Secretary of the Department decides whether a person, or company, is of a trustworthy nature and demonstrates the personal integrity to export agricultural goods from Australia. It is applied when someone is applying for an export licence, registering an export establishment, proposing an export arrangement, or being appointed as an authorised officer, approved assessor, or approved auditor (Export Control Act 2020, section 372). The test applied by the Department includes consideration of criminal convictions, the making of false or misleading statements, having previously contravened the Act, previous history as an applicant or licence holder, who the person associates with, financial interests. The roles in meat processing and export that require a FPP include: applicants and holders of meat export licences, auditors, third-party authorised officers performing inspection activities, and halal certifiers.

2.2 Export control rules

Export Control (meat and meat products) Rules 2021[342] provides more detailed specific commodity regulatory requirements than the Export Control Act in this case specifically for meat and meat products.

2.3 ECA Approved Arrangement

The purpose of the Approved Arrangement (AA) is to clearly describe those processes, procedures, and practices which, when applied by the occupier as described in the arrangement, provides the fundamental regulatory foundation as to how the department can issue export certification to an importing country with the appropriate confidence levels they require as to the accuracy and integrity of the consignment being exported.

2.4 Export licence

Exporters of edible meat, offal (including casings) and/or meat products of cattle, sheep or goat are required to hold a meat export licence.

Licencees are assessed on both technical competency and integrity. An AUS-MEAT Certificate of Accreditation is acceptable proof of technical competence. Integrity is assessed using the FPP Test. The applicant and all nominated persons listed on the application will be assessed by the department.

2.5 Export registration

Meat export establishments must be export-registered and comply with the Australian Meat Standard and participate in Australian monitoring programs such as the National Residue Survey (NRS) and National Carcase Microbiology Monitoring Program. Exporters must meet requirements for products and commodities to be accepted for import into specific overseas countries. Exporters are registered to be only able to export to specific markets for which their AAs are designed to comply.

[342] Export Control (meat and meat products) Rules 2021 Federal Register of Legislation - Australian Government

2.6 Importing country requirements

The Manual of Importing Country Requirements, (MICoR)[343] sets out requirements that exporters and DAFF must meet for products and commodities to be accepted for import into specific overseas countries. Exporters should also make enquiries in the country of import, either through the importer or directly, to confirm that their product meets the current importing country requirements. Exporters should seek other sources of information on commercial specifications for meat imported into a specific country because MICoR sometimes only includes requirements for which DAFF needs to provide certification.

2.7 Additional certification that may be required

Organic: If the export goods are to be labelled or described as organic or bio-dynamic, the operation must be certified organic by an approved certifying body to show that it complies with the National Standard for Organic and Bio-dynamic Produce.[344]

Halal: If the export is to be sold as halal certified, the registered establishment must seek accreditation with an approved Islamic organisation (AIO) who holds approval for the markets to which product is to be exported. Halal accreditation must be included in the establishment's AA. Halal certification is issued by both an AIO and DAFF under the Australian Government Approved Halal Program (AGAHP).

Labelling claims is another element – if an establishment can demonstrate the claims with a supporting system the AA will reflect document the system and those claims can appear on the product label.

AUS-MEAT accreditation is required. If the export product is deriving from ovine, bovine, or caprine species, it must have AUS-MEAT accreditation to process the meat for export.

3. Physical process

3.1 Primary packaging

When the primary packaging is, for example, a vacuum pack, the film is marked with the establishment number of the packing establishment. Additionally, labels may be applied either on the outer surface of the packaging film, or within the packaging. Some countries prescribe the use of labels on the pack and the information that those labels contain.

3.2 Carton

Cartons have lids that are sealed in place with a label on the end. For some markets the label is duplicated on the inside of the carton, sealing the plastic carton liner bag.

3.3 Container

Loading of containers of meat and meat products for export must be performed under the supervision or direction of a person designated in the approved arrangement at the establishment where the loading for export occurs, or under supervision or direction of a Commonwealth authorised officer. The AA must detail the procedures that will be followed during the loading for

[343] DAFF. Manual of Importing Country Requirements. Meat | Micor (agriculture.gov.au)
[344] DAFF Export National Standard for Organic and Bio-Dynamic Produce. National Standard for Organic and Bio-Dynamic Produce - DAFF (agriculture.gov.au)

export. [345] The usual practice to load the whole container at one time, but progressive loading may take place under certain conditions.[346]

Containers are sealed with official Australian Government seals to prevent non-authorised entry and details recorded on official export documentation.[347] Shipping in airfreight containers require additional controls.[348]

3.4 In transit protection

Exporters are now often using time-temperature real-time data loggers to inform the supply chain of the adequacy of temperature control during shipment[349]. These loggers usually provide accurate reporting of their location at the time of temperature recording and may provide additional information such as whether they are exposed to light. These data may contribute to detecting any tampering of a shipment and contribute to supply chain confidence in product integrity or be used to investigate and provide evidence should issues occur in transit.

4. Documentation

4.1 Export permit

The DAFF Export Documentation System (EXDOC) is used to generate export documents, which includes export permits and certificates and related documents as required by importing countries.

Exporters can access EXDOC, and request export permits, certificates, and related documents. This is usually done through third party IT systems which are integrated with individual meat establishment inventory and other IT systems.

An export permit is required for meat, offal and meat products intended for export. The primary function of an export permit is to verify that product is eligible for export to the intended destination of import. The Australian Border Force requires an export permit before issuing export clearance.

Applying for an export permit[350]

Before meat or meat products can be exported, the exporter must be in possession of an export permit. The electronic application (request for permit (RFP)/request for export documentation(REX)) is made to the department using EXDOC/NEXDOC. NEXDOC[351] , the Next Export Documentation System (NEXDOC) modernises the existing IT system platforms of EXDOC and includes additional features.

Declaration of 'verification of compliance'

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[345] DAFF (2022) Meat Export Policy: Loading for export and export permit application and issuing policy Loading for export and export permit application and issuing policy.docx (live.com)

[346] DAFF (2001) Meat Notice: Protocol for using of shopping containers for on-plant storage and progressive loading. MN 2001/01 Shipping containers for on-plant storage and progressive loading

[347] DAFF (2019) Industry Advice Notice: Implementation of new Official Marks – bolt seals and tamper-indicative seals. MN 2019-02 Implementation of new Official Marks - bolt seals and tamper-indicative seals

[348] DAFF (2002) Meat Notice: Airfreight Inspection Arrangements for Export Meat MN 2002/01 Airfreight inspection arrangements for export meat

[349] Meat & Livestock Australia (nd) Managing the cold chain and shelf life of chilled vacuum packed beef and sheet meat. Guide to data loggers and the shelf life model V3.docx (mla.com.au)

[350] DAFF (2022) Meat Export Policy: Loading for export and export permit application and issuing policy Loading for export and export permit application and issuing policy.docx (live.com)

[351] DAFF (2022) Meat Export Policy: Loading for export and export permit application and issuing policy Loading for export and export permit application and issuing policy.docx (live.com)

As part of the submission of the RFP application to the department (and issuing of the export permit and government certificate), a declaration verifying compliance must be made. This declaration must state that the meat and meat products described in the application meet the conditions of export and any relevant importing country requirements. The verification process must be conducted by a person who is authorised to use the EXDOC/NEXDOC system and appears on the establishment registration as someone in management or control for the establishment where the meat or meat products are last prepared before export. Auditable evidence must be maintained for all RFP compliance declarations made.

4.2 Meat Transfer Certificate

Export legislation (Export Control (Meat and Meat Products) Rules, (5-38)), requires the transfer of meat and meat product between establishments to be accompanied by a Meat Transfer Certificate (MTC), which can be either manual or electronic. Further details can be found in Chapter 11 (3.4).

4.3 EXDOC[352]

The EXDOC system provides for Electronic Data Interchange (EDI) and computer processing of documentation required by the department when issuing Export Permits and Certificates for meat and meat products. The transfer of messages between the department's EXDOC system and Exporter Systems adheres to the rules for Electronic Data Interchange for Administration, Commerce and Transport (EDIFACT).

The central documents involved are the RFP, provided by the exporter, and the Certificate, provided by the department. RFPs are processed by EXDOC, and if valid are allocated an Export Permit Number (EPN). The end result of such interchanges will normally be one or more Certificates, which can be produced by EXDOC in paper or electronic form. Paper Certificates are produced at the department's regional offices on specialised security-enhanced paper, while the electronic versions, if required, are transmitted directly to the relevant destination country government authority. EXDOC will also support remote printing of Certificates to exporter designated sites.

An export can often involve a number of parties, for example, in the case of meat, a slaughtering establishment, a packing establishment, the exporter, or agents acting on behalf of any or all of these. Typically, each party has partial input to an RFP, and will wish to pass the RFP on to the next party in the export cycle when their input is finalised. EXDOC regards all parties acting on behalf of an exporter as agents for that exporter.

4.4 eCert[353,354]

Australia issues certificates through eCert to a number of trading partners. eCert is an electronic certification system for government to government sanitary and phytosanitary certificates issued for traded food and agricultural commodities. It facilitates the exchange of information for traded agricultural products between governments regulators involved in cross border trade where export/import certification is required to facilitate entry of product.

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[352] DAFF (2023) EXDOC Exporter Interface System Specification. Version 9.9 EXDOC Exporter Interface System spec v9.7 October 2022

[353] DAFF (2010) EXDOC. eCert General User Manual. AQIS 2010 eCert General User Manual

[354] UN Economic Commission for Europe (UNECE) e-CERT: Electronic SPS Certificate. e-CERT: Electronic SPS Certificate | UNECE

Unlike paper-based certification, eCert uses secure transmission of data directly between the exporting and importing authorities. This removes risks of loss, damage, fraudulent alteration, or logistical delays which can occur with physical certificates.

The solution is reflecting established business processes that operate in accordance with international standards and bilateral agreements made by government regulators.

The structure of an electronic SPS certificate has been published by United Nations Centre of Trade Facilitation and Electronic Commerce (UN/CEFACT) as a global international standard under the name e-CERT.

4.5 Meat Messaging

Meat Messaging is an industry program administered by AUS-MEAT with program management through an industry committee (Red Meat Supply Chain Committee)[355] that has facilitated entry of some products into the USA.

The Meat Messaging system is an online (cloud-based) tool used to send and receive consignment specific information required by competent authorities to facilitate safe trade in meat and meat products. The system uses the internationally recognised GS1 standards for numbering and barcoding and GS1 EANCOM[356] electronic message standards. Meat Messaging does not replace existing regulatory activities, it supplements them, by providing accurate and transparent end-to-end traceability.

Electronic messages uploaded to Meat Messaging are derived from carton barcodes uploaded to a company's inventory/logistic system. Carton barcodes are mandatory and can be read by anyone involved in the handling and distribution of a product along the supply chain using a scanner containing publicly available software. For meat cartons, applied barcodes are a machine-readable version of information printed onto a meat carton label.

Australian exporting establishments registered for Meat Messaging send a Meat Messaging Message to the Meat Messaging portal for every shipment that leaves the establishment. The industry program holds the meat consignment information in a secure standards-based industry cloud portal. The Meat Messaging message information that is uploaded to the Meat Messaging portal is the same information that can be accessed on the physical carton/case/carcase. The Meat Messaging industry portal is accessed by supply chain participants and regulatory authorities to determine the authenticity, verification, and traceability of meat products.

The USA requires that a unique shipping mark is applied to all cartons of edible meat and meat products for import to the USA[357]. Shipping mark details are included on the health certificate and are used to support the identification and traceability of the meat and meat products. One of the more common reasons for the rejection of exported edible meat and meat products to the USA is due to missing, or illegible shipping marks. In these instances, FSIS has allowed the competent authority of the exporting country, or their agent, to remark impacted cartons at the exporters' expense. FSIS approved the use of barcodes to verify whether containers of imported product with

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355 AUS-MEAT Meat Messaging Production Site. Login to Meat Messaging - Production site

356 GS1 EANCOM is a subset of UN/EDIFACT, the international standard for Electronic Data Interchange (EDI). UN/EDIFACT accounts for over 90% of all EDI messages exchanged globally and is used by almost all national customs administrations, all major seaports, a large range of companies (including over 100,000 in the retail sector), and throughout international supply chains. Australian Government issued export e-Certification and Australian electronic Meat Transfer Certificates (eMTC) are also UN/EDIFACT compliant.

357 DAFF (2021) Meat Notice: Alternative protocol for confirming illegible or missing shipping marks for packed products (meat) exported to USA. MN2021 - Alternate protocol for managing illegible or missing shipping marks for the packed products (meat) exported to the USA (agriculture.gov.au)

missing or completely illegible shipping marks are part of a lot certified on the accompanying foreign inspection certificate. By access to the Meat Messaging portal, it is possible to verify the correct shipping mark to be applied to cartons on which the shipping mark is missing or illegible.

5. Outcome

As highlighted in this chapter – the Australia's export certification system is substantially underpinned by a range of government and industry systems, that are auditable, that ensures the integrity of product passing through the system both at the commercial level, and importantly at the government level where export certificates must accurately match consignments. Australia's ongoing commitment is to ensure supporting integrity systems remain accurate and contemporary particularly as consumer preferences change in addition to export market requirements.

The integrity of this component of the export chain can be measured by:

- Ongoing export sales to our international customers
- Foreign audit reviews of our export certification system
- Feedback from import authorities for non-compliance

The Australian government and industry take extremely seriously the performance of the integrity of the export processor to import chain. Performance of this outcome is monitored regularly through the Export Meat Industry Advisory Committee[358], a joint industry/government committee which is the primary formal consultative committee between the meat industry and DAFF as the meat export regulator. EMIAC is kept informed of issues and assesses the performance of Australian export systems' performance and recommends system changes where required.

The Export Meat Industry Advisory Committee (EMIAC)'s monitoring includes updates in information across the export integrity system, including Point-of-Entry rejections by importing countries. This includes published records of point of entry failures by some of Australia's key meat and meat product trading partners, such as the United States, which identifies reasons for rejections and routinely monitored by interested parties and regulators around the world.

The most comprehensive and transparent inspection system is that of the USA. Analysis of rejection reasons [359] reveals very few rejections of Australian product are associated with defects that could be related to food safety.

[358] DAFF. Export Industry Advisory Committee. Export Meat Industry Advisory Committee (EMIAC) - DAFF (agriculture.gov.au)

[359] FSIS Inspection – Import and Export Data Import and Export Data | Food Safety and Inspection Service (usda.gov) ; AUS-MEAT Meat Messaging Production Site. Rejection reason summary. Rejection Reason Summary (meatmessaging.info)

16. Shelf life of chilled Australian red meat products

Summary

The Australian red meat industry has for many decades exported high value chilled red meat beef and lamb products globally. Australian chilled red meat products, prepared through predetermined production pathways that include both long grain fed and grass fed, tailored to exact customers specifications, ensures the optimal eating experience.

This eating experience is enhanced through the chilled pathway through allowing continual aging, resulting a more tender product. Australia has extensive experience in ensuring controlled chilled cold chain pathways through the necessity of moving meat products across a vast continent and secondly moving meat products globally. This necessity is brought about through Australia being a secure provider of foods, exporting around 65% of the red meat product we produce.

The Australian red meat industry has invested substantially through its R&D organisations to fully understand the pathway and characteristics that impact on shelf life of chilled product including optimal eating quality. Good product hygiene combined with excellent time temperature-control, and the latest packing, wrapping, and sealing technology ensures long shelf life for beef of in excess of 120 days and 90 days for lamb. In addition to highly satisfied customers, the use of this technology ensures greater product value is captured in Australia and ultimately returned to producers; lower energy cost through only needing to chill product as opposed to freezing product; and lower food waste as a result of longer shelf life.

Importing authorities can take comfort in Australia’s chilled meat production processes and pathways being regulated closely by Australians competent authority for export certification being the Department of Agriculture, Fisheries and Forestry; and is transparently documented in each regulated establishment’s Approved Arrangement. This production system is extremely safe and mature.

Contents

1. Chilled meat

The chilling of Australian beef and lamb has had a long history in providing outstanding high-quality product with exceptional eating characteristics to our discerning export customers, particularly in the high-end restaurant trade around the globe. The scope of this chapter is chilled meat in export markets: chilled carcases, and vacuum-packed primals.

1.1 History

During the early 1960s scientific work described the preservation (extended shelf life) of beef using flexible packaging films, particularly those with low oxygen permeability, that, when held at low temperatures, would suppress the growth of bacteria that cause rapid spoilage in air and the development of a microbial community that had less adverse effect on meat quality (Ingram, 1962).

During the late 1960s, because of advances in packaging films and technology, it became possible for Australia to export chilled beef to distant markets, initially Japan, with chilled primals and subprimals.

The bacterial community (microbiome) of chilled vacuum-packed meat was found to be predominantly lactic acid bacteria (LAB), particularly *Lactobacillus* sp., many of which were later moved to a new genus, *Carnobacterium* (*carne* is Latin for meat). When beef of normal pH (5.4-5.8) was packed in a film of low oxygen permeability (<100 cm^3/m^2/day at 25°C) with an atmosphere of 20% carbon dioxide and <1% oxygen, LAB would grow to be the dominant bacteria at the time of spoilage (Aubrey F. Egan, 1983). Beef was reported to have a shelf life of up to 12 weeks at 0-1°C and lamb up to 8 weeks at -1°C (Aubrey F. Egan, 1983; Aubrey F. Egan & Shay, 1988). (Note that the carbon dioxide resulted from the metabolism of residual oxygen in the vacuum pack by muscle).

1.2 Process

In the most common process, carcases are chilled, and then cut into primals before packaging (see chapter 8, Chapter 13). Up to this stage, chilling has been applied to manage the safety of product. Primals are vacuum-packed, placed in cartons, and chilled to their final storage temperature. During this process, the control of product temperature begins to have an impact on the shelf life of the product.

1.3 Prerequisites for a long shelf life

Aubrey F. Egan and Shay (1988) identified the pre-requisites needed to optimise the shelf life of vacuum-packed meats as:

- A low initial bacterial count
- Packaging film with low oxygen permeability
- Good control of temperature throughout the storage period

Since the 1980s improvements have been made in product hygiene, implementation of good packaging practices and temperature control through the supply chain leading to longer shelf life. The reasons for this change in shelf life and an explanation of Australian shelf life science was reviewed by Sumner, Vanderlinde, Kaur, and Jenson (2021).

1.4 Achievable shelf life

The Oxford English Dictionary defines shelf life as: The length of time that a commodity may be stored without becoming unfit for use or consumption.

Shelf life refers to the deterioration in characteristics such as colour, odour and taste that occur once a product is processed and is being stored. These organoleptic or sensory characteristics can be assessed at all points along the marketing chain and judged by consumers.

All meat and meat products have a shelf life that is determined by the length of time that the characteristics of the product are expected to remain acceptable (i.e., suitable for human consumption) under specified conditions of packing and storage.

Australian chilled beef primal cuts are vacuum-packed giving Australian beef a shelf life of up to 120 days under optimal storage conditions.[360] Data collected, often under well-controlled conditions, often achieves longer, but there is some deterioration in product quality and little commercial advantage in claiming the additional shelf life, which is the reason why the industry usually claims 120 days only.

Australian chilled lamb primals are usually considered to have a shelf life of 90 days, which is a realistic maximum under optimal storage conditions.

An explanation for the long (and increased) shelf life and account of Australian shelf life science was presented by Sumner et al. (2021).

1.5 Spoilage

Shelf life may come to a premature end, through spoilage, caused by the growth and metabolism of specific bacterial species, particularly if any of the prerequisites for long shelf life are not met (1.3 above). Some spoilage bacteria seem to be frequently present, whereas other may only be present intermittently.

An odour, which may be described as dairy or cheesy, is caused by microbial by-products accumulating in the headspace around the meat and noted on opening of the vacuum bag. This normal near-to-end of shelf life 'confinement odour' dissipates within minutes, and meat is suitable for consumption. This observation may be followed soon after by a more persistent odour and a definite end of shelf life.

High pH meat, and presence of residual oxygen (or use of a packaging film with a high oxygen transmission rate) are often associated with spoilage. *Brochothrix thermosphacta* can produce unacceptable dairy-like odours caused by acetic, isobutyric and isovaleric acids (Campbell, Egan, Grau, & Shay, 1979). *Shewanella putrefaciens* produces hydrogen sulphide (H_2S) which reacts with myoglobin to produce sulphmyoglobin which results in green discolouration. Some *Pseudomonas* species can also produce H_2S (D. J. Nicol, Shaw, & Ledward, 1970).[361] Some lactobacilli such as *Latilactobacillus sakei* can produce H_2S which results in greening (A. F. Egan, Shay, & Rogers, 1989).

Some *Clostridium* species are able to grow at low temperatures and spoil vacuum-packed beef and lamb, in spite of good control of the vacuum-packing process and maintenance of low temperatures. Meat may be softened, with production of large amounts of exudate (drip), foul odours, and sometimes large amounts of gas (Adam, Flint, & Brightwell, 2010). This kind of spoilage has been noted in many countries, but rarely encountered in Australian beef or lamb.

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[360] Meat & Livestock Australia. Beef Product Guide. beef-product-guide-global.pdf (redmeatgreenfacts.com.au)
[361] CSIRO Meat Industry Services (2006) Colour defects in meat—Part 2: Greening, Pinking, Browning & Spots MEAT_TECHNOLOGY_UPDATE_06-6.pdf (csiro.au)

1.6 Safety

The safety of chilled, vacuum-packed meat is not in question. The recognised pathogens associated with meat (see Ch 1 – public health risk) do not grow at chilled product storage temperatures (below the usual maximum refrigeration temperature of 4°C).

2. Changes to chilled meat during storage

During chilled storage many qualities of the meat change. The key parameter to be considered in judging the acceptability of the product for human consumption are the sensory properties, because no microbiological or chemical changes make the product unfit for human consumption.

2.1 Microbiology

Bacterial concentrations are low at the time of packing product into vacuum bags (Chen et al., 2019; Frank et al., 2019; Kaur, Shang, Tamplin, Ross, & Bowman, 2017; Kiermeier et al., 2013; Small, Jenson, Kiermeier, & Sumner, 2012) and growth occurs, even at a storage temperature of around -0.5°C and reach a level of between 10^7 and 10^8 cfu/cm^2. The maximum count obtained can depend on the methods used. It is common practice in the Australian meat industry to incubate microbiological tests for total bacterial counts or lactic acid bacteria at 25°C for 4 days, whereas standard methods (e.g., International Standards Organization) employ 30°C for 3 days, and some proprietary methods (e.g., Petrifilm™) are incubated at 35° for 48 hours. The lower incubation temperature allows bacteria which grow on meat during storage to be counted, as some will not grow at 30 or 35°C (Simmons, Tamplin, Jenson, & Sumner, 2008). The very low counts observed by Small et al. (2012) are not usually encountered, and may have resulted from a combination of storage and testing conditions.

High bacterial counts do not predict the safety or suitability of vacuum packaged product. Maximum bacterial counts of 10^7 to 10^8 cfu/cm^2 were recorded well before the shelf life of the product ended (Chen et al., 2019; Frank et al., 2019; Kaur, Shang, et al., 2017; Kiermeier et al., 2013). Organoleptic testing confirmed that these high bacterial counts do not predict poor smell, odour, or taste of the product.

The dominant bacteria in vacuum packaged meat are LAB. This group of bacteria are characterised as producing lactic acid from glucose, and this is believed to have positive effects on vacuum packaged product as they produce lactic acid, thereby lowering the pH and inhibiting the growth of other (potentially harmful) bacteria (Leisner, Laursen, Prévost, Drider, & Dalgaard, 2007). Many fermented foods such a cheese, yoghurt, salami, and pickled vegetables are produced using LAB, which are not recognised as causing disease. LAB have been confirmed as the predominant bacterial group in Australian vacuum packaged meat (Chen et al., 2019; Frank et al., 2019; Kaur, Bowman, Porteus, Dann, & Tamplin, 2017; Kaur, Shang, et al., 2017; Kiermeier et al., 2013; Sumner & Jenson, 2011). The LAB are usual *Carnobacterium* spp., but sometimes *Lactobacillus* spp. (Chen et al., 2019) may predominate. *Lactococcus* spp. and *Leuconostoc* spp. may also be found (Kaur, Bowman, et al., 2017; Kaur, Shang, et al., 2017).

Other bacterial groups can also be found, but at lower levels (Chen et al., 2019); Kaur, Bowman, et al. (2017); (Kaur, Shang, et al., 2017; Kiermeier et al., 2013). These bacteria may include *Enterobacterales* (*Serratia* spp., *Yersinia* spp., *Hafnia* spp., *Providencia* spp.) (Kaur, Bowman, et al., 2017; Kaur, Shang, et al., 2017; Kiermeier et al., 2013) and *Clostridium* ((Kaur, Bowman, et al., 2017; Kaur, Shang, et al., 2017). Specific spoilage bacteria such as *Brochothrix thermosphacta* may also be detected without being responsible for the loss of quality observed (Kiermeier et al., 2013).

2.1.1 Microbiological criteria for determining end of shelf life

Some countries and purchasers of meat use microbiological criteria as a means of controlling the sale/purchase of raw meat. Maximum bacterial counts of 10^7 to 10^8 cfu/cm^2 are reached well before the shelf life of the product ends (Chen et al., 2019; Kaur, Shang, et al., 2017; Kiermeier et al., 2013). Microbiological testing (for total bacterial counts, or LAB) only provide a very rough indication of the time that may elapse before the end of shelf life; if the maximum count has been reached, then there is less shelf life remaining than if it has not.

2.2 Chemistry

Chemical changes occur through the shelf life of meat. Some of those changes are the result of the activity of meat enzymes and their continued action on muscle proteins, while others are the result of bacterial metabolism. Changes in meat colour also occur, as the ability of the myoglobin to bind oxygen decreases and other reactions with myoglobin may occur (Lawrie & Ledward, 2006). Meat becomes more tender due to the continued action of proteolytic enzymes, and later the meat becomes very soft. Liquid may also be released from the meat (drip, weep, exudate), usually reddish in colour because of the presence of myoglobin. The packaging may become looser. A detailed analysis of changes in beef over long term refrigerated storage has been performed (Frank et al., 2020; Frank et al., 2019).

2.2.1 Chemical criteria for determining end of shelf life

Some countries and purchasers of meat have chemical criteria for acceptance of raw meat. The most common specification is for Total Volatile Basic Nitrogen (TVBN, or TVB-N) reviewed in detail by Bekhit, Holman, Giteru, and Hopkins (2021). Volatile basic nitrogen compounds arise from the degradation of proteins and other nitrogen (N)-containing compounds. The TVBN content increases with storage time of meat and often its accumulation pattern somewhat parallels other biomarkers of spoilage, such as microbial count and changes in sensory acceptability. Post-mortem TVBN levels are dependent on the level of microbial and enzymatic activities that lead to spoilage; therefore, they are used as indices of meat freshness.

In seafood the accumulation of trimethylamine (TMA) is a major contributor to TVBN has led to the adaptation of TVBN and TMA contents as quality indicators of seafood. The lack of information regarding muscle-specific enzyme systems in land-based meat, that are able to catalyse the formation of TMA similar to aquatic systems, does not support the use of TVBN and TMA as standard quality parameters. In terms of beef there is no specific threshold to interpret TVBN results against, and when compared against existing recommendations there is little relationship with other spoilage thresholds based for lipid oxidation, microbiology, colour, or sensorial traits like odour.

A common specification is that used in China for fresh (chilled) and frozen mutton and beef: < 15 mg TVB-N per 100 g (National Standards of People's Republic of China (GB/T 9961–2008)). Both the Korean Ministry of Agriculture and Forestry and the Egyptian Organisation for Standardization and Quality Control specify that 20 mg TVB-N per 100 g is the limit for 'fresh' (it may also be observed that 'not fresh' is not the same as 'end of shelf life'). There are no useful studies with red meat to correlate this objective chemical measurement with an end of shelf life, though there are a number of studies with other meat/fish products. The observed range of available TVB-N limits allows stakeholders to select a limit that suits their narrative or agenda, rather than one that provides a true reflection of product freshness.

Australian beef can maintain low TVB-N, especially if the temperature is well-controlled, but will exceed importing country specifications prior to the end of organoleptic shelf life[362] (Chen et al., 2019; Frank et al., 2019).

2.3 Sensory

Many sensory parameters change little over storage time and then deteriorate relatively rapidly, heralding the end of shelf life. The packaging may become looser. Meat becomes more tender due to the continued action of proteolytic enzymes, and later the meat becomes very soft. Liquid may also be released from the meat (drip, weep, exudate), usually reddish in colour because of the presence of myoglobin. Changes in meat colour also occur, as the ability of the myoglobin to bind oxygen decreases and other reactions with myoglobin may occur (Lawrie & Ledward, 2006). A detailed analysis of changes in beef over long term refrigerated storage has been performed (Frank et al., 2020; Frank et al., 2019).

Often the first sensory characteristic to deteriorate is the odour on opening the pack (Kaur, Shang, et al., 2017; Small et al., 2012); the confinement odour is volatile and is only noticed soon after opening the pack.

3. Effect of storage conditions

3.1 Temperature

The effect of temperature on spoilage and shelf life of meat is well-known. It is 'obvious' that lower temperatures are better, but the relationship between temperature and time to end of shelf life has not been so obvious as to become well established in specifications or regulation. The regulated limits for refrigeration in some countries, usually specified as 0-5°C, are inadequate for long term storage of meat for two reasons: spoilage rates at 0°C and 5°C are vastly different, and storage below 0°C and close to the freezing point of meat is most satisfactory.

Gill et al. (1988) showed that small rises in temperature reduce shelf life significantly: at temperatures of 0°, 2° or 5°C, the storage life was reduced by about 30, 50 or 70%, respectively, compared with storage at -1.5°C.[363]

Many countries have regulations that specify the storage of refrigerated food at 0-4°C (32-40°F). In Australia, Food Standards Australia New Zealand specifies in the Food Standard Code, less than 5°C for hazardous foods[364] and the *Australian Standard for Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS 4696) does the same for smaller cut portions of meat. Such temperature specifications are usually framed in the context of food safety, rather than spoilage.

[362] Mahmoud, A H et al. (2020) Australian beef shelf life verification trial. MLA Report V.MFS.0438. Australian beef shelf life verification trial | Meat & Livestock Australia (mla.com.au)
[363] Gill, C., Phillips, D. & Loeffen, M. (1988b). A computer program for assessing the remaining storage life of chilled red meats from product temperature history. In: *Proceedings 1st International Refrigeration Conference: Refrigeration for Food and People*, 1988, Brisbane p 35-39
[364] FSANZ. Australia New Zealand Food Standards Code - Standard 3.2.2 - Food Safety Practices and General Requirements (Australia Only) (legislation.gov.au)

It is possible to store meat below 0°C without it freezing, and it is desirable to do so. The freezing point of meat begins at around -1.5 to -2.0°C (James & James, 2002) becoming hard frozen around -6°C. Storage of meat at a temperature of -1 to 0°C is desirable and practical.[365]

4. Data to support shelf life claims for chilled Australian red meat

4.1 Achieved shelf life for beef

Australian beef is traded around the world with few shelf life problems being encountered, therefore the expiry/best before/use by dates on the product must be aligned with the performance of the product under the conditions of the supply chain, or the product is consumed well within the labelled shelf life. This raises an important distinction between the determination of shelf life in the laboratory (or processor's cold room) and the conditions encountered in the supply chain.

A number of published peer-reviewed articles and reports have provided data on Australian beef shelf life under different conditions (Table 1). The shelf life achieved in laboratory and (partial) supply chain studies support the usual commercial claim of 120d shelf life at -0.5°C.

Table 1: Beef shelf life in laboratory and supply chain studies

Primal	Conditions	Measurement defining shelf life	Shelf life	Reference
Striploin Cube roll	Laboratory at -0.5°C	Organoleptic	26w	(Small et al., 2012)
Striploin	Seafreight to China then -1°C	Organoleptic	>20w	(Chen et al., 2019)
Striploin	Seafreight to Japan, then -0.5°C	Organoleptic	18-21w	(Sakai et al., 2020)
Brisket Eye round Topside	Laboratory at -0.45°C	Organoleptic	>20 w	Barlow et al., CSIRO[366]
Striploin OP Rib	Airfreight to Egypt, then -0.5°C	TVB-N, Total Viable Count, Drip %	18w	Mahmoud, et al., GAVS[367]

4.2 Achieved shelf life for lamb

Australian beef is traded around the world with few shelf life problems being encountered, therefore the expiry/best before/use by dates on the product must be aligned with the performance of the product under the conditions of the supply chain, or the product is consumed well within the labelled shelf life. This raises an important distinction between the determination of shelf life in the laboratory (or processor's cold room) and the conditions encountered in the supply chain.

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[365] CSIRO Meat Industry Services (2002) Storage life of meat https://meatupdate.csiro.au/Storage-Life-of-Meat.pdf

[366] Barlow, R et al. (2016) The effect of purge on the shelf life of vacuum packaged chilled meat. MLA Report G.MFS.0313. The effect of purge on the shelf life of vacuum packaged chilled meat | Meat & Livestock Australia (mla.com.au)

[367] Mahmoud, A H et al. (2020) Australian beef shelf life verification trial. MLA Report V.MFS.0438. Australian beef shelf life verification trial | Meat & Livestock Australia (mla.com.au)

A number of published peer-reviewed articles and reports have provided data on Australian lamb shelf life under different conditions (Table 2). The shelf life achieved in laboratory studies support the usual commercial claim of 90d shelf life at -0.5°C.

Table 2: Lamb shelf life in laboratory studies

Primal	Conditions	Measurement defining shelf life	Shelf life	Reference
Bone in and Bone out shoulders	Laboratory at -0.3°C	Organoleptic	>12w	(Kiermeier et al., 2013)
Bone in shanks	Laboratory at -1.2°C	Organoleptic	17w	(Kaur, Shang, et al., 2017)
Shoulder	Laboratory at -0.5°C	Organoleptic	>11w	Holds et al., SARDI[368]
Shoulder	Laboratory at 0 to -2.4°C	Organoleptic	12w	(Sumner & Jenson, 2011)

4.3 Shelf life of chilled then frozen meat

Meat is sometimes chilled, and after a time, it is frozen. This process may be used intentionally to allow desirable meat qualities to develop prior to freezing, or may be used to preserve meat that has not been sold, and then may have its shelf life extended by freezing (Coombs, Holman, Friend, & Hopkins, 2017). (See Ch 17- Frozen shelf life).

4.4 Shelf life of chilled carcases and sides

The practical storage life of carcases/beef quarters as a consensus of opinion[369] is:

Carcasses/quarters in air (0-2°C)	
Beef in Stockinette	3-4weeks
Beef in polywrap	12 days
Lamb/mutton	10-13 days
Lamb carcases flushed in 100% CO_2	up to 16 weeks

5. Predicting shelf life in the chilled transport chain

MLA funded University of Tasmania (UTAS) to produce a model for the prediction of beef and lamb shelf life when vacuum-packed and stored chilled. [370]

Temperature by far has the highest impact of overall shelf life of product. Providing that the meat is of good quality (pH), and packed well, controlling temperature gives the best insurance for a long shelf life. A short period of temperature abuse may not have a significant impact on product.

The Shelf Life Calculator developed by UTAS in conjunction with MLA can be used to predict remaining shelf life providing the TVC at the time of packing can be estimated, and the time:temperature record is available. Once these parameters are entered into the model and either the lamb or beef is selected, predictions for Total Viable Count (TVCs) and days remaining until detection of a strong odour on opening the pack can be predicted. The models were validated by

[368] Holds, G et al. (2010) Extended shelf life evaluation of sliced lamb shoulders. MLA Report A.MFS.0196. Extended shelf-life evaluation of sliced lamb shoulders | Meat & Livestock Australia (mla.com.au)
[369] CSIRO Meat Industry Services. (2002) Storage Life of Meat. CSIRO (2002) Storage life of meat
[370] Meat & Livestock Australia. Creative Commons Licenses | Meat & Livestock Australia (mla.com.au) Shelf Life Calculator

independent data and have good agreement between the observed and predicted shelf lives of vacuum-packed cuts.

The Shelf life Calculator is now being used widely in the industry. The shelf life output is not very sensitive to the TVC input to the model, so many establishments use a statistically based count based on carton meat TVC testing (median, 75th percentile etc). Time:temperature data is now most often available in real time through temperature loggers that transmit the data to the cloud; in some cases, the Shelf Life Calculator has been incorporated into the dashboards of the datalogger suppliers. [371]

6. Regulation of chilled shelf life

Most countries do not set standards for chilled, vacuum packaged meat, reflecting the high food safety status of these products plus an established cold chain which allows marketing through the retail and consumer phases in their countries. Examples of countries that do not set mandatory shelf life (expiry date) standards include the USA, the European Union, Japan, and Australia.

China is a special case because the industry entered into an agreement with the Chinese Government to provide a maximum of 120 days shelf life on chilled beef and 80 days for sheep meat and provide support to Chinese importers to understand and improve cold chain management.

Japan has a voluntary industry standard set by the Japan Meat Traders Association (JMTA) with different standards for each country exporting to Japan. The standards are based on testing conducted many years ago of Australian product and a large margin for variation was added to the observed organoleptic shelf life. The JMTA shelf life guidelines for Australian beef allow a shelf life of 77 days but many importers are moving away from this standard as they realise that the standard is unnecessarily conservative.

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17. frozen shelf life

17. Shelf life of frozen Australian red meat products

Summary

Australia has over 150 years of experience exporting frozen food, including red meat products internationally, which commenced in 1861/ Freezing provides a long shelf life for products.

The freezing of red meat products in Australia and its corresponding shelf life is undertaken through highly regulated processes to ensure only safe food with strong quality attributes are consistently achieved. The Australian Government and Australian industry take this processing step extremely seriously.

The regulated normal practice on Australian meat processing establishments is that exported meat will be reduced in a controlled regulated environment and process to a storage temperature of -18°C. As highlighted in this chapter, generally a use by date of 24 months, is the general industry standard that ensures high quality attributes of the product is maintained. The Australian red meat industry and the Australian government invest substantially in joint R&D to continually refine and improve freezing and shelf life technology, and validation of processes and technology through the collection of large datasets.

Shelf life of frozen red meat products in Australia complies to *The Australian Standard for Hygienic Production and Transportation of Meat and Meat Products* (AS 4696), and at export establishments is regulated by the Australian Department of Agriculture, Fisheries, and Forestry. Within each of these regulated export establishments, processes and controls relating to the freezing and labelling of frozen product will be documented and approved in their Approved Arrangement. Regulated inspections and audits will be conducted against this Approved Arrangement regularly. The outcome of this regulated process is that consumers, and importing authorities can be highly confident in the safety of the red meat products and its associated quality attributes.

Contents

1. Frozen meat

1.1 History

Freezing, as a method of preserving food, was known prior to modern technology enabling its widespread application (Lawrie & Ledward, 2006). Modern commercial mechanical refrigeration is suggested to have commenced in Sydney, Australia in 1861 and the first shipment of frozen meat from Sydney to London followed in 1868.[372] Over many years, frozen food and international trade in meat has flourished and enabled more countries to benefit from global food chains.

1.2 Volume

In 2020, 6.4 million tonnes of frozen red meat[373] was exported around the world, the second highest volume on record and a trade worth US$28.2 billion. The global trade in frozen meat more than doubled between 2000 and 2020.

Australia is a major exporter of frozen meat and has a rich history of shipping product to over one hundred markets worldwide. Australia is consistently among the top-three exporters of frozen beef and sheep meat during the decade ending 2020.

Australia exported more than 1.13 million tonnes of frozen beef and sheep meat in 2020, with the bulk of shipments spread across North Asia, Southeast Asia, North America, the Middle East, and Europe.

1.3 Regulatory system and oversight

1.3.1 The requirements of the Australian Standard

The *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696) requires that freezing of meat maintains and does not jeopardise its wholesomeness (Outcome of section 11 Chilling and Freezing). Some specific requirements include that:

> 11.4 all carcase parts are placed under refrigeration for freezing within two hours of stunning [if to they are to be frozen without prior chilling]
>
> 11.6 Refrigeration achieves prescribes temperature within a prescribed time and refrigeration index criteria are achieved (see Chapter 13, 2.7 Refrigeration Index)
>
> 11.8 carcase parts are maintained at the temperature prescribed

1.3.2 Oversight

The system for maintaining the wholesomeness and integrity of Australian meat exports is applied to frozen meat.

The Australian Government through the Department of Agriculture, Fisheries and Forestry (DAFF) who administers the Export Control Act (ECA) 2020, ensures that every carcase and carton of red meat produced for export meets all the requirements of the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696); and

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[372] Wikipedia. Frozen food. Frozen food - Wikipedia accessed 5.1.2023

[373] MLA calculations based on IHS Market Global Trade Atlas data; includes frozen beef, buffalo meat and sheepmeat from major exporting countries

importing country requirements. Components of this system include strong regulatory controls, traceability, product authenticity; high ethical standards throughout the production chain and particularly regarding animal welfare; strong assurance and monitoring systems; all resulting in accurate export certification.

The requirements of the Export Control Act and Rules, the Approved Arrangements, Australian Export Meat Inspection System (AEMIS) and Regulatory supervision are explained in Chapter 8, particularly, 2. Australia's Red Meat Export System.

1.4 Process

1.4.1 Processing prior to freezing

The processing of both chilled and frozen meat is identical to at least the end of the processing line when carcases are passed as fit for human consumption. The attention to hygiene (chapter 9) and traceability (chapter 11) is the same for all meat.

Product may be frozen immediately after boning and placing in cartons or may be frozen after a period of chilled storage.

1.4.2 Freezing process

The freezing temperature for meat isn't a single temperature, but begins at about -1.5°C and is completed (hard frozen) at about -5 to -6°C. Since constant refrigeration is applied, temperature decline slows at the point of phase change (Dykes, 2006).

Freezing usually occurs in a blast chiller using very cold air or in a plate freezer where cartons are held between very cold plates [374] Small stock carcases may also be frozen.[375] There are many factors that affect the time taken to freeze product, including the starting temperature, the final temperature, air speed, air/plate temperature, carton specifications etc. The freezing of meat in a plate freezer without the use of cartons has been investigated in Australia.[376]

Neither the Australian Meat Standard (AS4696) nor the Export Control (meat and meat products) Rules specify a temperature for storage of frozen meat, but the conventional temperature, specified by some countries, is -18°C (see below, 3.1 Temperature).

2. Safety and quality of frozen meat

The International Institute of Refrigeration (IIR) notes that 'the physical and biochemical reactions which take place in frozen food products lead to a gradual, cumulative and irreversible reduction in product quality such that after a period of time the product is no longer suitable for consumption (or the intended process)' (Bøgh-Sørensen, 2006).

During frozen storage microbiological growth is arrested, but meat will slowly deteriorate due to oxidative and other changes. Frozen storage life is normally limited by the development of adverse flavours caused by oxidative rancidity of fat. The temperature of storage, method of packaging and

[374] CSIRO Meat Research Laboratory. Meat Research News Letter. 76/1 29 January 1976. MEAT_RESEARCH_NEWS_LETTER_76-1.pdf (csiro.au)

[375] CSIRO Meat Research Laboratory. Meat Research News Letter. 80/2 21 April 1980 MEAT_RESEARCH_NEWS_LETTER_80-2.pdf (csiro.au)

[376] CSIRO Meat Industry Services 2009. Bulk-packed frozen meat for further processing: alternatives to current practice. Meat Technology Update 5/09. MEAT_TECHNOLOGY_UPDATE_09-5.pdf (csiro.au)

degree of saturation of the fat all affect the onset of these changes. The frozen storage life may also be reduced if the product is comminuted, because this process exposes more meat surfaces to oxygen.[377]

2.1 Microbiology

Many factors influence the growth and survival of microorganisms (bacteria, mould) in meat during freezing and frozen storage. However, the main factor affecting the growth of microorganisms during freezing is the availability of water (expressed as water activity, a_w). The transformation of water into ice significantly modifies the growth environment for microorganisms because water activity is progressively reduced preventing microbial growth (James & James, 2002).

Microorganisms do not grow below about -10°C (mould growth being most noticeable on meat held at low temperatures), thus spoilage is only normally relevant to handling before freezing or during/after thawing (James & James, 2002).

2.2 Chemistry

It is broadly accepted that fat oxidation remains the obstacle to very long-term storage of frozen meat (James & James, 2002). The initial reaction is between a molecule of oxygen and a fatty acid to form a peroxide. The presence of peroxides in fat does not change the flavour; rather, it is the breakdown products of the peroxides which produce the unpleasant rancid odour and flavour and determines the acceptable shelf life of the meat.

2.3 Sensory

In cartons, 'freezer burn' is the main appearance problem that may frequently affect the appearance of meat. Freezer burn results from the desiccation of the surface tissues, which produces a dry, spongy layer that is unattractive and does not recover after thawing (James & James, 2002).

While oxidation of oxymyoglobin can occur, affecting the colour of the meat (James & James, 2002), it is expected that the unacceptable changes in flavour, stemming from oxidative rancidity of fat, is the most likely sensory change in product (Lawrie & Ledward, 2006).

3. Storage conditions

3.1 Temperature

Early last century, -10°C was regarded as a suitable temperature for storing frozen food. However, lower temperatures were recognised as being more suitable for some purposes. In the late 1930s, the American Fruit and Vegetable Coalition advocated that a freezing temperature of 0°F (equivalent to -17.8°C) be maintained (advantageous for vitamin C levels in frozen orange juice, and largely on the basis that 0°F was a round number, rather than for scientific reasons (Bøgh-Sørensen, 2006). The IIR note that -10°C is a satisfactory temperature for meat storage (Bøgh-Sørensen, 2006). Lawrie (2006) reported that it is customary in Britain to store frozen meat at -10°C and notes research reporting that fats of beef and lamb are relatively resistant to such oxidation and may still be good after 18 months storage at -10°C. Research conducted in New Zealand in the 1980s stored lamb at -10°C with satisfactory results for 14-18 months, depending upon processing conditions (Winger,

[377] Food Science Australia (2002) Shelf life of meat. Storage life of meat

1984). Storage at a higher temperature would require less energy, providing economic and environmental benefits.

In 1964, the International Institute of Refrigeration recommended a minimum temperature of -18°C for frozen food.[378] By 1966 the Codex Alimentarius Commission was considering standards on frozen foods and recommended that the temperature of product should be maintained at -18°C (0°F) and that any rise in the temperature of product during transportation and unloading should be limited to very brief periods and never be warmer than -15°C.[379]

The current Codex Alimentarius *Code of Practice* recommends distribution of quick-frozen foods should maintain a temperature of -18°C but permits competent authorities to allow -12°C during transport with the product temperature reduced to -18°C as soon as possible.[380]

3.2 Time of storage

The IIR notes that 'storage life of nearly all frozen foods is dependent on the temperature of storage' and makes recommendations on practical storage life (PSL). PSL is defined as 'the period of frozen storage at a given temperature during which the product retains its characteristic properties and remains suitable for consumption or the intended process' (Bøgh-Sørensen, 2006). Few scientific publications present data on the PSL of meat at different storage temperatures (James & James, 2002).

The practical storage life suggested by the IIR (Table 1) should be subject to qualification:

1. Storage life for carcases are stated for unpackaged products. This may have reflected international trade in 2006 but changes in packaging practices may be expected to extend storage periods from those stated.
2. The IIR frames disclaimers around storage periods stating that their recommendations only provide a "*very rough guide* to their storage potential" and "*should not* be constructed as *absolute limits* to be applied rigidly"

Table 1: Practical storage life (PSL) in months of some frozen meat products

Product	**-12°C**	**-18°C**	**-24°C**
Beef carcass (unpackaged)	8	15	24
Beef cuts	8	18	24
Lamb carcass, grass fed (unpackaged)	18	24	>24
Lamb cuts	12	18	24
Veal carcass (unpackaged)	6	12	15
Ground beef	6	10	15

[378] Liebherr. The ideal freezer temperature. Why is -18°C the ideal freezer temperature? | Liebherr
[379] Joint FAO/WHO Program on Food Standards. Codex Alimentarius Commission. (1966) Report of the Second Session of the Joint ECE/Codex Alimentarius Group of Experts on Standardization of Quick (Deep) Frozen Foods. Annex I. Proposed Draft Provisional General Standard for Quick (deep) Frozen Foods at Step 3. ALINORM 66/25 October 1966. Microsoft Word - al66_25e.rtf (fao.org)
[380] Codex Alimentarius Commission. (2008). *Code of Practice for the Processing and Handling of Quick Frozen Foods*. FAO APPENDIX I (fao.org)

4. Shelf life of frozen Australian red meat

Meat & Livestock Australia (MLA) conducted a study to establish the PSL of frozen beef and lamb, such as would be exported from Australia.[381]

4.1 Experiment design

Australian beef and lamb cuts (strip loin and eye of loin, respectively) and manufacturing meat of varying fat levels were frozen at -18°C prior to transport to the Food Refrigeration & Process Engineering Research Centre (FRPERC) at the Grimsby Institute (UK). The cartons were then stored at -12°C, -18 °C, and -24°C until sampling and testing.

The data for highest fat-containing manufacturing meat are presented below, with literature suggesting that these products will deteriorate the quickest. Sensory scores for fat flavour in minced, cooked patties and a measure of oxidative rancidity (Thiobarbituric acid reactive substances, TBARS) are presented here as sensitive indicators of shelf life (Figures 2 and 3). Campo et al. (2006) investigated the flavour perceptions in beef and suggested that, as rancid flavours develop, there is a loss of desirable flavour notes. They reported that the higher the TBARS the less beef flavour could be perceived sensorially, with a strong relationship between TBARS level and perception of rancidity. They suggested that a TBARS value of around 2 could be considered the limiting threshold for the acceptability of oxidised beef.

A quantitative panel evaluation was performed on the meat using approximately ten assessors. The panel evaluated the samples on a ten-point quality scale in which intensity (having a characteristic quality in a high degree) ranged from very low (1) to very high (10). Scores less than 4 represent samples approaching unacceptable flavour.

4.2 Results

In this work, no clear relationships/trends between sample type, storage temperature, and time of storage were apparent in the majority of the measured quality parameters, apart from those relating to lipid oxidation and sensory evaluation.

The changes noted over 38 months storage for both frozen beef and lamb were considered to be insignificant (Figures 1 and 2).

[381] James, C. et al. (2022) The shelf-life of Australian frozen red meat MLA Final Report V.MFS.0428 The shelf-life of Australian frozen red meat | Meat & Livestock Australia (mla.com.au)

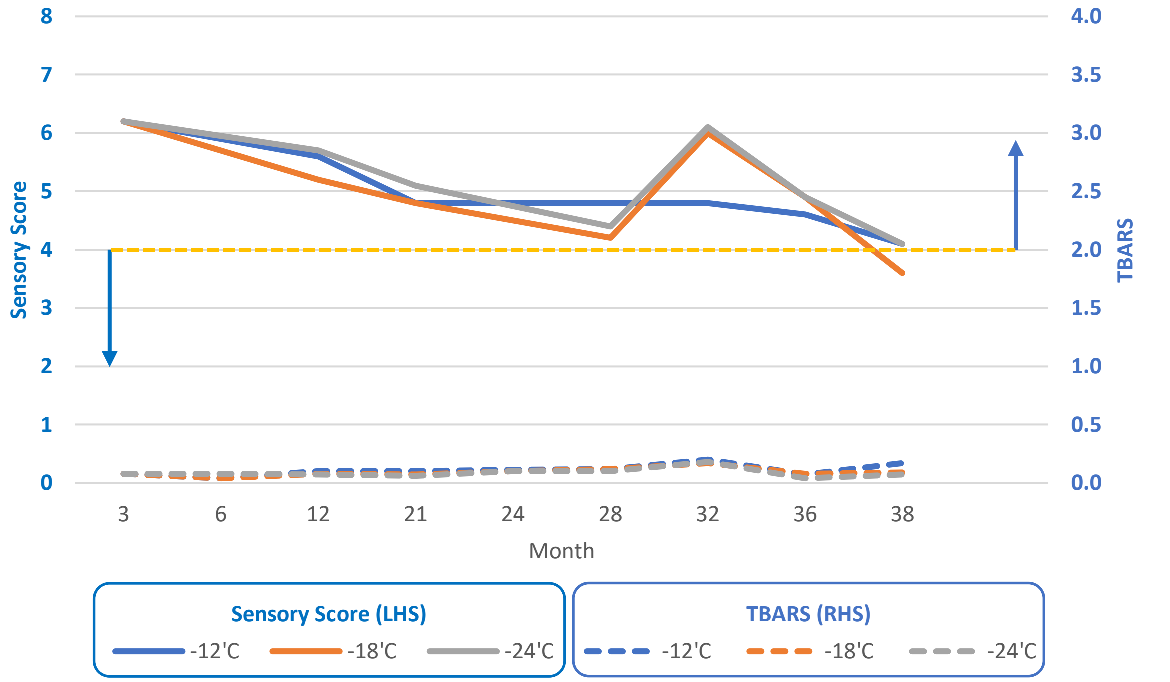

Figure 1. Frozen 65CL beef made into patties: mean sensory (solid line) and measure of oxidative rancidity [thiobarbituric acid reactive substances (TBARS) (mg malondialdehyde (MDA)/kg)] (Dashed lines) of samples measured at 3 (arrival), 6, 12, 21, 24, 28, and 32 months, stored at -12°C (green), -18°C (yellow) and -24°C (grey). The yellow dashed line represents a score approaching unfavourable sensory and oxidative rancidity (TBARS) results.

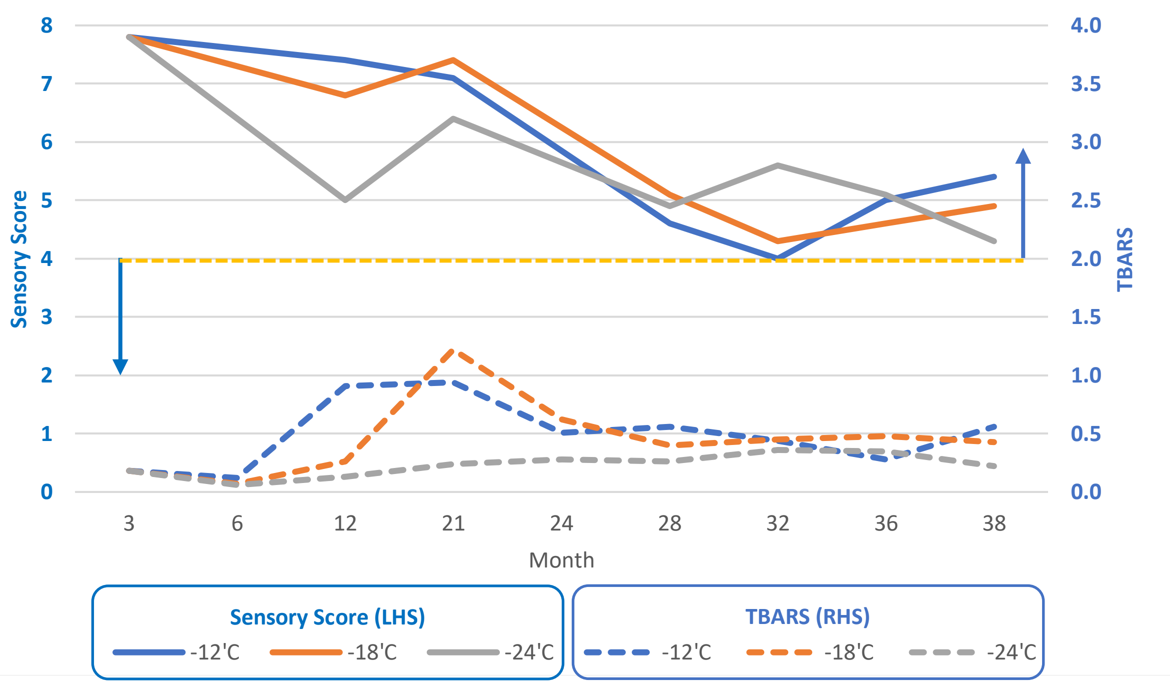

Figure 2. Frozen 65CL lamb made into patties: mean sensory (solid line) and measure of oxidative rancidity [thiobarbituric acid reactive substances (TBARS) (mg malondialdehyde (MDA)/kg)] (Dashed lines) of samples measured at 3 (arrival), 6, 12, 21, 24, 28, and 32 months, stored at -12°C (green), -18°C (yellow) and -24°C (grey). The yellow dashed line represents a score approaching unfavourable sensory and oxidative rancidity (TBARS) results.

4.3 Conclusions

While -18°C has become the standard temperature for the storage of frozen foods, red meat appears able to be stored successfully for many months or years at a temperature warmer than this threshold. No food safety hazards exist on frozen meat that has been held at, or reached, a temperature between -10°C and -18°C. Sensory degradation occurs only slowly at these temperatures and no food safety hazards arise. This study demonstrated that if held at, or around, -18°C, frozen beef and lamb can be stored without significant sensory degradation for a period of over 36 months. No food safety hazards arise.

Studies on beef and lamb quality over 1 year at -12°C and -18°C found no significant differences between the storage temperature in a range of chemical and meat quality parameters (Coombs, Holman, Collins, Friend, & Hopkins, 2017; Holman, Coombs, Morris, Bailes, & Hopkins, 2018; Holman, Coombs, Morris, Kerr, & Hopkins, 2017).

Qian et al. (2018) found no significant differences between the indicators for quality and shelf life of beef samples stored at -12 and -18 °C over a period of 168 days, which indicates that storage at -12 °C has nearly the same effects of preservation compared to storage at -18 °C.

5. Shelf life of chilled then frozen Australian red meat

Meat is sometimes chilled, and after a time, it is frozen. This process may be used intentionally to allow desirable meat qualities to develop prior to freezing, or may be used to preserve meat that has not been sold, and then may have its shelf life extended by freezing (Coombs, Holman, Friend, & Hopkins, 2017).

Studies on Australian beef suggest that storage for several weeks chilled can be followed by many months of frozen storage with satisfactory meat quality resulting (Holman et al., 2018; Holman et al., 2017).

Studies on Australian lamb suggest that chilled storage prior to conventional frozen storage can improve and preserve the meat qualities of lamb such as tenderness and colour stability parameters. Furthermore, the optimal pre-freeze chilled storage duration was identified as 2 to 4 weeks. Frozen storage proved acceptable for up to one year at both -12 and -18 °C regardless of prior chilled storage period with minimal quality deterioration (Coombs, Holman, Collins, et al., 2017).

6. Breaks in the frozen transport chain

A project conducted by MLA, CSIRO, and supply chain participants studied the effect of breaks in the frozen transport chain, such as when a container is off power, and the effect of cold chain breaks on product quality.[382].

Both shipping containers studied experienced significant periods during which no refrigeration was applied. There were three off-power periods, the longest of which was 13.5 hours. During these off-

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[382] Meat & Livestock Australia (2007) Effect of shipping practice on quality of frozen manufacturing beef. P.PSH.0200 Effect of shipping practice on quality of frozen manufacturing beef | Meat & Livestock Australia (mla.com.au)
Food Science Australia (2007) Do breaks in the cold chain affect frozen beef quality ? MEAT_TECHNOLOGY_UPDATE_07-1.pdf (csiro.au)

power periods, meat surface temperatures of cartons on the outside of the load rose by about 8°C to between -13 and -8.6°C. Meat surface temperatures within the load did not change.

In order to assess the effect of above specification temperatures on quality parameters of frozen manufacturing beef, quite extreme cases of un-refrigerated conditions were simulated, and the meat analysed. One set of six cartons was held at a constant -20°C, another set was allowed to warm in a similar manner to a container off-power for two days and a third set exposed to an ambient temperature of 25°C for five hours. The meat was stored at -20°C for four weeks prior to the first abuse, returned to -20°C for four weeks (to simulate the voyage to the USA) subjected to a second temperature abuse, then stored at -20°C for a further four weeks.

At the end of the 12 weeks storage period, the 18 cartons were ground using a similar procedure to that followed by the commercial grinders. Samples were taken and analysed for fat content, antioxidants, and products of lipid oxidation.

There were no differences in the amounts of α- tocopherol and β-carotene in either of the abused groups compared with the control, indicating that they had not been destroyed by accepting the free radicals of lipid oxidation.

Measurement of TBARS, peroxides and head space analysis for hexanal showed no differences between abused groups and the product stored at a constant -20°C. A sensory panel could not detect any significant difference between treatment groups.

These results indicate that frozen manufacturing beef exported by either refrigerated shipping container or 'conventional' shipping is not affected by short periods of exposure to ambient conditions or container off-power periods when subsequently stored for three months.

7. Regulation of frozen shelf life

Regulatory authorities in most countries do not mandate expiry dates, except where it can be scientifically shown that there is a food safety concern; rather, the convention in international trade is for the supplier to nominate a shelf life, which is usually applied to the product label (Table 2).

Table 2: Expiry date considerations for selected countries importing Australian frozen meats

Country	Requirements[383]
USA	Use-by dates may be printed on the label
EU	Labels on consumer-ready edible products must include the date of minimum durability, or, in the case of foodstuffs, which from a microbiological point of view are highly perishable, the 'use-by' date and any special storage conditions or conditions of use.
China	Outer packaging must contain shelf life and storage temperature (chilled meat if subsequently frozen, must be labelled as frozen with an amended shelf life claim, validated by the producer)
Japan	No known specific requirements for use-by dates and/or shelf life restrictions.
Korea	Meat must be chilled to a temperature of 20°C or colder within 20 hours of first being placed under refrigeration, and must be further reduced to a temperature of –10°C or colder within 80 hours of being placed under refrigeration for freezing. Product must be loaded out for export at a temperature of –10°C or colder. Once the shipping container has been sealed for export, the exporter must ensure that the container temperature is maintained at –18°C or colder during shipping until arrival in the Republic of Korea. The meat or meat products must be –18°C or colder on arrival in the Republic of Korea. The shelf life for chilled beef must be determined by the manufacturer. [384]

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[383] Australian Government, Department of Agriculture, Fisheries and Forestry. Manual of Importing Country Requirements. January 2023 Home | Micor (agriculture.gov.au)

[384] WTO case (DS-5,1995) United States v Korea. agreement to allow manufacturers of various products to determine their own shelf-life. WTO | dispute settlement - the disputes - DS5

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18. *Salmonella*

Summary

While *Salmonella* is well-known as causing disease associated with the consumption of meat and meat products, the hygienic practices and controls implemented in the Australian red meat industry result in low prevalence of this microorganism in beef and lamb and low rates of disease attributed to beef or lamb consumption.

Good practices in animal production, such as attention to animal health and welfare, good practices in feedlots and in animal transport minimise the likelihood of animals shedding *Salmonella* at the time of slaughter.

Regulated actions by meat processors, and Government supervision verified by routine testing, provide confidence that *Salmonella* is managed in Australian red meat products. Compliance with the requirements of the Australian Meat Standard and the Export Control (meat and meat products) Rules are enforced at processing establishments by the Department of Agriculture, Fisheries and Forestry and monitoring for *Salmonella* on carcases, supervised by the Department, demonstrates infrequent occurrence of the organism.

Investigation of foodborne illness in Australia, and further analysis of data arising from these investigations has led to the conclusion that *Salmonella* in beef and lamb products are not responsible for a significant proportion of foodborne illnesses in Australia. The national foodborne disease reduction strategy does not mention red meat at all and focuses attention on other products of animal origin. In addition to low prevalence of *Salmonella* in beef and lamb products, cooking practices and kitchen hygiene contribute to further lowering the risk to Australian consumers.

The Australian system complies with Codex Guidelines for control of *Salmonella* in beef. Internationally, both in Codex Alimentarius and at the national level, most effort in recent years has been directed to *Salmonella* in poultry supply chains. The most significant risks from red meat products are those products that are not cooked thoroughly.

Salmonella will not grow in chilled or frozen product being exported, so providing cooking practices and kitchen hygiene are similar to Australia, then the risk to consumers in other countries will also be low.

Contents

1. The bacterium

1.1 Biology and nomenclature

The genus comprises two species, *Salmonella bongori* and *S. enterica*, the latter of which is divided into six subspecies, though subspecies names are rarely used. *S. bongori* is associated with reptiles, so rarely is significant in food or public health microbiology. The taxonomic group contains more than 2500 serotypes (also called serovars) defined on the basis of the somatic 'O' (lipopolysaccharide) and flagellar 'H' antigens. The full name of a serotype is given as, for example, *Salmonella enterica* subsp. *enterica* serotype (or, serovar) Typhimurium, but can be abbreviated to *Salmonella* Typhimurium. Strains of some serovars (Typhimurium, Enteritidis) are further differentiated by (bacterio)phage typing (PT).

Historically, salmonellae have been clinically categorized as invasive (typhoidal) or non-invasive (nontyphoidal salmonellae) based on host preference and disease manifestations in humans. Since the behaviour and significance of the serovars causing typhoid are different, the other *Salmonella* are often referred to as ''non-typhoidal *Salmonella*'' or NTS.

1.2 History

Salmonella was recognised as a pathogen of humans and animals in the 19th century. In the early 20th century, the serological differentiation of strains was developed and has dominated the naming of *Salmonella* as well as laboratory testing (until recently, when molecular methods have begun replacing the serological methods).

1.3 Ecology

Salmonella are considered to be inhabitants of the gastrointestinal tract of human and animals. Some serotypes are less virulent than others, and strains may be carried without causing disease. Certain serotypes are, or tend to be, specific to certain hosts, e.g., *Salmonella* Typhi in humans, *S.* Dublin in cattle and sheep, *S.* Enteritidis in poultry.

1.4 Pathogen

The presence of *Salmonella* in a ready-to-eat food sample is generally taken as evidence of a food safety risk, therefore, requiring regulatory action. While it has been known for a long time that certain serotypes are unlikely to cause disease in humans, there has been little interest in designating these serotypes as of lower significance to food control authorities. The prevailing idea is that the presence of one *Salmonella* serotype is taken as evidence that the conditions under which the food was processed, prepared, or stored could result in the presence of other *Salmonella*.

1.5 Minimum growth temperature

The minimum growth temperature of *Salmonella* serotypes has not been studied in great detail, but it seems generally accepted that the minimum growth temperature is around 7 - 8°C (Huang, Hwang, & Phillips, 2011) (see Chapter 13).

1.6 Death during cooking

In the USA, death (lethality) of *Salmonella* is used as the major parameter for the control of antimicrobial processes in the preparation of cooked meats.[385] Roast, cooked, and corned beef must be processed to achieve at least a 6.5-$\log_{10}$ reduction of *Salmonella* or an alternative lethality (e.g., at least a 5 $\log_{10}$ reduction). At a reference temperature of 60.0°C, 9 minutes holding time is

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[385] FSIS. 2021. Cooking Guideline for Meat and Poultry Products (revised Appendix A) FSIS Cooking Guideline for Meat and Poultry Products (Revised Appendix A) (usda.gov)

considered sufficient to achieve a 6.5 $\log_{10}$ lethality of *Salmonella*. At 70°C, this reduction is achieved in seconds.

2. *Salmonella* through the beef supply chain

2.1 Animal

Salmonella may be carried without clinical signs in the gastrointestinal (GI) tract, and gall bladder of cattle, but may also cause infections ranging from enterocolitis to abortion, osteomyelitis, and terminal dry gangrene.

2.1.1 Gastrointestinal tract

An Australian study (N. Fegan, Vanderlinde, Higgs, & Desmarchelier, 2004) tested a total of 310 faecal samples (10g) collected at the time of slaughter for *Salmonella*, 155 were from lot-fed cattle and 155 from grass-fed cattle. *Salmonella* spp. were isolated from 21 (6.8%) of the cattle and the prevalence amongst grass-fed cattle (4.5%) was not significantly different to that found in lot-fed cattle (9%). Counts of *Salmonella* in positive faeces varied from <3/g of faeces to 2.8×10^3/g and 71% of positive samples had counts <10/g faeces. There was no significant difference in the mean $\log_{10}$ number of *Salmonella* in faeces of cattle from each production system. The serotypes isolated were:

Grassfed	Feedlot
Typhimurium (3)	Typhimurium (10)
	Orion (3)
	Give (1)
Muenchen (1)	
Aberdeen (1)	
Anatum (1)	
Senftenberg (1)	

In another Australian study (N Fegan, Vanderlinde, Higgs, & Desmarchelier, 2005) *Salmonella* were isolated from 16% of faecal samples collected on the slaughter floor (n=68) of one processor. Counts were low (none over 100/g). The prevalence and serotypes varied on sampling days (25 animals tested per day)

Group 1	Group 2	Group 3	Group 4
Senftenberg (3)	Senftenberg (1)	Zanzibar (1)	Muenchen (1)
Mbandaka (2)			
Orion (2)			
Give (1)			

A further Australian study (Barlow et al., 2015) tested, 910 beef cattle, 290 dairy cattle, and 300 veal calf faecal samples collected at slaughter were examined for the presence of *Salmonella*. *Salmonella* was recovered from 14.4% of samples and was more likely to be isolated from dairy cattle samples (25.9%) than from beef cattle (11.5%) or veal calf samples (12.0%) (Figure 1).

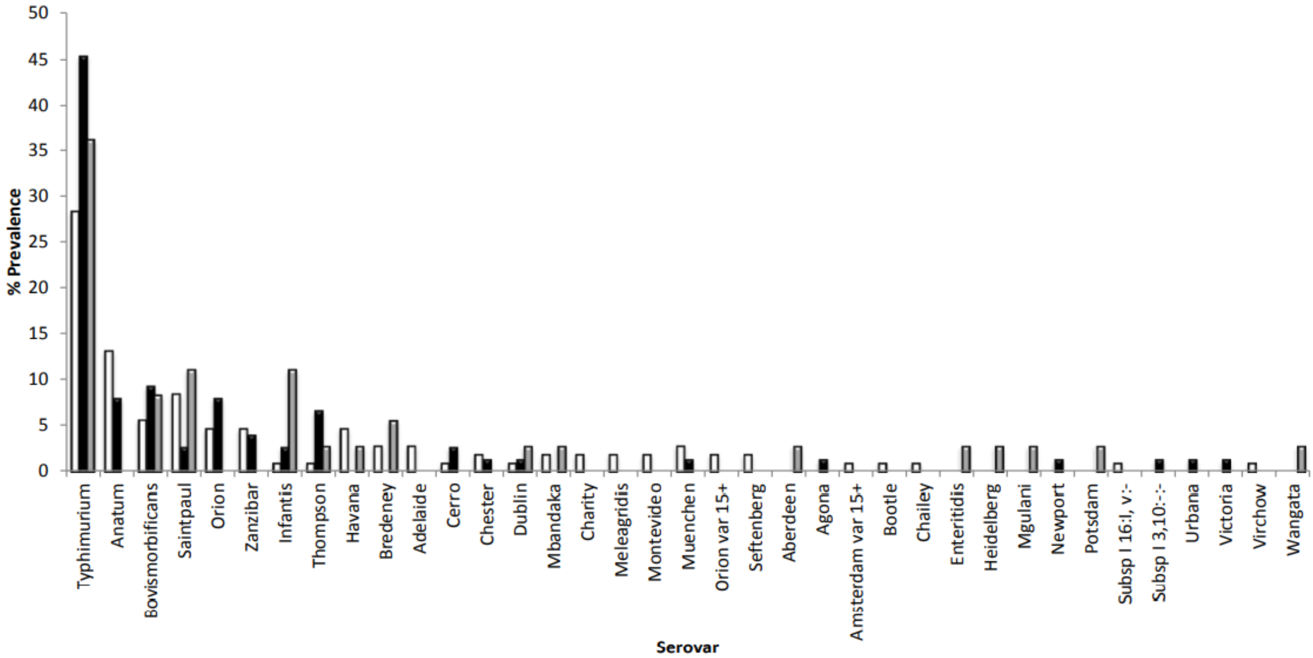

Figure 1: Distribution of *Salmonella* serovars in beef cattle (white columns), dairy cattle (black columns) and veal calf (grey columns) faecal samples

A further study carried out in Australia (Abraham et al., 2022) collected faecal samples at the time of slaughter (n=1001) through a structured national survey. *Salmonella* was isolated from 83/591 (14.0%) of beef cattle, 34/194 (17.5%) of dairy cattle and 67/216 (31.0%) of veal calf faecal samples, giving an overall prevalence in Australian cattle of 18.4%. Of the *Salmonella* isolates collected from beef cattle, 36/235 (15.3%) were from feedlot cattle, 7/71 (9.9%) were from grain assisted, grass-fed cattle and 40/285 (14.0%) were from grass-fed cattle (Table 1).[386]

[386] Barlow et al. (2020) Antimicrobial resistance in commensal bacteria in bovine faeces at slaughter MLA final report V.MFS.0432 Antimicrobial resistance in commensal bacteria in bovine faeces at slaughter | Meat & Livestock Australia (mla.com.au)

Table 1: *Salmonella enterica* serotypes isolated from a national survey of cattle faeces at slaughter

Serovar	Number	percentage
Typhimurium	36	19.6
Saintpaul	22	12.0
Anatum	16	8.7
Bovismorbificans	15	8.2
Montevideo	8	4.3
Zanzibar	8	4.3
Reading	8	4.3
Orion	7	3.8
Virchow	6	3.3
Infantis	6	3.3
Ohio	5	2.7
Mbandaka	5	2.7
Muenchen	4	2.2
Senftenberg	4	2.2
unknown	4	2.2
Newington	3	1.6
Oslo	2	1.1
Tennessee	2	1.1
Chester	2	1.1
Potsdam	2	1.1
Aberdeen	2	1.1
Johannesburg	2	1.1
Cerro	2	1.1
unknown	2	1.1
Poona	1	0.5
Agona	1	0.5
Heidelberg	1	0.5
Liverpool	1	0.5
Adelaide	1	0.5
Litchfield	1	0.5
Singapore	1	0.5
Wangata	1	0.5
Chailey	1	0.5
Havana	1	0.5
Newport	1	0.5

2.1.2 Hide/fleece/skin

Faecal material contaminates the hide and is thought to be the main route by which *Salmonella* contaminates a carcase.

In one Australian study (N Fegan et al., 2005) *Salmonella* were detected on 68% of hides, but only 16% of faecal samples collected from animals on the slaughter floor. The concentration of *Salmonella* on hides did not exceed 0.18 cfu/cm^2. The prevalence and serotypes varied on sampling days (25 animals tested per day).

Group 1	Group 2	Group 3	Group 4
Bredeny (9)	Bredeny (1)		
Senftenberg (4)	Senftenberg (1)		
Anatum(3)	Anatum(1)		
Give (3)			
Kottbus (2)			
Tennessee (2)			
Zanzibar (2)		Zanzibar (4)	Zanzibar (1)
	Give (6)		
	Virchow (6)		Virchow (3)
	Saintpaul (2)		
		Muenchen (19)	Muenchen (1)

Not only did hides have a higher prevalence of *Salmonella*, they also had a wider range of *Salmonella* serotypes, suggesting that hides could be collecting places for serotypes excreted by other animals and possibly well before the sampling time (N Fegan et al., 2005).

Oral cavity (29%) and rumen (25%) samples were also found to have a high prevalence of *Salmonella*, but at low concentrations (N Fegan et al., 2005).

2.2 Carcase

An Australian study (N Fegan et al., 2005) found 2% of prechill carcases and 3% of post-chill carcases to contain detectable *Salmonella*. The enumeration of *Salmonella* suggested a relationship between the numbers present on hides and in oral cavities and the contamination of carcasses. It is possible that the source of contamination of these carcasses may not have been the animals themselves, but rather, the environment (including equipment) or personnel within the abattoir.

The Department of Agriculture, Fisheries and Forestry (DAFF) Meat Inspection Program conducts microbiological tests on carcases which may provide a contemporary estimate of *Salmonella* prevalence on carcases.

In an Australian study utilising sponge sampling of large areas of the carcase (Horchner, Huynh, Sumner, Vanderlinde, & Jenson, 2020) the prevalence of *Salmonella* was found to decrease from 1.14% to 0.45% for the forequarter and 1.29% to 0.23% for the hindquarter between post-hide removal and pre-chill carcases. The following serotypes were found:

Post-hide Removal: S. Hvittingfoss, S. Bredeney, S.Muenster, S. Adelaide, S. Infantis, S. subspecies II serotype: 42:g,t-, S. Poona, S. Bovismorbificans, S. Typhimurium, S. Senftenberg, S. Havana, S. Anatum, S. Oranienburg, S. Chester, S. Cerro.

Pre-chilling: S. subspecies 1 serotype: 16:l,v:-, S. Tennessee, S. Zanzibar, S. Mbandaka, S. Havana, S. Dublin[387]

Concern has been expressed about the potential for lymph nodes to harbour *Salmonella*, as these are not detected by carcase or manufacturing beef sampling but are incorporated into ground beef products. An Australian study (Bailey, Huynh, Govenlock, Jordan, & Jenson, 2017) tested lymph nodes (n = 197), consisting of the superficial cervical (prescapular), prepectoral, axillary, presternal, popliteal, ischiatic, subiliac (precrural), coxalis, and iliofemoralis (deep inguinal), which were collected from five geographically separated Australian abattoirs over a period of 14 months. The observed prevalence of *Salmonella* within peripheral lymph nodes was 0.48% (7 of 1,464). In six of

[387] Liu, J (2017) Beef and veal baseline survey 2016 – Final report Meat & Livestock Australia, report V.MFS.0332. Final Report V.MFS.0332 - National (mla.com.au)

seven nodes, the maximum possible *Salmonella* level was below the limit of detection of 80 CFU per node. The serotypes isolated were Kentucky, Chailey, Dublin, Virchow (2 isolates from the same herd), Typhimurium (2 isolates from the same animal).

2.3 Chilling

E. coli levels detected on a carcase reduce significantly during chilling in air, or spray chilling, which is thought to be the result of *E. coli* becoming transiently unculturable (Mellefont, Kocharunchitt, & Ross, 2015). The same phenomenon appears to occur with *Salmonella* (tested in a laboratory-scale spray chilling system; >1.5 log_{10} cfu/cm^2 reduction on a fat surface) (Kocharunchitt, Mellefont, Bowman, & Ross, 2020).

2.4 Primals

A 2011 national survey of beef primals (striploins, n=572 and outsides, n=572) did not detect *Salmonella* on any sample (sponge samples of 300 cm^2 area) (Phillips, Bridger, Jenson, & Sumner, 2012).

2.5 Manufacturing beef

A 2011 national survey of frozen boneless beef (manufacturing beef, n=1165) did not detect *Salmonella* on any sample (cored samples of 25g) (Phillips et al., 2012). A study conducted in Australia in 2019 collecting samples using N-60 sampling, and testing of 375g samples by FSIS MLG methods detected *Salmonella* in 0.7% of samples, all at concentrations <0.3 MPN/g (Jenson, Huynh, Liu, & Horchner, 2020).

2.6 Between packing and purchase

A survey of ground beef at Australian retail establishments in 2005 revealed *Salmonella* prevalence of 1.1% in ground beef, all serotype Typhimurium (Phillips, Jordan, Morris, Jenson, & Sumner, 2008).

2.7 Cooking

Cooking temperatures should inactivate (kill) *Salmonella*. On a steak, *Salmonella* will be on the surface, but in ground product (e.g., burger patty) *Salmonella* will be distributed throughout the product and the temperature reached at the centre during cooking becomes critically important. In Australia, it is conventional to cook burger patties thoroughly (properly) but in some countries (e.g., USA) the centre of a burger patty may be undercooked (rare). Steak tartare and unheated meat pastes are commonly eaten in some countries, which poses a *Salmonella* risk.

3. *Salmonella* through the sheep meat supply chain

Few data have been collected in recent years. The following summary comes from a 2006 review[388] (Pointon, Kiermeier, & Fegan, 2012):

> Withholding sheep from feed or feeding after starvation can result in a 10^3 to 10^6 fold increase in the level of *Salmonella* in the rumen and faeces of sheep (Grau et al, 1969). Grau and Smith, (1974) showed that the level of *Salmonella* shed by sheep increased with holding time at the abattoir. In heavily contaminated pens the levels increased by about 1-log unit per day. The rate of contamination

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[388] Pethick, D (2006) Investigating feed and water curfews for the transport of livestock within Australia – a literature review. MLA final report Project Code: LIVE.122A Investigating feed and water curfews for the transport of livestock within Australia - A literature review | Meat & Livestock Australia (mla.com.au)

of the fleece also increased rapidly, after three days nearly all of the animals were contaminated. In less heavily contaminated pens the levels increased more slowly and fewer hides became contaminated (~20%). Contamination of carcases with *Salmonella* followed a similar pattern, with the number of positive carcases increasing with holding time prior to slaughter. Serotypes isolated included Adelaide, Havana, Meleagridis, Oranienburg and Derby. It was concluded that the fleece was the primary source of contamination of carcases. *Salmonella* was also isolated more often after evisceration (Grau 1979) inferring this to be a major point of carcase contamination.

3.1 Animal

3.1.1 Gastrointestinal tract

In an Australian national survey of ovine faeces conducted in 2017-18, *Salmonella* was isolated from 81 of 800 samples (10.1%) tested. The prevalence of *Salmonella* was higher in sheep (19.3%) than pasture-fed (7.5%) or feedlot (4.3%) lamb samples. Counts of *Salmonella* were generally very low with mean counts of 0.9, 0.6 and 0.4 $\log_{10}$ MPN/g faeces recorded for feedlot lamb, sheep, and pasture-fed lamb, respectively.[389]

An Australian study examined 5 groups of sheep coming to slaughter at 2 Australian processors (164 sheep in total) and isolated *Salmonella* spp. from 20% of faeces. The mean $\log_{10}$count of *Salmonella* spp. in faeces was 1.43 MPN/g.(LL Duffy, Small, & Fegan, 2010).

3.1.2 Hide/fleece/skin

An Australian study examined 5 groups of sheep coming to slaughter at 2 Australian processors (164 sheep in total) and isolated *Salmonella* spp. from 13% of fleeces. The mean $\log_{10}$count of *Salmonella* spp. on fleece was -0.24 MPN/cm^2.(LL Duffy et al., 2010). A total of 55 *Salmonella* isolates were found to belong to 11 different serotypes (S. Agona, S. Anatum, S. Bovismorbificans, S. Give, S. Kottbus, S. Muenchen, S. Potsdam, S. Reading, S. Tennessee, S. Typhimurium and S. Welikade). There was significant differences between groups; Group 4 sheep contained all 11 serotypes across the samples, but group 5 sheep only harboured S. Agona and S. Bovismorbificans (LL Duffy et al., 2010).

3.2 Carcase

An Australian study examined 5 groups of sheep coming to slaughter at 2 Australian processors (164 sheep in total) and isolated *Salmonella* spp. 1.3% of pre-chill carcases. The mean $\log_{10}$count of *Salmonella* spp. on carcases were below the countable limit (-1 $\log_{10}$MPN/cm^2).(LL Duffy et al., 2010).

3.3 Chilling

The DAFF Meat Inspection Program conducts microbiological tests on carcases which may provide a contemporary estimate of *Salmonella* prevalence.

3.4 Primals

A 2011 national survey of sheep primals (legs, n=613, and shoulders, n=613) revealed *Salmonella* on 17/613 (2.8%) leg samples, 5/613 (0.8%) shoulders (sponge samples of 300cm^2 area). It is believed that these samples were collected during a period atypical weather (high recent rains and flooding

389 Mellor, G (2019) Pathogens and antimicrobial resistance in ovine faeces at slaughter. MLA Final Report V.MFS.0417 Pathogen and antimicrobial resistance in ovine faeces at slaughter | Meat & Livestock Australia (mla.com.au)

over much of South Eastern Australia) and therefore not representative of the typical achievement of contemporary processing standards (Phillips, Tholath, Jenson, & Sumner, 2013).

3.5 Boneless sheep meat

A 2011 national survey of boneless sheep meat revealed *Salmonella* in 17/551 (3.1%) samples of frozen boneless product (25g core drilled samples). It is believed that these samples were collected during a period atypical weather (high recent rains and flooding over much of South Eastern Australia) and therefore not representative of the typical achievement of contemporary processing standards (Phillips et al., 2013).

3.6 Between packing and purchase

A survey of diced lamb at Australian retail establishments in 2005 revealed *Salmonella* in 2 (0.6%) of the 360 diced lamb samples (serovars were *Salmonella* Infantis and *Salmonella* Typhimurium PT 193), (Phillips et al., 2008).

3.7 Cooking

Cooking temperatures should inactivate (kill) *Salmonella*. On a steak, *Salmonella* will be on the surface, but in ground product (e.g., burger patty) *Salmonella* will be distributed throughout the product and the temperature reached at the centre during cooking becomes critically important. In Australia, it is conventional to cook burger patties thoroughly (properly) but in some countries (e.g., USA) the centre of a burger patty may be undercooked (rare). Uncooked lamb products are rarely consumed.

4. *Salmonella* through the goat meat supply chain

A study on the ecology of *Salmonella* in goats (L. Duffy, Barlow, Fegan, & Vanderlinde, 2009) found that a large percentage of animals carried *Salmonella*, either in their rumen or faeces. Four lots of goats were sampled from two abattoirs in Queensland on two occasions. Rumen contents were contaminated in 72 of the 121 samples analysed (59.5%), while the faeces were contaminated in 57% (68/120) of samples. While it is acknowledged that there is a paucity of information on goats, studies indicate the influence of feed withholding on rumen pH and subsequent microbial growth reflects that demonstrated for beef and sheep described in previous sections (Pointon et al., 2012) .

5. *Salmonella* and public health

5.1 *Salmonella* virulence

Some serotypes of *Salmonella enterica* are restricted, or are predominantly found in one host species, and are referred to as “host-restricted” whereas others have broad host spectrum known as “host-adapted” serovars. This points to the wide range of factors that *Salmonella* requires to colonize its hosts through invading, attaching, and bypassing the host’s intestinal defence mechanisms. Many virulence markers and determinants have been demonstrated to play crucial role in its pathogenesis; and these factors included flagella, capsule, plasmids, adhesion systems, and type 3 secretion systems. The epidemiologically important NTS serovars linked with a high burden of foodborne *Salmonella* outbreaks in humans worldwide included Typhimurium, Enteritidis, Heidelberg, and Newport. (Jajere, 2019).

In the US, the Food Safety and Inspection Service was petitioned to declare 31 serotypes of *Salmonella* to be adulterants since they had all been involved in causing outbreaks.[390] FSIS rejected the petition without prejudice and was clear that it intended to develop its own regulatory agenda on *Salmonella* in the meat supply. The USDA Agricultural Research Service (ARS) has defined Highly Pathogenic Salmonella (HPS) as including certain serotypes (Dublin, Enteritidis, Newport, Typhimurium (including monophasic), abbreviated DENT) and those possessing certain (as yet not published) HPS gene markers and, in response, CSIRO investigated Australian *Salmonella* isolated from red meat sources, as well as human isolates .[391] Except for S. Typhimurium, few *Salmonella* from Australian red meat sources belonged to the major HPS serovars (DENT). Some serovars of Australian *Salmonella* isolates clustered mostly by host (animal or human for S. Typhimurium, S. Anatum and S. Infantis), while no obvious distinction between animal and human isolates was observed for the other serovars (S. Saintpaul and S. Bovismorbificans). A small number of genes were shown to be more prevalent in humans, while others were more prevalent in animals.

5.2 Attribution to red meat

The Australian national register of foodborne outbreaks for the years 2001-2016 was examined for outbreaks due to *Salmonella enterica*. 990 outbreaks were reported, of which 476 had some evidence to implicate a food. Beef (6/476), lamb (5/476) were each identified as the food vehicle for around 1% of the outbreaks in which a food source was supported by statistical, laboratory, or descriptive evidence (Ford et al., 2018). The analysis does not indicate where consumption occurred (home or type of food service business). Association was with roast beef, and products that should have been thoroughly cooked, so may be examples of post-cooking contamination. The lamb products were often offal, possibly with post cooking contamination, but in some outbreaks liver has been consumed raw (Hess, Neville, McCarthy, Shadbolt, & McAnulty, 2008).

5.3 Risk assessment

Internationally, the WHO/FAO Joint Meetings on Microbial Risk Assessment have been concerned with *Salmonella* in egg-laying and meat chickens.

5.4 Risk management

Over the past 30 years, Shiga toxin-producing *Escherichia coli* (STEC) have consumed most of the attention as significant risks in red meat (beef) products, while *Salmonella*, has been associated, and to some degree, addressed in poultry products.

FAO/WHO and Codex Alimentarius

The FAO/WHO Joint Expert Meeting on Risk Assessment (see Ch 1,3.2 Scientific input) considered, with the involvement of Australian experts, interventions for *Salmonella* in the beef supply chain in 2016[392] which was used to produce *Guidelines for Salmonella control in beef*.[393] Australia's

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[390] Marler Clark (2020) FSIS. Petition 20-01 Petition for interpretive rule related to certain *Salmonella* serotypes Petition for Interpretive Rule Related to Certain *Salmonella* Serotypes | Food Safety and Inspection Service (usda.gov)

[391] Mellor, G et al. 2023. Molecular risk assessment of Salmonella in red meat. MLA Report V.MFS.0460. V.MFS.0460 - Molecular risk assessment of Salmonella in red meat | Meat & Livestock Australia (mla.com.au)

[392] FAO and WHO. (2016). *Interventions for the control of non-typhoidal Salmonella spp. in beef and pork: meeting report and systematic review*. FAO. https://www.who.int/publications/i/item/9789241565240

[393] Codex Alimentarius Commission. (2016). Guidelines for the Control of nontyphoidal *Salmonella* spp. in beef and pork meat. In (Vol. CAC/GL 87-2016). Rome: FAO. https://www.fao.org/fao-who-codexalimentarius/sh-proxy/en/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FStandards%252FCXG%2B87-2016%252FCXG_087e.pdf

processing systems are in compliance with these guidelines, particularly in the application of Good Hygienic Practice-based Control Measures.

Australia
Australia's national foodborne illness reduction strategy 2018-2021[394] did not mention red meat at all, but rather focussed on other animal products.

USA
The FSIS discontinued the testing program for *Salmonella* on beef carcasses, though they continued testing for *Salmonella* in ground beef and introduced testing for *Salmonella* in beef trim[395], in parallel with STEC.[396]

Performance standards for broiler chickens have existed for some time[397], and FSIS is intending to declare certain poultry products to be adulterated if they contain more than a certain concentration of *Salmonella*[398]. This is of note because of the use of a concentration as a limit rather than detection, as in the case of STEC.

Europe
The European Union maintains two approaches to *Salmonella*; on one hand, artisanal production methods are encouraged (for example, unpasteurized milk cheeses), and on the other hand, general provisions of the food law allow competent authorities to remove any product that may pose a risk to consumers from the market.

EU microbiological criteria can be found in Commission Regulation (EC) No 1441/2007[399] on microbiological criteria for foodstuffs. This regulation has criteria for *Salmonella* in minced meat, mechanically separated meat, and meat preparations intended to be eaten raw – but not for primals, beef trim and meat intended to be cooked.

6. Testing methods

Salmonella testing methods have developed over a long period of time, and generally enrichment methods, for the detection of *Salmonella* in a defined quantity of product (usually, 25g or multiples of 25g – see chapter 12 microbiological criteria) are subjected to testing.

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394 Australia. Food Regulation Secretariat. (2018) Australia's Foodborne Illness Reduction Strategy 2018-2021 Food Regulation - Australia's Foodborne Illness Reduction Strategy 2018-2021+

395 FSIS (2019) Changes to the *Salmonella* Verification Testing Program: Proposed Performance Standards for *Salmonella* in Raw Ground Beef and Beef Manufacturing Trimmings and Related Agency Verification Procedures Federal Register. Docket 2018-0045. Federal Register 84(208)57688 Changes to the *Salmonella* Verification Testing Program: Proposed Performance Standards for *Salmonella* in Raw Ground Beef and Beef Manufacturing Trimmings and Related Agency Verification Procedures | Food Safety and Inspection Service (usda.gov)

396 FSIS (2023) Sampling verification activities for Shiga toxin-producing Escherichia coli (STEC) in raw beef products. FSIS Directive 10,010.1 Rev 5 FSIS Directive 10010.1 Rev 5 Sampling Verification Activities for Shiga Toxin-Producing Escherichia Coli (STEC) in Raw Beef Products (usda.gov)

397 FSIS. Science and Data. Data sets. *Salmonella* verification testing program. *Salmonella* Verification Testing Program Monthly Posting | Food Safety and Inspection Service (usda.gov)

398 USDA (2022) USDA announces action to declare *Salmonella* an adulterant in breaded stuffed raw chicken products. Press Release no. 0167.22 August 1, 2022. USDA Announces Action to Declare *Salmonella* an Adulterant in Breaded Stuffed Raw Chicken Products | Food Safety and Inspection Service

399 Commission Regulation (EC) No 1441/2007 of 5 December 2007 amending Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs. LexUriServ.do (europa.eu)

There is an ISO method for *Salmonella* in foods ISO 6579-1:2017[400], which is adopted as an Australian Standard method, with a few changes for Australian conditions.[401] European countries usually adopt ISO Standards. In the USA, the FSIS has their own in-house method[402]

A number of rapid (usually, DNA-based) methods for detection of *Salmonella*, which are validated against ISO and/or FSIS methods. They are usually considered acceptable based on publication of a validation study.

Methods for rapid quantification of *Salmonella* (usually by RT-PCR) are becoming available, in line with the FSIS introduction of quantitative *Salmonella* standards for some poultry products.

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19. *Escherichia coli*

Summary

Escherichia coli is a bacterium with strains that benefit human health, those posing no risk to human health, and pathogens causing urinary and gastrointestinal infections through to serious infections and impacts on health that can lead to death. While *E. coli* can be found in many foods, serious infections, caused by Shiga toxin-producing *E. coli* (STEC) are often associated with consumption of beef products, and leafy green vegetables that have been contaminated by cattle. Sheep may also carry STECs, but the potential for sheep to cause illness is not widely recognised.

Codex Alimentarius Commission has produced Guidelines for control of STEC based on risk assessments and scientific advice. For meat products, thorough cooking is the most effective control, and occurrence is often associated with the consumption of raw and undercooked meat products (especially ground beef patties). Countries that have risky consumption practices often apply microbiological criteria on raw ground beef, or the parts of meat likely to be ground, to limit the occurrence of STEC in products at consumption.

Australia generally complies with the Guidelines produced by Codex. Good practices in animal production, such as attention to animal health and welfare, good practices in feedlots and in animal transport minimise the likelihood of animals shedding STEC at the time of slaughter.

Regulated actions by meat processors, and Government supervision verified by routine testing, manage the occurrence of STEC in Australian red meat products. Compliance with the requirements of the Australian Meat Standard and the Export Control (meat and meat products) Rules are enforced at processing establishments by the Department of Agriculture, Fisheries and Forestry. Testing for *E. coli* on carcases, supervised by the Department, demonstrates infrequent occurrence of the organism, but does not preclude the presence of some STEC in final products. Australia has negotiated a testing program for certain types of STEC in beef destined for grinding in the USA, as an additional safeguard for that country.

There is evidence that Australian animals not only have generally low occurrence of STEC, but also that the types of STEC found in Australian cattle are not as likely to cause serious infections in humans as those found in other countries. The public health record in Australia rarely associates STEC infections with meat.

E. coli (and therefore STEC) will not grow in chilled or frozen product being exported, so providing cooking practices and kitchen hygiene are similar to Australia, then the risk to consumers in other countries will also be low.

Contents

1. The bacterium

1.1 Biology

Escherichia coli is abbreviated as *E. coli* (NOT E.coli, Ecoli, or ecoli), after being spelt out in full the first time it is used in a document.

Escherichia coli is a species of bacteria that is commonly found in the lower intestine of warm-blooded animals (may also be found in reptiles and birds). Most *E. coli* strains are harmless.

E. coli encompasses an enormous population of bacteria that exhibit a very high degree of both genetic and phenotypic diversity. *E. coli* remains one of the most diverse bacterial species: only 20% of the genes in a typical *E. coli* genome is shared among all strains.

1.2 Commensal

The harmless strains are part of the normal microbiota of the gut and can benefit their hosts by producing vitamin K2 and preventing colonisation of the intestine with pathogenic bacteria. *E. coli* is expelled into the environment with faecal matter. Non-Shiga toxin-producing strains of *E. coli* (see below) are sometimes called generic *E. coli* to ensure a clear differentiation from Shiga toxin-producing *E. coli* (STEC).

1.3 Indicator

E. coli and other facultative anaerobes constitute about 0.1% of gut microbiota of humans. Cells can survive outside the body for a limited time, which makes them potential indicator organisms when testing environmental samples for faecal contamination.

1.4 Pathogen

Most *E. coli* strains do not cause disease, naturally living in the gut, but pathogenic strains can cause a number of diseases including gastroenteritis, haemorrhagic colitis, urinary tract infections, and neonatal meningitis, depending on the genes they possess.

Most of the human pathogenic *E. coli* strains are not found in animals, but those causing gastroenteritis and haemorrhagic colitis can be found in the faeces of cattle and sheep. *E. coli* O157, for example, can produce Shiga toxin. The Shiga toxin causes inflammatory responses in target cells of the gut, resulting in lesions which may result in the bloody diarrhea, haemolytic-uraemic syndrome (HUS), kidney failure, and even death.

The Shiga toxin is like the toxin produced in *Shigella dysenteriae* (which causes dysentery in humans). When the toxin-producing *E. coli* were first found, the toxin had not been isolated and identified, but they were noted to be toxic to Vero (African Green Monkey kidney) cells, so the strains were labelled as verocytotoxic, or verotoxic (VTEC). For many years there has been parallel usage of STEC and VTEC, but it seems that STEC is becoming the standard name (FAO and WHO, 2018).

1.5 Classification

A common subdivision system of *E. coli*, but not based on evolutionary relatedness, is by serotype, which is based on major surface antigens (O antigen: part of lipopolysaccharide layer; H: flagellin; K antigen: capsule), e.g., O157:H7). At present, about 190 serogroups are known. Serogroups are now often determined using genetic methods rather than by serotyping.

Numerous other methods have been used for classifying and identifying *E. coli* strains. Two contemporary methods are particularly relevant: whole genome sequencing (WGS) and typing of virulence genes.

WGS is the process of determining the entirety, or nearing the entirety, of the DNA sequence of an organism's genome. The tool of gene sequencing to pinpoint functional variants (single nucleotide polymorphisms – SNPs, or 'snips') is often used to distinguish closely related strains.

Pathogenic *E. coli* have been subdivided based on the diseases they cause and the presence of various virulence markers. The major virulence genes in STEC are the Shiga toxin (*stx*) genes and the Intimin (effacing and attaching, *eae*) genes. There are two major *stx* types, *stx1* and *stx2* and these are each divided into a number of subtypes. There are a number of *eae* gene subtypes. Typing of these genes is performed based on sequence and are significant determinants of disease severity.

1.6 Minimum and maximum growth temperatures

The minimum temperature for growth of *E. coli* is accepted to be around 7°C (Maxwell K. Shaw, 1968; Maxwell K. Shaw & Ingraham, 1967; M. K. Shaw, Marr, & Ingraham, 1971). This is the reason that the *Australian Standard for the Hygienic Production and Transportation of Meat and Meat Products for Human Consumption* (AS4696) specifies the time in which a carcase or major cut must be chilled on the surface to no more than 7°C. It is also the reason why the Refrigeration Index (Chapter 13, 2.7) is calculated for temperatures above 7°C.

Some estimates of the minimum growth temperature (T_{min}) (Mellefont & Ross, 2003; Rosso, Lobry, Bajard, & Flandrois, 1995; Van Derlinden, Bernaerts, & Van Impe, 2008) are below this temperature, due to methods of measurement, modelling, and extrapolation of results, and determination of whether growth is maintained in a stable manner for a long period (balanced growth).

1.7 Death during cooking

The maximum growth temperature of *E. coli* is accepted to be about 45-47°C (Rosso et al., 1995; Van Derlinden et al., 2008) though this is not particularly relevant to meat processing or safety. Death rates of *E. coli* during cooking processes are usually expressed at a reference temperature of 60°C, at which most *E. coli* strain viability will take 2 minutes or less to decrease 10-fold (D_{60}), however, some strains will take 15 minutes to more than an hour (Dlusskaya, McMullen, & Gänzle, 2011). These temperature resistant *E. coli* do not appear to be pathogenic to humans (i.e., they are non-STEC) (Liu, Gill, McMullen, & Gänzle, 2015).

1.8 Regulated *E. coli* types

In the USA, several *E. coli* types are regulated as adulterants. The definition of each type becomes complex because the definition is in terms of laboratory test results. *E. coli* O157:H7 (often just called *E. coli* O157) was the first type to be declared an adulterant followed by the 'big 6 STEC' *E. coli* O26, O45, O103, O111, O121 and O145). These serogroups account for most of the illness in the USA.

In Europe, there are no serotypes particularly regulated as in the USA. The top 5 serogroups identified as causing most of the illnesses were historically identified as *E. coli* O157, O26, O103, O111 and O145 (the same serogroups as detected by the ISO/TS 13136:2012 method used in the EU). In 2020, the five most reported serogroups were O26, O157, O103, O145, and O146[403] In 2011 there was a large outbreak associated with *E. coli* O104:H4.[404]

[403] European Centre for Disease Prevention and Control (ECDC). Annual Epidemiological Report for 2020. STEC infection Annual Epidemiological Report 2020 (europa.eu)

[404] European Centre for Disease Prevention and Control (ECDC). Escherichia coli – Threats and outbreaks – Outbreak: STEC O104:H4 2011. Outbreak: STEC 0104:H4 2011 (europa.eu)

In Australia, there are state-based requirements, and restrictions on sale of some products known to contain STECs. In the period 2000-2010, 58.0% of STEC isolated from infected humans were found to be O157 strains, with O111 (13.7%) and O26 (11.1%) strains also commonly found (Vally et al., 2012).

2. Generic *Escherichia* coli through the beef and sheep meat supply chains

2.1 Animal

2.1.1 Gastrointestinal tract

E. coli is nearly always found in cattle faeces. A survey of faeces from a large number of cattle at the time of slaughter found about 3% of faecal samples had <10 cfu/g. The average count was 5 x 10^5 cfu/g (log_{10} 5.7) in grass-fed cattle and 2.5 x 10^5 cfu/g (log_{10} 5.4) in grass-fed cattle. Maximum counts were towards 100 times higher than the average counts (Fegan, Vanderlinde, Higgs, & Desmarchelier, 2004).

2.1.2 Hide/fleece/skin

Faecal material contaminates the hide and is thought to be the main route by which *E. coli* contaminates a carcase. This has been studied for *E. coli* O157 (see below).

2.2 Carcase

E. coli, and other bacteria, transfer from the hide during the dehiding process, and contamination of the carcase may also occur from saliva, ingesta and faeces, as well as through the air. Hot carcases are not usually tested for *E. coli*. Some data are available from large area sampling of both hot, then chilled carcases (see Chapter 9 process hygiene).

2.3 Chilling and chilled carcases

The measurement of *E. coli* on carcases is a key measure of the successful application of hygienic measures during the slaughter, and carcase dressing process. Contemporary data should always be available through the Department of Agriculture, Fisheries and Forestry (DAFF) Meat Inspection Program. Chilled carcases are usually tested in this program.

Chilling reduces the count on carcases, but that is not because *E. coli* dies, but rather it becomes temporarily unable to be cultured. The temperature to which a carcase is chilled is and how fast it is chilled determines how much growth occurs during the chilling process. (see Chapter 13 – chilling and temperature control during processing)

In 2004, standard carcase sampling (equivalent to US Food Safety and Inspection Service (FSIS) methods, and the Product Hygiene Indicators (PHI) program) of beef revealed a prevalence of *E. coli* on carcases at 8.0% with a mean count of 0.16 cfu/cm^2 (-0.8 log_{10} cfu/cm^2) for carcases on which *E. coli* could be detected (Phillips, Jordan, Morris, Jenson, & Sumner, 2006b). The mean is now much lower, in part due to the efforts by beef processors to ensure that manufacturing beef has no detectable regulated STEC strains. The decrease in detectable *E. coli* on carcases has been documented for the years 2008 and 2009, demonstrating a decrease from about 8% to 5% (Sumner, Kiermeier, & Jenson, 2011).

In 2004 standard carcase sampling (equivalent to US FSIS methods, and the PHI program) of sheep revealed a prevalence of *E. coli* on carcases at 43.0% with a mean count of 1.07 cfu/cm^2 (0.03log_{10}

cfu/cm^2) for carcases on which *E. coli* could be detected (Phillips, Jordan, Morris, Jenson, & Sumner, 2006a).

2.4 Primals

A 2011 survey of beef primals (striploins and outsides) revealed a prevalence of *E. coli* of 10.7 and 25.2% respectively, at mean concentrations of -0.5 log_{10} cfu/cm^2 and -0.3 log_{10} cfu/cm^2 respectively (Phillips, Bridger, Jenson, & Sumner, 2012).

A 2011 survey of sheep primals (legs and shoulders) revealed a prevalence of *E. coli* of 42.9% on legs and 34.6% on shoulders, at concentrations of -0.44 log_{10} cfu/cm^2 and -0.63 log_{10} cfu/cm^2 respectively (Phillips, Tholath, Jenson, & Sumner, 2013).

The DAFF Meat Inspection Program conducts microbiological tests on ‘’carton meat” which may provide a contemporary estimate of *E. coli* prevalence on primals.

2.5 Manufacturing meat

A 2011 survey of frozen boneless beef revealed a prevalence of *E. coli* of 2.1 % with a mean count for samples in which *E. coli* was detected of 1.3 log_{10} cfu/g (Phillips et al., 2012).

A 2011 survey of frozen boneless sheep meat revealed a prevalence of *E. coli* of 12.5% with a mean count for samples in which *E. coli* was detected of 1.51 log_{10} cfu/g (Phillips et al., 2013).

The DAFF Meat Inspection Program conducts microbiological tests on ‘’carton meat” which may provide a contemporary estimate of *E. coli* prevalence on manufacturing meat.

2.6 Between packing and purchase

A survey of beef and lamb at Australian retail establishments in 2005 revealed an *E. coli* prevalence of 17.8% in ground beef and 16.7% in diced lamb with average counts for samples in which *E. coli* was detected of 1.49 log_{10} cfu/g and 1.67 log_{10} cfu/g, respectively (Phillips, Jordan, Morris, Jenson, & Sumner, 2008).

2.7 Cooking

Cooking temperatures should inactivate (kill) *E. coli*. On a steak, *E. coli* will be on the surface, but in ground product (e.g., burger patties) *E. coli* will be distributed throughout the product and the temperature reached at the centre during cooking becomes critically important. In Australia, it is conventional to cook burger patties thoroughly (properly) but in some countries (e.g., USA) the centre of a burger patty may be undercooked (rare). The legal responsibility, in the USA, for pathogenic *E. coli* in an undercooked burger patty clearly lies with the supplier of the ground beef.[405]

3. STEC through the beef supply chain

3.1 Animal

Much more is known about *E. coli* O157 than the other STECs because it causes more disease in humans and was declared an adulterant in the USA earlier than the other STECs.

[405] Ferguson, Alex (2009) E. coli in Ground Beef not Victim’s Fault. Food Safety News E. coli in Ground Beef not Victim's Fault | Food Safety News

3.1.1 Gastrointestinal tract

The major animal carriers are healthy ruminants, primarily cattle, and, to a lesser extent sheep and goats. Intestinal carriage is usually intermittent or short-term (Ferens & Hovde, 2011). Cattle carrying STEC do not usually have any symptoms, and the number being shed in faeces can vary rapidly over time.

In contrast to humans, most *E. coli* O157:H7-infected cattle remain free of disease and are tolerant of *E. coli* O157:H7 for most of their lives. Adult cattle are tolerant of *E. coli* O157:H7 infection as there is a lack of systemic vascular damage in calves and adult cattle with *E. coli* O157:H7 infection. Species differences in the tissue level of globotriaosylceramide (Gb3) expression and Shiga toxin binding explain, in part, why *E. coli* O157:H7 infections cause haemorrhagic colitis and HUS in humans but usually remain asymptomatic in the bovine reservoir host (Pruimboom-Brees et al., 2000).

In Australia, faecal samples were collected from grass-fed (pasture) and lot-fed (feedlot) cattle at slaughter and tested for the presence of *E. coli* O157 using automated immunomagnetic separation (AIMS). *E. coli* O157 was enumerated in positive samples using the most probable number (MPN) technique and AIMS. A total of 310 faecal samples were tested (155 from each group). *E. coli* O157 was isolated from 13% of faeces (10g samples) with no significant difference between grass-fed (10%) and lot-fed cattle (15%). The numbers of *E. coli* O157 in cattle faeces varied from undetectable (<3 MPN/g) to $1.1x10^5$ MPN/g. Twenty-six (67%) of 39 O157 positive faeces had <10 MPN/g and three (8%) had counts between 10^3–10^5 MPN/g. There was no significant difference between concentrations of *E. coli* O157 in the faeces of grass-fed or lot-fed cattle (Fegan et al., 2004).

A longitudinal study of Australian grass-fed cattle for the presence of *E. coli* O157 (Lammers et al., 2015) demonstrated that the prevalence of *E. coli* O157 in 10g faecal samples could range from 0-57% in the same animals in a herd over a 9-month period. Even within a short period of time (sampling twice per day for 7 days) in animals believed to be shedding, significant variations in concentration of *E. coli* O157 were observed (Lammers, Jordan, Mc, & Heller, 2016). The strain of *E. coli* O157 changed over time, with different genetic clusters (variants) predominating at different times (Ahlstrom et al., 2017).

An early study of non-O157 serotypes in Australian cattle was conducted by Barlow and Mellor (2010). 300 cattle faecal samples were investigated for the presence of STEC of serogroups O26, O45, O91, O103, O111, O121, O145 and O157. Samples that were found to contain an *stx* and *eae* gene were further processed in an attempt to isolate a strain of one of the O serotypes. Only 1 *E. coli* O91, 1 *E. coli* O26 and 5 *E. coli* O157 were isolated, though 78 enrichment broths contained both *stx* and *eae* genes.

An Australian survey of 1500 cattle faeces (10 g) samples collected at the time of slaughter were tested for the presence of *E. coli* O157 and the six serogroups declared adulterants in the USA (G E Mellor et al., 2016). The prevalence for *E. coli* O157, O26 and O111 meeting the US definition of an adulterant was 6.7%, 1.0% and 0.3% respectively. All serogroups were detected using a molecular (PCR) test of the primary enrichment broth, but *E. coli* O45, O103, O121 and O145 were not isolated on agar. Younger animals (including calves) were more likely to shed an STEC than older animals. Counts of *E. coli* O157 ranged from <-0.52 to 6.89 log_{10}MPN/g of faeces. 70% of samples containing *E. coli* O157 had counts less than 3.00 log_{10}MPN/g of faeces with 38% at or below the limit of detection for the MPN procedure (- 0.52 log_{10}MPN/g of faeces). Differences were observed in the *E. coli* O157 count for each of the animal classes, with younger animals significantly more likely to be associated with counts exceeding 3.00 log_{10}MPN/g of faeces. *E. coli* O26 counts ranged from <- 0.52 to 4.38 log_{10}MPN/g of faeces. The lowest count of *E. coli* O26 was observed in adult beef (0.96 log_{10}MPN/g faeces) while the highest count (4.38 log_{10}MPN/g of faeces) was detected in a veal calf.

E. coli O111 was isolated from three young beef samples, all of which had counts <-0.52 $\log_{10}$MPN/g faeces, and one veal calf sample (2.63 $\log_{10}$MPN/g faeces).[406]

E. coli O157 isolated from Australia have been known to be most frequently (about 78%) non-motile (Fegan & Desmarchelier, 2002; Glen E. Mellor et al., 2012), even though they possess the flagellar H7 antigen gene (Pintara, Guglielmino, Rathnayake, Huygens, & Jennison, 2018). The prevalence of Shiga toxin genes is very frequently (about 92%) *stx2c* , either alone (about 16%), in combination with *stx1* (about 74%) or with *stx2* (about 3%) (Fegan & Desmarchelier, 2002; Glen E. Mellor et al., 2013).

Supershedding
Supershedding is the term used when an animal is excreting a high concentration of STEC in faeces. This level is often arbitrarily set at 10^4 or 10^5 cfu/g. The significance of supershedders is that these animals are more likely to contaminate their hides and the hides of other animals, and therefore overwhelm the hygiene interventions of the processing establishment (Fegan, Higgs, Vanderlinde, & Desmarchelier, 2005). There is no clear reason why an animal may be a supershedder and this status may change from day to day (Lammers et al., 2016; Lammers et al., 2015). The ratio between O157 and total *E. coli* may also vary widely (Fegan et al., 2004) which makes prediction of STEC occurrence from *E. coli* data impossible.

3.1.2 Hide/skin
The bacteria may be harboured extra-intestinally with little correlation to faecal shedding (Ferens & Hovde, 2011). The extra-intestinal sources of relevance to meat processing are the hide (reviewed in Ferens and Hovde (2011)) and also the oral cavity. Faeces spreads from one animal to its own hide or more likely (in enclosed areas) the hides of neighbouring animals) and then to the oral cavity due to animals licking each other. Contamination may also spread through the air.[407]

Fegan et al (2005) studied 4 groups of 25 cattle coming to slaughter and found hide and oral prevalence to be greater than faecal prevalence. Hide (and oral) concentrations were not high (on the slaughter floor- following cleaning) compared to the faeces of neighbouring animals on the slaughter chain (presumably members of the same social group of animals). The available evidence pointed to transfer from hide to carcase.

3.2 Carcase
The same study by Fegan et al (2005) detected *E. coli* O157 on the carcase at concentrations below 0.12 MPN *E. coli* O157/cm^2 on unchilled carcases from animals either shedding very high levels of *E. coli* O157 or having relatively high levels on hides. The matching carcase side had undetectable *E. coli* O157 after chilling. This evidence suggests that the standards of processing may have been adequate to control transfer of contamination when found at usual levels but were inadequate to prevent the transfer of contamination when very high levels of *E. coli* O157 were encountered.

3.3 Chilling
There is no reason to expect that the behaviour of STEC during chilling would differ from that of other *E. coli*.

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[406] Mellor, G and Barlow, R (2014) The prevalence of pSTEC in cattle from different systems used for production of Australian beef. MLA Final report G.MFS.0286 (combined report with G.MFS.0285) g.mfs.0285_g.mfs.0286_final_report.pdf (mla.com.au)
[407] Chandry, P. Scott (2016) Metagenomic analysis to explore the mechanisms of carcass contamination. MLA Report G.MFS.0327 G.MFS.0327 Final Report (mla.com.au)

3.4 Primals

A 2011 national survey of beef primals (striploins, n=572 and outsides, n=572) did not detect *E. coli* O157 on any sample (sponge samples of 300 cm2 area) (Phillips et al., 2012).

The DAFF Meat Inspection Program conducts microbiological tests on ‘’carton meat” which may provide a contemporary estimate of STEC prevalence on primals.

3.5 Manufacturing beef

Routine testing in the DAFF national microbiological monitoring program for STEC has detected every serogroup declared an adulterant in the USA, despite some of these never having been isolated by CSIRO, who have conducted tests on thousands of samples. The national program tests beef trim samples collected continuously across the country, whereas CSIRO have usually tested faecal samples collected in relatively restricted places and times. Validated methods have been the basis for all the testing and CSIRO also have the time and funding to go beyond the requirements of a standard method in an attempt to isolate adulterant STEC. It is likely that some of the routine testing conducted under the national program yields spurious positive results due to the nature of the tests, rather than any error on the part of laboratories.

As part of work to understand the statistical basis for STEC testing and to provide data for risk assessment, the distribution and concentration of *E. coli* O157 in lots of beef destined for grinding (manufacturing beef) that failed to meet Australian requirements for export was determined. For each of five lots from which *E. coli* O157 had been detected, 900x5g samples from the external carcass surface were tested. *E. coli* O157 was not detected in three lots, whereas in two lots *E. coli* O157 was detected in 2 and 74 samples. For lots in which *E. coli* O157 was not detected, the *E. coli* O157 level was estimated to be 12 cells per 27.2-kg carton. For the most contaminated carton, the total number of *E. coli* O157 cells was estimated to be 813. In the two lots in which *E. coli* O157 was detected, the pathogen was detected in 1 of 12 and 2 of 12 cartons. These results indicate that despite the application of stringent sampling plans, sampling and testing approaches are inefficient for controlling microbiological quality (Kiermeier, Mellor, Barlow, & Jenson, 2011).

3.6 Between packing and purchase

There is no reason to believe that STECs behave any differently to generic *E. coli.*

3.7 Cooking

There is no reason to believe that STECs behave any differently to generic *E. coli*. There is a group of *E. coli* that appear to be particularly heat resistant, but these strains do not produce Shiga toxin (Liu et al., 2015).

4. STEC through the sheep meat supply chain

4.1 Animal

4.1.1 Gastrointestinal tract

The major animal carriers are healthy ruminants, primarily cattle, and, to a lesser extent sheep and goats. Intestinal carriage is usually intermittent or short-term (Ferens & Hovde, 2011).

A small survey of 164 sheep across two Australian processing establishments detected *E. coli* O157 in the faeces of 4.9% of sheep, varying between 0 and 17.5% in different groups of sheep with a concentration range of $\log_{10}$ 0.96–3.38 MPN/g (Duffy, Small, & Fegan, 2010).

A large national survey was conducted to produce data on the prevalence and concentration of STEC from sheep faeces at slaughter. The survey comprised 800 faecal samples, collected from across Australian processors and three animal groups: pasture-fed lamb (n=414), feedlot lamb (n=163) and sheep (n=223). By culture confirmation, Top 7 STEC were recovered from 28 of the 800 samples processed (3.5%); 27 samples contained STEC O157 (3.4%), two samples contained STEC O26 (0.3%), with one sample containing both O157 and O26. Analysis of animal groups revealed that Top 7 STEC were present in 4.9% of sheep, 4.3% of feedlot lamb and 2.4% of pasture-fed lamb. Despite considerable effort to isolate Top 7 STEC, serogroups O45, O103, O111, O121, and O145 were not isolated from any sample. Counts of STEC O157 were generally low with 17 of the 27 samples (63%) containing O157 at concentrations less than 1 $\log_{10}$ MPN/g faeces. The remaining samples contained O157 at 1 (n=1), 1.7 (n=1), 1.8 (n=2), 2.3 (n=1), 3.3 (n=2), 3.7 (n=2) and 6.3 (n=1) $\log_{10}$ MPN/g of faeces. The two STEC O26 isolates were present at 0.15 and 3.0 $\log_{10}$ MPN/g faeces. STEC O157 isolates most often possess *stx1a* and *stx2c* toxin genes (72%), which places them into level 3 (potential for diarrhoea and bloody diarrhoea) of the risk classification scheme proposed by Joint FAO/WHO Expert Meetings on Microbiological Risk Assessment (JEMRA) (FAO and WHO, 2018) and is consistent with the predominant *stx* subtypes observed in Australian cattle populations. The remaining O157 isolates were shown to possess *stx1a* alone (16%; JEMRA level 4- potential to cause diarrhoea and bloody diarrhoea) and *stx2c* alone (12%; JEMRA level 3- potential to cause diarrhoea and bloody diarrhoea). The two O26 isolates possessed a single toxin type, *stx1a* (JEMRA level 4- potential to cause diarrhoea and bloody diarrhoea), which is also consistent with the predominant profile observed in Australian cattle isolates.[408]

4.1.2 Fleece/skin

A small survey of 164 sheep across two Australian processing establishments detected *E. coli* O157 on the fleece of 3% of sheep, varying between 0 and 8.6% in different groups of sheep at concentrations below the limit of quantification (Duffy et al., 2010).

4.2 Carcase

A small survey of 164 sheep across two Australian processing establishments detected *E. coli* O157 on 1 sheep carcase (0.6%) (Duffy et al., 2010).

Since the presence of STEC is not regulated in major sheep meat markets, no other data have been collected.

4.3 Chilling

There is no reason to expect that the behaviour of STEC during chilling would differ from that of other *E. coli*.

4.4 Primals

A 2011 national survey of sheep primals (legs, n=613, and shoulders, n=613) revealed 2/613 leg and 1/613 should samples to have detectable *E. coli* O157 (sponge samples of 300cm^2 area) (Phillips et al., 2013).

4.5 Boneless sheep meat

No data are known to be available.

[408] Mellor, G I et al. (2019) Pathogen and antimicrobial resistance in ovine faeces at slaughter. final report Meat & Livestock Australia V.MFS.0417 Pathogen and antimicrobial resistance in ovine faeces at slaughter | Meat & Livestock Australia (mla.com.au)

4.6 Between packing and purchase

No data are known to be available.

4.7 Cooking

There is no reason to believe that STECs behave any differently to generic *E. coli*. There is a group of *E. coli* that appear to be particularly heat resistant, but these strains do not produce Shiga toxin (Liu et al., 2015).

5. *E. coli* and public health

There are several types of *E. coli* that are able to cause disease in humans (e.g., urinary tract infections, travel-associated diarrhoea) but the type that is of great interest in meat safety are the Shiga toxin-producing *E. coli* (STEC) still sometimes known in parts of the world (e.g., Europe) as Verocytotoxin-producing *E. coli* (VTEC). STEC are known to cause diarrhoea, bloody diarrhoea, and haemolytic uraemic syndrome (HUS) in humans and are therefore known, from a clinical perspective, as enterohaemorrhagic *E. coli* (EHEC).

5.1 Phylogeny

A phylogenetic analysis of *E. coli* O157 concluded that the common ancestor of the set of isolates tested occurred around 1890 (1845–1925) and originated from the Netherlands. Phylogeographic analysis identified 34 major transmission events. The earliest were predominantly intercontinental, moving from Europe to Australia around 1937 (1909–1958), to the United States in 1941 (1921–1962), to Canada in 1960 (1943–1979), and from Australia to New Zealand in 1966 (1943–1982). These events pre-date the first reported human case of *E. coli* O157:H7, which was in 1975 from the United States. It was concluded that inter- and intra-continental transmission events have resulted in the current international distribution of *E. coli* O157:H7, and it is likely that these events were facilitated by animal movements (e.g., Holstein Friesian cattle). These findings will inform policy on action that is crucial to reduce the further spread of *E. coli* O157:H7 and other (emerging) STEC strains globally (Franz et al., 2018). Australian strains are also notable for their non-motile phenotype (Pintara et al., 2018).

5.2 Bovine and human types

While the majority of bovine strains of *E. coli* O157 are not transmitted to humans, there is little doubt that cattle are the main source of human EHEC infections (Ferens & Hovde, 2011).

An early phylogenetic analysis demonstrated two lineages of *E. col* O157 (Kim, Nietfeldt, & Benson, 1999). Most Australian cattle strains (31/37) were found in lineage II, but human isolates were mostly in lineage I, with a few bovine isolates (Kim et al., 2001). These data support the idea that, while human infections with *E. coli* O157 come from a bovine source (by some route), not all bovine *E. coli* O157 are likely to cause disease in humans.

5.3 Virulence

Manning et al. (2008) investigated the association of Shiga toxin genes and the types of clinical disease reported in subgroups (clades) of *E. coli* O157. They found that in the three most common clades (2, 7 and 8), clades 2 and 8 were more often associated with bloody diarrhoea, and clade 8 more frequently with more severe disease, while clade 7 strains were associated with milder clinical infections.

These ideas have developed and have been summarized in an international consultation (FAO and WHO, 2018). JEMRA[409] provided advice on characterizing STEC as causes of human illness and attribution to foods. The following is a summary from that report:

Pathogenicity of STEC is complex but in general, infection entails three features:

- ingestion of a contaminated food or other vehicles;
- colonization of intestinal epithelial cells by STEC; and
- production of Shiga toxins (Stx) which disrupts normal cellular functions and causes the cell damage.

The evidence suggests that production of Stx alone without adherence of bacterial cells to gut epithelial cells is insufficient to cause severe illness. STEC infection can be asymptomatic. People with or without HUS can die. This risk-based discussion focuses on mild diarrhoea, bloody diarrhoea, and HUS.
The principal adherence factor in STEC is the intimin protein coded by the *eae* gene. Intimin is crucial in the attaching-effacing (AE) lesion. The *eae* gene is highly polymorphic, with over 34 different genetic variants (alleles) designated by Greek letters.
STEC are characterized by the production of Shiga toxins (Stx); there are two main types, designated Stx1 and Stx2, with three Stx1 (Stx1a, Stx1c and Stx1d) and seven Stx2 (Stx2a, Stx2b, Stx2c, Stx2d, Stx2e, Stx2f and Stx2g) subtypes reported. STEC strains can produce any of the Stx or combination of Stx subtypes but not all subtypes have been implicated in severe illness.
Studies have shown Stx2 to be more important than Stx1 in the development of HUS. Among the Stx2 toxin group, the subtype genes most reported to be associated with severe disease are stx2a, stx2c and stx2d.
The following table provides a risk-ranking of STEC strains according to their genes and potential for causing disease.

Combinations of STEC virulence genes and the estimated potential to cause diarrhoea (D), bloody diarrhoea (BD) and haemolytic uraemic syndrome (HUS)[1]

Level	**Trait (gene)**	**Potential for:**
1	stx_{2a} + *eae* or *aggR*	D / BD / HUS
2	stx_{2d}	D / BD / HUS[2]
3	stx_{2c} + *eae*	D / BD[3]
4	Stx_{1a} + *eae*	D / BD[3]
5	Other stx subtypes	D

Notes: 1. Depending on host susceptibility or other factors e.g., antibiotic treatment

2. association with HUS dependent on stx2d variant and strain background

3. some subtypes have been reported to cause BD, and on rare occasions HUS

The FAO/WHO Joint Expert Meeting on Risk Assessment[410] (FAO and WHO, 2018) concluded:

1. While there are hundreds of STEC serotypes, many have not been implicated in human illness. Thus, serotype data of STEC strains is not reliable for predicting risk and the potential of the STEC to cause severe diseases.

2. Risk and the severity of STEC infections are best predicted using STEC virulence factors (genes).

3. All STEC, regardless of Stx subtype it produces, can probably cause diarrhoea, especially in susceptible individuals, and therefore, pose some risks.

[409] FAO and WHO. (2018). *Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring*. Rome: FAO. Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring: report (who.int)

[410] FAO and WHO. (2018). *Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring*. Rome: FAO. Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring: report (who.int)

4. Based on existing scientific knowledge, STEC strains with Stx2a subtype and adherence genes *eae* or *aggR* poses highest risk and have the strongest potential to cause BD and HUS.

5. The association of other Stx subtypes with HUS is less conclusive and can vary, depending on multiple bacterial and host factors.

6. Human factors, such as health, genetics and immunosusceptibilities can affect the severity of outcomes in STEC infections.

7. A set of criteria is provided as guidance to managing the various levels of potential risk and severity from STEC infections. Selection of the level depends on desired risk management objectives, resource availability and laboratory capabilities.

> Example 1 – level 5: test for all STEC (*stx* genes) may reduce the potential risk of diarrhoea from STEC infections, but data may not always reflect true risk of diarrhoea.
>
> Example 2 – Level 1: testing for *stx2a* and *eae* or *aggR* may be the best approach to minimizing the risk of HUS from STEC infections.
>
> Example 3 – Levels 2, 3 and 4: testing for other Stx subtypes may further reduce incidences of HUS, but data may not always provide definitive association with HUS.

8. A strategy for testing isolates to assess the potential to cause serious illness against the criteria is also provided.

9. If available, use of metagenomics may be an alternative strategy to obtaining data on STEC virulence criteria and provide additional information by accessing STEC genetic sequence databases that exists worldwide.

The US National Advisory Committee on Microbiological Criteria for Foods (NACMCF)[411] produced a report with similar observations to the JEMRA report, in the US context, and additionally maintained a link with the US top 7 serogroups of STEC in their classification.

5.4 Characterisation of Australian STECs

Variable virulence in STEC strains could conceivably lead to changes in risk management practices, but the path to those changes are tortuous and needs to be informed by the development of new scientific understanding and assessment. Australia has contributed to the development of the science.

Subsequent to Manning et al. (2008) and prior to JEMRA[412] (FAO and WHO, 2011), a joint Australian – US team studied the relative virulence of Australian and US *E. coli* O157 strains (Glen E. Mellor et al., 2013; Glen E. Mellor et al., 2015).

The significant difference in the phylogeny of Australian and US *E. coli* O157 was, again, confirmed. Lineages differed between the two continents, with most Australian isolates belonging to lineage I/II (LI/II) (LI, 2%; LI/II, 85% (Manning clade 7); LII, 13%) and the majority of U.S. isolates belonging to LI (LI, 60%; LI/II, 16%; LII, 25%). Shiga toxin genes (*stx*) transfer *between E. coli* strains by bacteriophage which remain in the bacterial cell because they are inserted into the bacterial chromosome.

[411] [USA] National Advisory Committee on Microbiological Criteria for Foods. (2019). Response to Questions Posed by the Food and Drug Administration Regarding Virulence Factors and Attributes that Define Foodborne Shiga Toxin-Producing Escherichia coli (STEC) as Severe Human Pathogens . *J Food Prot*, *82*(5), 724-767. https://doi.org/10.4315/0362-028x.Jfp-18-479

[412] FAO and WHO. (2018). *Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring*. Rome: FAO. Shiga toxin-producing Escherichia coli (STEC) and food: attribution, characterization, and monitoring: report (who.int)

Australian strains frequently carried *stx1* in the *argW* gene but the US strains did not. The US strains much more frequently had the *stx2*-gene (also referred to as *stx2a*) compared to Australian isolates (4% of Australian isolates versus 72% of U.S. isolates) (Glen E. Mellor et al., 2013).

Subsequent work identified a number of lineages defined using SNP data. *E. coli* O157 isolates clearly segregated into SNP lineages that were associated with origin in Australia, USA, or Argentina. No Australian isolates were in Manning clade 8. Isolates within SNP lineages that were strongly associated with the carriage of *stx2a* produced comparatively more Shiga toxin than did those lacking the *stx2a* subtype. Furthermore, the proportion of isolates in *stx2a*-associated SNP lineages was significantly higher in Argentina and the United States than Australia ($P < 0.05$). This study provides evidence for the geographic divergence of *E. coli* O157 and for a prominent role of *stx2a* in total Stx production (Glen E. Mellor et al., 2015).

Following the JEMRA report, work commenced to understand the risk classification of Australian top 7 STECs as well as strains that were not in the top 7 serogroups[413]. Using the FSIS definition, 3.0% of faecal samples contained STEC that were classified as adulterants while 27.9% were shown to contain non-adulterant STEC. By comparison, using the JEMRA system, 8.5% of samples contained STEC belonging to levels 1, 2 or 3 which have the highest potential for severe disease and 22.4% contained STEC belonging to levels 4 or 5 which have lower potential to cause haemolytic uremic syndrome (HUS) but may cause diarrhoea or bloody diarrhoea. Using the NACMCF risk scheme, no isolates were assigned to category 1 (highest health risk), 3.0% of samples were assigned to levels 2 and 3 (equivalent to current FSIS definitions) and 27.9% were assigned to risk levels 4 and 5 (lowest health risks). Using enrichment broths that had a positive screening test for STEC, by the FSIS definition, 5.5% of samples contained STEC that were classified as adulterants, while 33.0% contained STEC that were deemed non-adulterant. By comparison, using the JEMRA risk scheme, 14.0% of samples were assigned to levels 1, 2 or 3 which contain STEC that have the highest potential for severe disease, 24.5% were assigned to levels 4 or 5 which contain STEC with reduced potential to cause HUS but may cause diarrhoea or bloody diarrhoea. Using the NACMCF risk scheme, 0% of samples were assigned to level 1 (containing STEC of highest health risk), 5.5% were assigned to risk levels 2 and 3 (contain STEC that conform to current FSIS definition for adulterants) and 33.0% were assigned to risk levels 4 and 5 (STEC of lowest health risk).

The scientific work to establish a relationship between the genes carried by STEC strains and their potential to cause disease, and therefore, public health significance is continuing to develop. Whether these findings will be incorporated into risk management remains to be seen with significantly different approaches being taken in different countries.

5.5 Risk assessment

E. coli O157 in hamburgers was an early target for risk assessment, and several assessments, including one in Australia, were performed[414] (FAO and WHO, 2011), though none were used to determine risk management approaches.

A subsequent Australian risk assessment considered the supply of Australian manufacturing beef to the USA, and production of hamburger patties of 100% Australian beef (which never occurs because lean Australian manufacturing beef is mixed with fatty US trim) and supply to both the domestic and

[413]. Mellor, G et al., (2022) Molecular assessment and characterisation of Australian Shiga toxin-producing E. coli (STEC) V.MFS.0440 - Molecular assessment and characterisation of Australian Shiga toxin-producing E. coli (STEC) | Meat & Livestock Australia (mla.com.au)

[414] FAO and WHO. (2011). *Enterohaemorrhagic Escherichia coli in raw beef and beef products: approaches for the provision of scientific advice: meeting report.* . Rome: FAO. Enterohaemorrhagic Escherichia coli in raw beef and beef products: approaches for the provision of scientific advice: meeting report (who.int)

the hamburger restaurant market (quick service restaurants). The assessment was limited to *E. coli* O157 and data on manufacturing beef was constructed from national data collection, plus re-testing from cartons of meat in which *E. coli* O157 had been detected (Kiermeier et al., 2011). *E. coli* O157 was not distributed even through the lot and was present in low concentration, with implications for the likelihood of the sampling and testing regime to accurately detect a lot in which *E. coli* O157 was present. The risk assessment uses these testing data and assumed that no product was removed from the supply chain (that is, as though no testing occurred), that hamburgers were made from 100% Australian beef, and that all beef was consumed, even if temperature abused in the supply chain. The risk assessment predicts 49.6 illnesses (95% CI: 0.0–148.6) from the 2.46 billion hamburgers made from 155,000 t of Australian manufacturing beef exported to the United States in 2012. A previous risk assessment had estimated a total of 19,000 illnesses in the USA per year, so the number of illnesses predicted to be due to Australian beef (in this risk assessment) is very small. A consensus dose response model (likelihood of illness after consuming a certain dose of *E. coli* O157) was used, which was not modified for the likely low virulence of Australian *E. coli* O157 strains. All the illnesses were due to undercooking in the home and less than one illness is predicted from consumption of hamburgers cooked to a temperature of 68°C in quick-service restaurants (Kiermeier, Jenson, & Sumner, 2015). Further assessment using the model estimated that implementation of the testing program required by the USDA Food Safety and Inspection Service would only reduce the number of illnesses by about 10%, with diminishing returns on additional testing (Kiermeier, Sumner, & Jenson, 2015).

5.6 Attribution to red meat

There is little doubt that cattle are the main source of human EHEC infections (Ferens & Hovde, 2011), but human infections are not necessarily through the consumption of red meat. There is little recognition of sheep meat as a vehicle of STEC causing human infection (EFSA BIOHAZ Panel et al., 2020).

A global collation and analysis of public health data showed that the most important food types identified as sources of globally documented outbreaks caused by STEC were produce (leafy salad vegetables such as lettuce and spinach), beef, and dairy products. The ranking of the top three food categories varied between regions. The proportion of STEC cases estimated to be attributable to beef and produce were highest in the American and European regions. In Western Pacific, dairy appeared to play a more important role, followed by produce; beef ranked third. Possible explanations for regional variability include differences in the proportion of specific foods in the diet and how they are prepared for consumption, the frequency of STEC contamination of foods and differences in how outbreaks are investigated and reported. An additional potential source of variability between regions is differences in the prevalence of STEC strains with the potential to cause severe illness, such as bloody diarrhoea or HUS. More than half of the outbreaks documented globally could not be attributed to any source (Pires, Majowicz, Gill, & Devleesschauwer, 2019).

5.7 Risk management

In 2022, the Codex Committee on Food Hygiene forwarded the draft *Guidelines for the control of Shiga toxin-producing Escherichia coli (STEC) in raw beef, fresh leafy vegetables, raw milk and raw milk cheeses* to the Codex Alimentarius Commission for adoption at the 2023 meeting.[415] In general, Australia follows these Guidelines.

[415] Codex Alimentarius Commission. 2022. Report of the fifty-third session of the Codex Committee on Food Hygiene. Paragraphs 23-59, and 79 and Appendix III https://www.fao.org/fao-who-codexalimentarius/sh-proxy/pt/?lnk=1&url=https%253A%252F%252Fworkspace.fao.org%252Fsites%252Fcodex%252FMeetings%252FCX-712-53%252FReport%252FREP23_FHe.pdf

Approaches to risk management differ by country. The following attempts to demonstrate different approaches and suggest the considerations that may have contributed to risk management decisions. The Japanese approach is the most specific, requiring an effective control near to the point of consumption, and the EU approach is the most general, potentially affecting large quantities of product that may not be used in high-risk products.

5.7.1 Japan

In response to an outbreak and deaths due to consumption of raw beef, the Ministry of Health, Labour and Welfare now requires “A piece of meat to be eaten raw should be sealed and heat sterilized at a temperature of 60°C for over 2 min to a depth of 1 cm from the surface”. The cooked product is cut off and the meal prepared from the uncooked portion in the middle of the block. This method must only be performed by trained personnel, and more meat is shaved off than the pre-existing methods in which the thin surface area has been trimmed without heat sterilization. The method was designed to reduce illness by 90% (Jenson, Vanderlinde, Langbridge, & Sumner, 2014; Miya et al., 2014).

The Japanese approach is expensive for the restaurant, and therefore the consumer, but limits the public health intervention to only the identified risky product, and the cost is borne only by the consumer of that product.

5.7.2 United States

The risk management approach in the United States has evolved, often in response to outbreaks, and consumer lobby group pressure since the first significant outbreak of *E. coli* O157 associated with hamburgers in 1993. The outbreak resulted in more than 600 illnesses with four children dead from having consumed undercooked hamburgers (Murano, Cross, & Riggs, 2018).

E. coli O157:H7 was declared as an adulterant in raw ground beef by FSIS in 1994 and explicitly included in the Pathogen reduction and HACCP regulations (9 CFR 304). Moreover, because of the increasing awareness of the public health impact of the non-O157 STEC, FSIS additionally declared, in 2011, the top six non-O157 (O26, O45, O103, O111, O121, and O145) STEC serogroups as *adulterants in raw, non-intact beef products and raw, intact beef products that are intended for use in raw, non-intact beef products* (USDA-FSIS, 2011) and later (USDA-FSIS, 2020) in ground beef, bench trim, and other raw ground beef components.

The focus in the USA has been on strains that are frequently associated with human disease, and products that, due to internalisation of STEC from the meat surface, and survival due to under-cooking, may pose a risk. US product liability law uses the principle of ‘strict liability’ which means that a person is legally responsible for the consequences flowing from their actions even in the absence of fault or criminal intent; the processor is responsible for the STEC in the hamburger, not the consumer or restaurant for failing to cook adequately.

If liability laws are insufficient to encourage processors to reduce (or try to eliminate) STEC in their product, then the testing programs of the FSIS[416] are a blunt instrument to encourage compliance. Product that is ‘in commerce’ or approved for shipping may be tested, and detection of an STEC will require a product recall. To avoid these situations, processors hold product while FSIS conducts their test (usually defining the lot size to be very small), and additionally conduct an enormous number of their own tests, holding the product until a result is available. Any product affected by an STEC detection is redirected for use in an application in which thorough cooking is assured (e.g., canned products, pre-cooked Taco fillings).

[416] FSIS (2023) Sampling verification activities for Shiga toxin-producing Escherichia coli (STEC) in raw beef products. FSIS Directive 10,010.1 Rev 5 FSIS Directive 10010.1 Rev 5 Sampling Verification Activities for Shiga Toxin-Producing Escherichia Coli (STEC) in Raw Beef Products (usda.gov)

5.7.3 EU

In the EU, the monitoring of foodborne disease outbreaks of human STEC infections was made mandatory in 2003 through the Zoonoses Directive 99/2003.[417] In the Hygiene Package Criteria regulation 2073/2005[418], EU emphasized that "*VTEC represents a hazard to public health in raw or undercooked beef and possibly meat from other ruminants, minced meat and fermented beef and products thereof, raw milk and raw milk products, fresh produce, in particular sprouted seeds, and unpasteurized fruit and vegetable juices*". Later, in the wake of the huge 2011 STEC O104:H4 outbreak (associated with sprouted seeds), the EU finally defined Shiga toxin-producing *E. coli* O157, O26, O111, O103, O145 and O104:H4 as a food safety criterion for sprouts or spent irrigation water (EU 209/2013).[419]

While there is no specific regulation regarding STEC in meat, there is a general regulatory authority relating to unsafe food (Regulation EC 178/2002), and some EU member states use this authority to test, and potentially recall, product containing any Shiga toxin-producing *E. coli*, not just the serogroups mentioned above. A draft guidance document[420] has been produced, which is based on the premise that it is not possible to fully define human pathogenic STEC or predict the potential to cause human disease and considers the normal conditions of use of the food and vulnerability of certain groups of consumers. For this reason, isolation of an *E. coli* with an *stx* gene (and an *eae* gene, though this gene may not always be considered), in meat which *may* be consumed undercooked is sufficient to cause a recall and listing of the product on a public database (the Rapid Alert System for Food and Feed). Some member states utilise this draft guidance document, but it is never likely to be finalised because consensus cannot be reached between member states.

The approach taken by some EU member states, considers all STEC in almost all meat to be a risk that needs to be controlled, and applies that control at the most general level.

6. Laboratory methods

Laboratory methods for STEC are complex. There is a desire to detect the presence of low numbers of STEC in product, that have specific characteristics (O serogroups) against a background of non-Shiga toxin-producing *E. coli*. Enrichment methods are used on large sample sizes, all *E. coli* are enriched (and many other bacteria also), and then STEC of public health interest need to be differentiated from non-STEC. Collection of samples for laboratory analysis is an important aspect of testing programs.

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[417] EU (2003) Directive 2003/99/EC of the European Parliament and of the Council of 17 November 2003 on the monitoring of zoonoses and zoonotic agents, amending Council Decision 90/424/EEC and repealing Council Directive 92/117/EEC EUR-Lex - 32003L0099 - EN - EUR-Lex (europa.eu)

[418] EU (2005) Commission Regulation (EC) No 2073/2005 of 15 November 2005 on microbiological criteria for foodstuffs EUR-Lex - 32005R2073 - EN - EUR-Lex (europa.eu)

[419] EU (2013) Commission Regulation (EU) No 209/2013 of 11 March 2013 amending Regulation (EC) No 2073/2005 as regards microbiological criteria for sprouts and the sampling rules for poultry carcases and fresh poultry meat EUR-Lex - 32013R0209 - EN - EUR-Lex (europa.eu)

[420] European Commission. Health and Consumers Directorate-General. (nd) DRAFT Guidance document on the application of article 14 of Regulation (EC) no. 178/2002 as regards food contaminated with Shiga toxin-producing Escherichia coli (STEC) Working document. https://www.ceirsa.org/fd.php?path=201708%2FDraft_VTEC_guidance_document_on_application_Art_14_GFL_REV_3-3.pdf

6.1 Sampling

The most prescriptive expectations of sampling arise in the USA – due to the FSIS testing and subsequent industry requirements. Since *E. coli* contaminates the carcase surface, either from the hide or directly from faeces, the most sensitive testing is performed on samples of the meat surface.

The cornerstone of US control programs for STEC has become N-60 sampling[421,422] in which 60 pieces of sliced off surface meat, collected at random through the lot, each measuring about 25x75mm and no more than 3mm thick are composited into a 375g sample (325g by FSIS for regulatory testing). It must be noted that this sampling is NOT the same as n=60 in the ICMSF sampling plans (see Chapter 12 microbiological criteria). The maximum lot size is prescribed, though lot size has little effect on the likelihood of detecting STEC, if the product contamination is relatively uniform.

In Australia, a method involving collection of small grab samples was shown to be equivalent to N-60 testing. Testing for generic *E. coli*, for portion samples, 48 (96%) were positive, while 45 (90%) of surface slice samples were positive (P value = 0.37). The number of positive sub-samples obtained using the portion and surface slice methods were not significantly different (P value = 0.47). Surface slices have greater surface area to mass ratio only when slices are less than about 3 mm in thickness, which is difficult to achieve, by use of a knife and hook/tongs for sampling.

Since export of manufacturing beef from Australia is frozen, FSIS will sample from frozen blocks when testing at Port of Entry into the USA. FSIS describe these methods in detail in their directives to inspectors[423] and provide video instruction[424]. Sampling conducted in Australia is generally the same as FSIS sampling, except that 12 cartons are chosen for sampling and 5 small samples collected from each, in the belief that this will provide a more representative sample of the lot than the FSIS method of taking 12 samples from each of 5 cartons.

Various drill devices have been designed to remove and collect surface material from the surface of chilled trim pieces within a product bin, but the use of these devices may have been superseded by sampling cloths.

A cloth sampling device has been validated against the N-60 excision method and been found to be very satisfactory, and possibly even more suitable for detection of STEC in lots of manufacturing beef (Arthur & Wheeler, 2020; Wheeler & Arthur, 2018). It is likely that FSIS will use this cloth sampling device for their routine testing of chilled manufacturing beef.[425]

6.2 Testing

Testing has evolved rapidly for regulatory and trade purposes, and, contrary to most other microbiological methods, relies on molecular techniques as a reference method. An entire chapter

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[421] Beef Industry Food Safety Council. (2019) Guidance document for Lotting and Sampling of Beef Products for Pathogen Analysis, lotting and sampling of beef products for pathogens analysis update april - 2019.pdf (bifsco.org)

[422] University of Nebraska. Standard Operating Procedure for E. coli O157:H7 Sampling of Beef Lean Trim g1973.indd (unl.edu)

[423] FSIS (2023) Sampling verification activities for Shiga toxin-producing Escherichia coli (STEC) in raw beef products. FSIS Directive 10,010.1 Rev 5 FSIS Directive 10010.1 Rev 5 Sampling Verification Activities for Shiga Toxin-Producing Escherichia Coli (STEC) in Raw Beef Products (usda.gov)

[424] Youtube. USDAFoodSafety. STEC Sampling of Imported Raw Beef Products. STEC Sampling of Imported Raw Beef Products - YouTube

[425] FSIS. 2022. Use of a Non-Destructive Surface Sampling Device to Sample Domestic Beef Manufacturing Trimmings and Bench Trim. Federal Register 78:71291. https://www.federalregister.gov/documents/2022/11/22/2022-25333/use-of-a-non-destructive-surface-sampling-device-to-sample-domestic-beef-manufacturing-trimmings-and

could be devoted to the intricacies of choosing and method and performing STEC testing. The two common methods are the FSIS Microbiological Laboratory Guidebook method and the ISO method.

FSIS Microbiological Laboratory Guidebook (MLG)[426] method is the FSIS in-house method, which is modified from time-to-time, for detection, isolation, and identification of top seven Shiga toxin-producing *Escherichia* coli (STEC) from meat products and carcass and environmental sponges (chapter 5 in the MLG). Since FSIS does not mandate testing within the USA, it does not mandate the use of this method anywhere but in their own laboratory. However, other methods are often validated against this method, and Australia and the US have an agreement about methods that are used in Australian laboratories for the purpose of testing product to be exported to the USA.

FSIS testing occurs in stages, and a positive result at each stage determines that the testing continues. The FSIS method involves enrichment of meat samples in a broth that is not very selective for *E. coli*. The broth is then tested for the presence of *stx* and *eae* genes and for the presence of genes specific for the regulated O serogroups. These genes could be in different *E. coli* strains, but the test is not able to determine whether that is the case. At this point it is possible to determine that the sample has a potential positive STEC (FSIS definition):

> Potential positive STEC – enriched samples that test positive for the STEC screening PCR (stx AND eae) and serogroup during this rapid screening procedure are reported as a potential positive. Potential positive samples proceed to the IMS bead procedure and mRBA for isolation.

Potential positive STEC enrichment broths are then plated onto a differential agar, which will help to identify possible *E. coli* colonies, and multiple colonies are then tested by agglutination tests to see if any are of a top 7 serogroup as indicated by the screening of the enrichment broth. Agglutinating colonies of a top 7 serogroup *E. coli* are then tested for the *stx*, *eae* and O-specific gene. At this point it is possible to determine that a sample has a presumptive positive STEC (FSIS definition):

> Presumptive positive STEC is defined as having one or more typical colonies on plating agar agglutinate with STEC latex agglutination reagents and positive on the presumptive PCR assay (for *stx* and *eae*)

A purified colony is then tested to ensure that it is *E. coli*, agglutinates the O-group antiserum and contains *stx*, *eae* and O-group genes. FSIS definition:

> Confirmed positive STEC: a sample is considered positive for STEC when the *E. coli* isolate belongs to one of the seven targeted serogroups and contains a stx and an eae gene.

Several rapid methods are approved by DAFF for testing product for export to the USA.[427]

The EU utilises the ISO/TS 13136: 2012 method[428] for testing STEC. The ISO method appears to be synonymous with the Pall Genedisc® method for the EU top 5 strains. The ISO method involves enrichment of a sample and testing the enriched broth for *stx* and *eae* genes, and if positive, for O-group specific genes. Colonies are isolated on agar and tested to demonstrate the presence of *stx*, *eae* and the O-specific gene in the same strain. As a Technical Specification (TS) the document is liable to be significantly revised as more information becomes available. In 2023, a revision was underway.

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[426] FSIS. Microbiology Laboratory Guidebook. Microbiology Laboratory Guidebook | Food Safety and Inspection Service (usda.gov)

[427] DAFF. ELMER 3. Approved methods for microbiological testing of meat and meat products. Approved methods for microbiological testing of meat and meat products - DAFF (agriculture.gov.au)

[428] ISO/TS 13136 (2012) Microbiology of food and animal feed – Real-time polymerase chain reaction (PCR)-based method for the detection of food-borne pathogens – Horizontal method for the detection of Shiga toxin-producing *Escherichia coli* (STEC) and the determination of O157, O111, O26, O103 and O145 serogroups.

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20. Antimicrobial resistance

Summary

Antimicrobial resistance (AMR) is an international health issue, with links between human and animal health, and the environment (a One Health issue). Many international organisations, as well as national governments, including the Australian Government, have plans for addressing AMR issues.

AMR usually applies to the resistance of bacteria to antibiotics used to treat infections. The use of antimicrobials (AMU) can select for AMR bacteria, which then can multiply and cause difficult-to-treat infections which can then be passed to others. Antimicrobial stewardship (AMS), taking care to use antibiotics prudently, and prevent resistance from spreading, is a key aspect of controlling AMR. AMR is a technically complex area, with much that is not known, and a perceived need for policy to move ahead of strong scientific evidence and solid risk assessment

This is an emerging issue which has not yet caused trade barriers, but the potential to do so in the near future is high. The EU has legislation that impacts ‘third countries’ and may become a WTO dispute. Recent free trade agreements (UK and potentially, EU) contain chapters committing to cooperation on AMR.

Australian agriculture is in a good position because of the strong regulatory framework provided by the Australian Government over a long period, including the requirement for veterinary prescription before giving antibiotics to animals, that many antibiotics of importance in human medicine are not registered for use in animals, and the awareness of the veterinary profession and producer organisations. Data demonstrates a low prevalence of AMR bacteria in cattle and sheep, and AMU appears to be low.

Australia has a strong scientific and evidence base to support its position on AMR, though importing countries, and supply chains, are always in a position where they can demand considerable data and proof of compliance which is potentially a large burden on the supply chain.

Contents

1. International issues about antimicrobials

The use of antibiotics throughout history, to treat clinical disease and prevent infection in both humans and animals has been followed soon after by the failure of these drugs to control previously treatable bacterial infections(Davies & Davies, 2010). The phenomenon of antimicrobial resistance (AMR) is a continual and growing problem for treatment of human and animal infections.

The One Health approach, recognising that human, animal, plant, and environmental health are interlinked is the preferred paradigm for addressing AMR. One Health is defined as

> “an integrated, unifying approach that aims to sustainably balance and optimize the health of people, animals and ecosystems. It recognizes the health of humans, domestic and wild animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent.” [429]

From an animal industry perspective there seems to be a priority on consideration of optimal health for humans.

1.1 Definitions

There is some confusion about definitions (see definitions below). ‘Antibiotics’ are a very broad group of compounds that includes to anything that kills or inhibits bacteria, fungi or microparasites (H. M. Scott et al., 2019) and can be used interchangeably with ‘Antimicrobial’. Sometimes ‘antimicrobial’ is applied very broadly to include antibiotics, antiseptics, antifungals, antivirals, antimalarials and anthelmintics.[430] The term ‘antimicrobial’ is used in conjunction with resistance, whereas ‘antibiotic’ is used when discussing a pharmacologically active agent (H Morgan Scott et al., 2019).

Some antibiotics are never used in humans but may be used in animals, and it is not always clear when the medical community uses the term ‘antibiotic’, whether they mean all chemicals, the ones able to be used in humans, or the ones registered for use.

Definitions:

Antibiotic - naturally occurring, semi-synthetic or synthetic substances that exhibit antibacterial activity to kill or inhibit the growth of bacteria, at concentrations attainable *in vivo*. Biocide substances, such as disinfectants or antiseptics, are excluded from this definition.[431]

Antimicrobial - Any substance of natural, semi-synthetic, or synthetic origin that at *in vivo* concentrations kills or inhibits the growth of microorganisms by interacting with a specific target.[432]

Antimicrobial class - Agents with related molecular structures, often with a similar mode of action because of interaction with a similar target and thus subject to similar mechanism of resistance. Variations in the properties of antimicrobial agents within a class often arise as a result of the

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[429] One Health High-level Expert Panel (2022) Annual Report 2021. ohhlep-annual-report-2021.pdf (who.int)
[430] Australia’s National Antimicrobial Resistance Strategy – 2020 and beyond | Antimicrobial resistance (amr.gov.au)
[431] Common approach of G7 CVOs on the definitions of therapeutic, responsible and prudent use of antimicrobials in animals. 5 October 2017. Microsoft Word - G7 CVOs Second Forum - 5 October 2017 (salute.gov.it)
[432] FAO and WHO. (2022). *Foodborne antimicrobial resistance: Compendium of Codex standards*. Foodborne antimicrobial resistance (fao.org)

presence of different molecular antimicrobial substitutions, which confer various intrinsic activities or various patterns of pharmacokinetic and pharmacodynamic properties.[433]

Antimicrobial Resistance (AMR) - The ability of a microorganism to multiply or persist in the presence of an increased concentration of an antimicrobial agent relative to the susceptible counterpart of the same species.[434]

1.2 International policy setting – quadripartite

The World Health Organization (WHO), World Organization for Animal Health (WOAH) and Food and Agriculture Organization (FAO), joint efforts are a coordinated One Health approach and constitute the Tripartite Collaboration on AMR. The Tripartite signed a Memorandum of Understanding on One Health and AMR in 2018. The United Nations Environment Programme (UNEP) then joined the Tripartite and it has become known as the 'Tripartite plus' or Quadripartite. The Quadripartite have their own multi-stakeholder platform.[435]

1.2.1 WHO

Antimicrobial resistance is considered by WHO as one of the biggest threats to global health, food security, and development today.[436] WHO, along with the other members of the Tripartite lead the global response to AMR through the Global Action Plan on Antimicrobial Resistance (2015)[437]. Additionally, in 2021, Australia along with 112 other member states signed The Call to Action on Antimicrobial Resistance (AMR) – 2021[438] The key objectives from the Global Action Plan include optimising the use of antimicrobials in human and animal health, which will encourage stewardship programmes.

WHO's work on AMR is guided by the WHO Strategic and Technical Advisory Group for Antimicrobial Resistance (STAG-AMR).[439] The Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR) has published lists of *Critically Important Antimicrobials for Human Medicine* [440] through several revisions. A further revision (now under the responsibility of the WHO Advisory Group of the Critical Important Antimicrobials for Human Medicine (AG-CIA))[441] is expected to be finalised in 2023. These lists have provided a categorisation of antibiotics and are influential in setting human prescribing practices, and restriction of antibiotics for animal treatment. It is expected that the 2023 revision will designate some antimicrobial classes as "authorised for use in humans only", and others as "not medically important for humans".

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433 FAO and WHO. (2022). *Foodborne antimicrobial resistance: Compendium of Codex standards*. Foodborne antimicrobial resistance (fao.org)

434 FAO and WHO. (2022). *Foodborne antimicrobial resistance: Compendium of Codex standards*. Foodborne antimicrobial resistance (fao.org)

435 FAO. AMR multi-stakeholder partnership platform. The platform | Antimicrobial Resistance | Food and Agriculture Organization of the United Nations (fao.org)

436 World Health Organization. (2018). *Antibiotic resistance*. World Health Organization. http://www.who.int/news-room/fact-sheets/detail/antibiotic-resistance

437 WHO (2015). Global Action Plan on Antimicrobial Resistance, World Health Organization, Geneva. 9789241509763_eng.pdf;jsessionid=6721150D9417A3F5F3157AD1E4C0B067 (who.int)

438 United Nations (2021). Call to Action on Antimicrobial Resistance. Call to Action on Antimicrobial Resistance (AMR) - 2021.pdf (un.org)

439 WHO, Strategic and Technical Advisory Group for Antimicrobial Resistance (STAG-AMR) Strategic and Technical Advisory Group for Antimicrobial Resistance (STAG-AMR) (who.int)

440 WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR). (2018). *Critically important antimicrobials for human medicine* (6th revision ed.). WHO. Critically important antimicrobials for human medicine : 6th revision (who.int)

441 WHO Advisory Group of the Critically Important Antimicrobials for Human Medicine (AG-CIA)

1.2.2 WOAH

WOAH has a Strategy on Antimicrobial Resistance and the Prudent Use of Antimicrobials[442].Also a range of resources and reports, including an annual report on use of antimicrobial agents intended for use in animals[443] and a list of antimicrobials of veterinary importance.[444] It is not clear how the lists from WOAH coordinate with those from WHO; if anything, the WHO list appears to take precedence.

1.2.3 FAO

The major activity of FAO affecting meat market access is the work of the Codex Alimentarius Commission, producing codes and standards on AMR. These include the Guidelines for Risk Analysis of Foodborne Antimicrobial Resistance (CAC/GL 77-2011) and Code of Practice to Minimize and Contain Antimicrobial Resistance (CAC/RCP 61-2005).[445] The FAO also develops guidelines for different production systems, and this organisation seems to have taken the lead on the environmental aspects of the AMR, in cooperation with UNEP. For example, the FAO (with WHO and WOAH) developed the technical brief on water, sanitation, hygiene, and wastewater management to prevent infections and reduce the spread of antimicrobial resistance (2020).[446]

1.2.4 UNEP

The UNEP has developed a strategic framework for collaborating on AMR with the other members of the Quadripartite, with a focus from UNEP on pollution, water, and oceans. [447] The environmental dimensions of AMR have been examined[448] and a further report provides evidence of the importance of the environment.[449]

1.3 Importing country expectations

1.3.1 Japan

Japan established the Japanese Veterinary Antimicrobial Resistance Monitoring System (JVARM) in 1999.[450] JVARM is said to conform to the OIE recommendations for AMR surveillance and laboratory testing, but their AMU data is based on aggregate sales data, and some antimicrobials are registered for multiple species.

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[442] WOAH. 2016. Strategy on Antimicrobial Resistance and the Prudent Use of Antimicrobials. Strategy on Antimicrobial Resistance and the Prudent Use of Antimicrobials - WOAH - World Organisation for Animal Health

[443] Antimicrobial resistance - WOAH - World Organisation for Animal Health

[444] OIE LIST OF ANTIMICROBIALS OF VETERINARY IMPORTANCE (woah.org)

[445] FAO and WHO. (2022). *Foodborne antimicrobial resistance: Compendium of Codex standards*. Foodborne antimicrobial resistance (fao.org)

[446] FAO. 2020 Technical brief on water, sanitation, hygiene and wastewater management to prevent infections and reduce the spread of antimicrobial resistance. Technical brief on water, sanitation, hygiene and wastewater management to prevent infections and reduce the spread of antimicrobial resistance (fao.org)

[447] FAO, WOAH, WHO, UNEP. 2022. Strategic Framework for collaboration on antimicrobial resistance. Strategic Framework for collaboration on antimicrobial resistance | UNEP - UN Environment Programme

[448] UNEP. 2022. Environmental dimensions of antimicrobial resistance: Summary for policymakers. Summary for Policymakers - Environmental Dimensions of Antimicrobial Resistance | UNEP - UN Environment Programme

[449] UNEP. 2022. Bracing for Superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance. Bracing for Superbugs: Strengthening environmental action in the One Health response to antimicrobial resistance | UNEP - UN Environment Programme

[450] The Japanese Veterinary Antimicrobial Resistance Monitoring System (JVARM) https://www.maff.go.jp/nval/tyosa_kenkyu/taiseiki/monitor/e_index.html

Japan's AMR surveillance in cattle involves samples from healthy animals at abattoirs and susceptibility testing for *E. coli*, *Enterococcus*, *Campylobacter* and *Salmonella*. Additionally, they reported on resistance in diseased animals to *Salmonella*, *Staphylococcus aureus* and *E. coli*.

1.3.2 USA

Since 2010 the FDA have reported annually on amounts of antimicrobials sold for food producing animals[451]. The National Antimicrobial Resistance Monitoring System (NARMS) is a US public health surveillance system that tracks antimicrobial susceptibility of select foodborne enteric bacteria. NARMS was established in 1996 as an interagency, collaborative partnership between US Food and Drug Administration (FDA), the Centers for Disease Control and Prevention (CDC), and the U.S. Department of Agriculture (USDA). NARMS monitors AMR in food animals through the USDA Food Safety and Inspection Service (FSIS)[452]. Sampling is conducted quarterly of product and cecal contents for *Campylobacter*, *E. coli*, *Salmonella* and *Enterococcus*.

1.3.3 UK

In the animal sector, the UK produce the Veterinary Antibiotic Resistance and Sales Surveillance Report (UK-VARSS) annually since 2013.[453] This is based on aggregate sales of veterinary medicines, but the UK government are looking at systems to evaluate AMU in individual sectors. Additionally, the UK has set voluntary targets for reductions in AMU in the livestock sectors.

Regarding the FTA between the UK and Australia, section 1.7 of the Agreement in Principle; Animal welfare and antimicrobial resistance (AMR) says "appropriate provisions on cooperation on combatting antimicrobial resistance including bilaterally and in relevant international fora on areas of mutual interest".[454] There are no specifics with respect to AMU or AMR reporting.

1.3.4 EU

The EU One Health Action Plan against AMR was adopted by the European Commission in June 2017[455] and includes an objective for 'stronger bilateral partnerships for stronger cooperation'. Inclusion of AMR-related provisions is now a current practice for the Commission in all new Free Trade Agreements.

The European Medicines Agency publishes the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) report.[456] This reported on aggregate veterinary sales from 31 European countries, and adjusts for population corrected unit (PCU, an assumed weight of animals), based on numbers of animals slaughtered. All types of cattle are grouped together, but sheep are reported separately with goats. Not all European countries are publishing species-specific data regularly.

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[451] US Food & Drug Administration Center for Veterinary Medicine (2022). Summary Report on Antimicrobials Sold or Distributed in 2021 for Use in Food-Producing Animals. FDA Releases Annual Summary Report on Antimicrobials Sold or Distributed in 2021 for Use in Food-Producing Animals | FDA

[452] USDA webpage for NARMS (National Antimicrobial Resistance Monitoring System) https://www.ars.usda.gov/southeast-area/athens-ga/us-national-poultry-research-center/bacterial-epidemiology-antimicrobial-resistance-research/docs/narms/

[453] UK-VARSS (2022). Veterinary Antibiotic Resistance and Sales Surveillance Report (UK-VARSS 2021). Veterinary Antimicrobial Resistance and Sales Surveillance 2021 - GOV.UK (www.gov.uk)

[454] Australian Government Department of Foreign Affairs and Trade (2021). Australia-UK Free Trade Agreement negotiations: agreement in principle. https://www.dfat.gov.au/sites/default/files/aukfta-negotiations-agreement-in-principle-17-june-2021.pdf

[455] European Commission 2017. EU Action on Antimicrobial Resistance EU Action on Antimicrobial Resistance (europa.eu)

[456] European Medicines Agency, European Surveillance of Veterinary Antimicrobial Consumption(ESVAC), 2009-2023. European Surveillance of Veterinary Antimicrobial Consumption (ESVAC): 2009 - 2023 | European Medicines Agency (europa.eu)

The EU also produce an annual AMR summary report "The European Union Summary Report on Antimicrobial Resistance in zoonotic and indicator bacteria from humans, animals and food". The version published in 2020 was for the 2018/2019 period.[457]

Use of veterinary medicines in the EU is controlled through the Veterinary Medicinal Products Regulation (Regulation (EU) 2019/6).[458] Two parts of this regulation are of particular interest to countries wishing to export to Europe: exporting countries needing to comply with EU restrictions on the use of antibiotics (article 118), and some antibiotics being reserved for use in humans (article 37(4).[459] The regulation on medicated feed[460] restricts the use of ionophores.

1.4 Commercial expectations

Some retail and food service businesses have developed antibiotic policies in response to AMR concerns, and perceived public pressure. An example of this public pressure, in the USA is the Chain Reaction report which ranks America's top quick service restaurants on their policies relating to antibiotic use in their beef supply chains.[461]

McDonald's, while criticised by the Chain Reaction report for inaction, has a *Vision for Antimicrobial Stewardship* (2017) and is slowly implementing their *Antibiotic Policy for our Beef Supply Chain*.[462] Quantitative targets have been set for antibiotic use, as well as not permitting medically important antimicrobials to be used for growth promotion, and placing restrictions on the use of critically important antibiotics for human medicine. In 2023, data collection for the Australian supply chain commenced, but it is not clear whether data collection will be a sample of producers whose product is processed and finds its way into the McDonald's supply chain, or whether it will be comprehensive, including all producers and all processors.

Some meat products are making claims about antibiotic use, ranging from general statements which require attention to footnotes to understand (e.g., only in the last phase of production, critically important, or important antibiotics to human medicine, only non-therapeutic use) while others make bold claims of 'no antibiotics ever'. Some retailers are very clear about the latter message, which requires any treated animal to be segregated in the supply chain and be directed to another customer.

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[457] EFSA and ECDC (European Food Safety Authority and European Centre for Disease Prevention and Control), 2021. The European Union Summary Report on Antimicrobial Resistance in zoonotic and indicator bacteria from humans, animals and food in 2018/2019. EFSA Journal 2021;19(4):6490, 179 pp. https://doi.org/10.2903/j.efsa.2021.6490

[458] European Medicines Agency. Veterinary Medicinal Products Regulation. Veterinary Medicinal Products Regulation | European Medicines Agency (europa.eu)

[459] European Medicines Agency (2022) Advice on the designation of antimicrobials or groups of antimicrobials reserved for treatment of certain infections in humans - in relation to implementing measures under Article 37(5) of Regulation (EU) 2019/6 on veterinary medicinal products (europa.eu)

[460] Regulation (EU) 2019/4 of the European Parliament and of the Council of 11 December 2018 on the manufacture, placing on the market and use of medicated feed, EUR-Lex - 32019R0004 - EN - EUR-Lex (europa.eu)

[461] U.S. PIRG, NRDC, CR, FACT, ARAC and CFS (2021). CHAIN REACTION VI. How top restaurants rate on reducing antibiotic use in their beef supply chains. https://uspirg.org/sites/pirg/files/reports/ChainReaction-VI/Chain%20ReactionVI_small.pdf

[462] McDonald's Corporate. Responsible Antibiotic Use. Responsible Antibiotic Use (mcdonalds.com)

2. Australian Government response to AMR issues

2.1 National strategy

The Australian Government, through the Department of Health and Aged Care (DoHAC) and DAFF are working towards the execution of *Australia's National Antimicrobial Resistance Strategy 2020 & beyond* (2020)[463], through the *One Health Master Action Plan for Australia's National Antimicrobial Resistance Strategy*[464] and the *Australian Animal Sector National Antimicrobial Resistance Plan* (2018).[465] The strategy and plan align with the WHO Global Action Plan and the WOAH (OIE) strategy.

2.2 Australian Strategic and Technical Advisory Group on AMR (ASTAG)

The Australian Strategic and Technical Advisory Group on AMR (ASTAG)[466] develops and provides expert advice on AMR-related issues, including current and emerging issues, research priorities and implementation approaches to support Australia's National Antimicrobial Resistance Strategy – 2020 and Beyond. The Antimicrobial Resistance Governance Group (ARGG) uses this advice to decide on the actions needed to combat AMR.

ASTAG includes members with expertise from across the fields of human health, animal health, food, agriculture, and the environment. Through its membership, it will strengthen links between governments, industry, professional bodies, and other key stakeholders, to support a coordinated and sustainable response to AMR.

Consistent with the recommendations of WHO, ASTAG has produced 'Importance Ratings and Summary of Antibacterial Uses in Human and Animal Health in Australia', [467] which classifies all antibiotics registered for use in Australia (in both humans and animals) according to an importance rating and noting whether an antibiotic is used in humans.

3. Antimicrobial use in Australian red meat animals

3.1 Antimicrobials registered for use in animals in Australia

The Australian Pesticides and Veterinary Medicines Authority (APVMA) is responsible for registration of veterinary chemicals (including antimicrobials) for use in animals. The APVMA strictly applies a process of scientific review for new antimicrobial products, which includes an antimicrobial resistance risk assessment to determine the possible impact of use on the health of Australians and sets risk management controls on use accordingly. This approach is uniquely conservative by global standards.[468]

No antimicrobials 'authorized only for use in humans' proposed by WHO (2023) and no antimicrobials 'reserved for use in humans' by the EU are registered for animal use in Australia. The

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[463] Australia's National Antimicrobial Resistance Strategy – 2020 and beyond | Antimicrobial resistance (amr.gov.au)

[464] One Health Master Action Plan for Australia's National Antimicrobial Resistance Strategy – 2020 and beyond | Antimicrobial resistance (amr.gov.au)

[465] DAFF. *Australia's Animal Sector Antimicrobial Resistance Action Plan 2023-2028* australias-animal-sector-amr-action-plan-2023-2028.pdf (agriculture.gov.au)

[466] Australian Strategic and Technical Advisory Group on AMR (ASTAG) | Antimicrobial resistance

[467] Australian Government. Antibiotic Resistance. Importance Ratings and Summary of Antibacterial Uses in Human and Animal Health in Australia | Antimicrobial resistance (amr.gov.au) version 1.0 (2018)

conservative approach to registration of antimicrobial products for use in food-producing animals in Australia can be seen in the table below of some important antibiotic classes that have not be registered for use in Australia (fluoroquinolones, colistin) despite being registered in Europe and/or the USA.

Class	Australia[469]	Europe[470]	USA[471]
Fluoroquinolines	no	yes	yes
Antipseudomonal penicillins	no		no
Carbapenems	no	no	no
Colistin	no	yes	no
glycopeptides	no	no	no
lipopeptides	no	no	no
ketolides	no	no	no
monobactams	no	no	no
4th or 5th generation cephalosporins	no	Yes-4th	no
3rd generation cephalosporins with a β lactamase inhibitor	no	no	no

States/Territories implement legislation aimed at maintaining high professional standards in animal health by ensuring only veterinarians with a current registration can prescribe antimicrobials. Prescription of antimicrobials by a veterinarian has been progressively implemented since the 1970s (penicillins, tetracyclines, aminoglycosides, cephalosporins, sulphonamides, trimethoprim, chloramphenicol in 1977, others in 2004).[472].

As a result of the implementation of APVMA policies and state-based veterinary registration requirements, there are a limited number of antibiotics that can be prescribed to production animals in Australia (Table 1 below).

Antivirals and antimalarials are not used in food producing animals in Australia and there are no antimycotics registered for veterinary use.

Antihelmintics are used in production animals, but not for worms relevant to human health.

[469] ASTAG 2018

[470] European Medicines Agency Categorisation of antibiotics for use in animals (europa.eu)

[471] FDA 2021 Antimicrobials sold or distributed for use in food-producing animals. 2021 Summary Report on Antimicrobials Sold or Distributed for Use in Food-Producing Animals (fda.gov)

[472] Coombe, J. (2021). *Antimicrobial Stewardship in Australian Livestock Industries* (2nd ed.). Animal Industries Antimicrobial Stewardship RD&E Strategy (AIAS). https://aiasrdestrategy.com.au/2021/07/ams-in-australian-livestock-industries-2nd-edition/

Table 1 Antibacterial agents registered for antibacterial use in livestock by Australian Pesticides and Veterinary Medicine Authority (APVMA, Information accessed June 2021) (from Coombe, 2021)[473]

Antibacterial Agent	*Class (WHO 2023 DRAFT)*	*ASTAG 2018*[474]	*WHO 2018*[475]	**Registered for use in**	
				Cattle	***Sheep***
Novobiocin	Aminocoumarin	low nhu	5	X[D]	
Spectinomycin	Aminocyclitol	med	4		
Apramycin	Aminoglycoside	med	*2*	X	
Dihydrostreptomyci	Aminoglycoside	low nhu	2	X[DG]	X[G]
Framycetin	Aminoglycoside	low	2	X[J]	X[J]
Neomycin	Aminoglycoside	low	2	X	X
Streptomycin	Aminoglycoside	low	2	X	
Trimethoprim[S]	Sulfonamide, DHFR I*	med	3	X	X
Flavophospholipol	Glycophospholipid	low nhu	5	X[K]	
Lasalocid	Ionophore	low nhu	5	X[FK]	X[K]
Maduramicin	Ionophore	low nhu	5		
Monensin	Ionophore	low nhu	5	X[FK]	X[K]
Narasin	Ionophore	low nhu	5	X[FK]	X[K]
Salinomycin	Ionophore	low nhu	5	X[FK]	X[K]
Semduramicin	Ionophore	low nhu	5		
Lincomycin	Lincosamide	med	3	X[D]	
Erythromycin	Macrolide	low	1	X	X
Oleandomycin	Macrolide	low nhu	1	X[D]	
Tilmicosin	Macrolide	low nhu	1	X	
Tulathromycin	Macrolide	low nhu	1	X	
Tylosin	Macrolide	low nhu	1	X	
Avilamycin	Orthosomycin	low nhu	5		
Florfenicol	Amphenicol	low nhu	3	X	
Tiamulin	Pleuromutilin	low	4		
Bacitracin	cyclic	low	4	X[J]	X[J]
Polymyxin B	Polymyxins	high	1	X[J]	X[J]
Olaquindox	Quinoxaline	low nhu	5		
Virginiamycin	Streptogramin	high	3	X	X
Sulfadiazine [T+/-]	Sulfonamide, DHFR I	low nhu	3	X	X
Sulfadimidine[T+/-]	Sulfonamide, DHFR I	low nhu	3	X	X
Sulfadoxine [T+/-]	Sulfonamide, DHFR I	low nhu	3	X	X
Sulfaquinoxaline	Sulfonamide, DHFR I	low			
Chlortetracycline	Tetracycline	low nhu	3	X	
Oxytetracycline	Tetracycline	low nhu	3	X	X

[473] Coombe, J. (2021). *Antimicrobial Stewardship in Australian Livestock Industries* (2nd ed.). Animal Industries Antimicrobial Stewardship RD&E Strategy (AIAS). https://aiasrdestrategy.com.au/2021/07/ams-in-australian-livestock-industries-2nd-edition/

[474] Australian Government. Antibiotic Resistance. Importance Ratings and Summary of Antibacterial Uses in Human and Animal Health in Australia | Antimicrobial resistance (amr.gov.au) version 1.0 (2018)

[475] WHO Advisory Group on Integrated Surveillance of Antimicrobial Resistance (AGISAR). (2018). *Critically important antimicrobials for human medicine* (6th revision ed.). WHO. Critically important antimicrobials for human medicine : 6th revision (who.int)

Cephapirin	Cephalosporins (1st and 2nd gen)	med	3	X[H]	
Cephalonium	Cephalosporins (1st and 2nd gen)	med	3	X[D]	
Cefuroxime	Cephalosporins (1st and 2nd gen)	med	3	X[D]	
Ceftiofur	Cephalosporin (3rd gen)	high	1	X	
Amoxicillin	Penicillins (aminopenicillins)	low	2	X	X
Ampicillin	Penicillins (aminopenicillins)	low	2	X[D]	
Cloxacillin	Penicillins (anti-staphylococcal)	med nhu	3	X[DJ]	X[J]
Penethamate	Penicillins (narrow spectrum)	low nhu	2	X	X
Penicillin (and salts)	Penicillins (narrow spectrum)	low	2	X	X
Amoxicillin with Clavulanic acid	Penicillins (with β lactamase inhibitor)	med	2	X[D]	

* DHFR I dihydrofolate reductase inhibitor
ASTAG, version 1.0 2018: nhu no human use.
IMPORTANCE for human medicine: *WHO, version 6 2018; 1 HPCIA (Highest Priority Critically Important Antimicrobials for human use); 2 CIA (Critically Important Antimicrobials for human use); 3 HIA (Highly Important Antimicrobials for human use); 4 IA (Important Antimicrobials for human use); 5 nhu (No Human Use)*Registered Use in Australia:
[S] combination with a sulfonamide; [T+/-] with or without trimethoprim, [D] active only available in an intramammary product, [F] Label claim for coccidiosis or [K] growth promotion [G](Dihydro)streptomycin/penicillin combination available under APVMA permits [J] Topical and/or ocular and/or aural use

3.2 Controls on antibiotic use in Australia

When an antibiotic is registered for use in a production animal species there are three major administrative considerations to its use:

1. label restraints. A restraint is an absolute limitation or restriction placed on the use of the product. The limitation is required to manage a risk associated with the use of the product that may be necessary for human safety, public health, or environmental protection (for example, issues related to residues, antibiotic resistance). [476]
2. residues. Maximum residue limits (MRLs) are prescribed in Australia, and by trading partners, as the maximum amount of a chemical (in this case, antibiotic) allowed to be in a specified tissue (often kidney) or product (milk, egg) at the time of slaughter. As a result, there is a withholding period (displayed on the product label) that must be observed between the end of the prescribed treatment and slaughter.
3. Off label use. Where needed, veterinarians may use antibiotics "off label". According to the Australian Veterinary Association prescribing guidelines [477] "these must be prescribed only in accordance with prevailing laws and regulations. Confine use to situations where medications used according to label instructions have been ineffective or are unavailable and where there is scientific evidence, including residue data if appropriate, supporting the off-label use pattern and the veterinarian's recommendation for a suitable withholding period and, if necessary, export slaughter interval (ESI)".

[476] APVMA. Label content - veterinary products Label content | Australian Pesticides and Veterinary Medicines Authority (apvma.gov.au)
[477] Australian Veterinary Association (2023) Guidelines for prescribing, authorising and dispensing veterinary medicines. Version 4 updated. The AVA Prescribing, Authorising and Dispensing Guidelines

3.3 Antimicrobial use – prescribing guidelines

Veterinarians are responsible for their practices to the relevant state-based registration board and their professional ethics. The Australian Veterinary Association has published *Guidelines for prescribing, authorizing and dispensing veterinary medicines*,[478] including antibiotics. Additionally, prescribing guidelines have been prepared for:

- Cattle[479,480]
- Sheep[481,482]

3.4 Data on antibiotic use in Australia

Reporting of data on antimicrobial sales for veterinary use has been infrequent. A report on sales data for 2005 – 2010 was published in 2014.[483] and reported aggregate sales data in tonnes of active constituent, combining all cattle (beef, extensive and intensive and dairy) together with sheep in the report. Under *Australia's National Antimicrobial Resistance Strategy* consideration is being given to producing data more regularly.

A 2013 report, funded by MLA titled *A survey of antibacterial product use in the Australian cattle industry*[484] reported approximate numbers of cattle treated with different classes of antimicrobials in 2012. The survey found a low rate of use of antibiotics across the industry, Of the 37 antimicrobial active constituents used in products for cattle, only ceftiofur, a third-generation cephalosporin, and virginiamycin, a streptogramin, were perceived as having potential to select resistance of public health importance. Ceftiofur is used occasionally in the treatment of existing respiratory infection and virginiamycin is used to prevent grain poisoning. Both are prescription (Schedule 4) drugs, meaning their use requires veterinary prescription.

A number of publications concerning international antimicrobial use are published in peer-reviewed journals. Australia is ranked based on the data cited above and the outcomes are dependent on the modelling assumptions. Tiseo, Huber, Gilbert, Robinson, and Van Boeckel (2020) assess Australia's use as low, whereas Mulchandani, Wang, Gilbert, and Van Boeckel (2023) assess Australia's use as high, based on different assumptions.

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[478] Australian Veterinary Association (2013) Guidelines for prescribing, authorising and dispensing veterinary medicines. Version 4 The AVA Prescribing, Authorising and Dispensing Guidelines

[479] University of Melbourne. Australian Veterinary Prescribing Guidelines AGVIC_AVPG_A5_Flipbook_PRINT_V2.pdf - Google Drive

[480] AMR Vet Collective. AMR Vet Collective | Guidelines (in preparation, 2023) AMR Vet Collective | Guidelines

[481] Animal Health Australia Antimicrobial-Prescribing-Guidelines-Sheep.pdf (animalhealthaustralia.com.au) Antimicrobial prescribing guidelines – Animal Medicines AustraliaAMR Vet Collective | Guidelines

[482] AMR Vet Collective. AMR Vet Collective.

[483] Australian Pesticides and Veterinary Medicines Authority 2014 Quantity of antimicrobial products sold for veterinary use in Australia July 2005 – June 2010 21 Mar 2021 - Report on the Quantity of Antimicrobial Products Sold for Veterinary Use in Australia: July 2005 to June 2010 released | Australian Pesticides and Veterinary Medicines Authority - Trove (nla.gov.au)

[484] Lean, I., Page, S., Rabiee, A., and Williams, S. (2013) A survey of antibacterial product use in the Australian cattle industry. Report B.FLT.0373. Meat & Livestock Australia, Sydney, New South Wales. https://www.mla.com.au/contentassets/efae6463c1e0406eaf75c98c184abed3/b.flt.0373_final_report.pdf

4. Antimicrobial resistance in bacteria from Australian animals

The results obtained from surveys of antimicrobial resistance (AMR) of bacteria isolated from animals can be affected greatly by study design (number of samples, how collected, point in the supply chain), the bacteria selected for testing (species), the AMR testing methods (which antibiotics, which laboratory method, which cut-off point chosen for resistance). A significant difference in the way that resistance results are expressed is the use of clinical breakpoints and epidemiological cut-off (ECOFF) values. Clinical breakpoints are used to estimate the likelihood of therapeutic success (sensitive, or resistant), whereas ECOFFs detect emerging resistance (decreased susceptibility((wild type WT, or not wild type NWT)(Moyaert, de Jong, Simjee, & Thomas, 2014).

4.1 AMR in cattle at slaughter

In 2013, faecal samples were collected at slaughter from 910 healthy Australian beef cattle, (including feedlot cattle), 290 dairy cattle and 300 veal calves. All *Salmonella* isolates (n= 217) were susceptible to cephalosporins, and fluoroquinolones and 91.5% of beef cattle and all veal calf and dairy cattle *Salmonella* isolates were susceptible to all other antimicrobials except florfenicol. A total of 800 *E coli* isolates, 469 from beef cattle, 155 from dairy cattle, and 176 from veal calves, were selected for AMR testing. All *E. coli* isolates tested were susceptible to fluoroquinolones and all isolates from beef and dairy cattle were susceptible to 3rd and 4th generation cephalosporins. 92.1% of beef cattle, 96.8% of dairy cattle and 93.2% of veal isolates were susceptible to all other antimicrobials tested except florfenicol. (R. S. Barlow et al., 2015).

In a follow up study in 2019, 969 *E. coli* isolates from faecal samples were collected from 591 healthy beef cattle, 194 dairy cattle, and 216 veal calves at slaughter in Australian abattoirs (R. Barlow et al., 2022). Most, (80.8, 87.6, and 88.5%) of beef cattle, dairy cattle, and veal calf isolates were susceptible to all antibiotics tested. *Salmonella* spp. were also isolated from these 1001 samples collected in 2019 (Abraham et al., 2022). No isolates were resistant to colistin, nalidixic acid, meropenem, gentamicin, florfenicol or chloramphenicol. Resistance was reported to other antibiotics at a low rate (Abraham et al., 2022).

The 2019 study also measured the resistance of *Enterococcus* sp.[485] And found 75.8% were WT for resistance against all antimicrobials tested. Populations of NWT isolates to antimicrobials considered highly or critically important to human medicine are low and there is limited evidence of specific production practices, such as grain-feeding, leading to widespread disproportionate development of NWT isolates.

A 2023 report on over 1,000 Salmonella isolates from red meat sources, collected between 2001 and 2019, examined whole genome sequences for the presence of antibiotic resistance genes, which were detected at a low frequency.[486]

A study in South Australia investigated the AMR profile of faecal *E. coli* in cattle upon entering a feedlot and again post slaughter after 90 days on feed, to better understand the effect of antimicrobial use in the feedlot on the development of AMR. At entry, the prevalence of antimicrobial resistance was 0.7% for amoxicillin/clavulanic acid, ampicillin, streptomycin, and

[485] Barlow et al. 2020 MLA Report V.MFS.0432 Antimicrobial resistance in commensal bacteria in bovine faeces at slaughter | Meat & Livestock Australia (mla.com.au)
[486] Mellor, G. 2023. Molecular risk assessment of Salmonella in red meat. MLA Project Report V.MFS.0460. V.MFS.0460 - Molecular risk assessment of Salmonella in red meat | Meat & Livestock Australia (mla.com.au)

trimethoprim/sulfamethoxazole. At exit, prevalence of resistance to tetracycline was 17.8%, ampicillin 5.4%, streptomycin 4.7%, and sulfisoxazole 3.9% (Messele et al., 2022).

A pilot surveillance of resistance of bovine respiratory disease (BRD) pathogens to common veterinary antimicrobial agents across seven Australian feedlots in 2019 found low levels of resistance in *Pasteurella multocida* (23.1%) to the macrolide class of antimicrobials.

4.2 AMR in sheep at slaughter

A survey of sheep at slaughter was conducted [487] comprising 800 faecal samples, collected from across three animal groups: pasture-fed lamb (n=414), feedlot lamb (n=163) and sheep (n=223). 81 *Salmonella* isolates were tested for antimicrobial susceptibility. The resistance to clinically significant antimicrobials was generally low across all isolate groups. Of the 100 *E. coli* tested, 97% were considered pan-susceptible regardless of whether epidemiological (ECOFF) or clinical breakpoints were used. When ECOFF breakpoints were considered, 100% of *E. faecalis* (n=34) and 83% of *E. faecium* (35 of 42 isolates) were considered wild type.

4.3 AMR in goats at slaughter

Faecal samples were collected from four consignments of 100 Australian rangeland goats at slaughter at one of 4 localities in Western Australia. *Salmonella enterica* was detected in 106 samples of which 84% were susceptible to all antibiotic tested. No isolate was resistant to fluoroquinolones or extended spectrum cephalosporins (Al-Habsi et al., 2018).

5. Antimicrobial stewardship in Australian red meat animals

Antimicrobial stewardship (AMS) is the term used to describe actions to limit the use of antimicrobials and ensure they are used appropriately to minimise the development of AMR. It is used to underpin global activities in human and animal health to protect the efficacy of antimicrobials. Australia has an extensive history of implementing AMS principles, long before the term 'AMS' was coined, and should be considered a global leader in this space. Antibiotic stewardship has been introduced to the feedlot sector[488] and is now a required element of the National Feedlot Accreditation Scheme.[489]

Through the Animal Industries' Antimicrobial Stewardship RD&E strategy (AIAS)[490], the major livestock industries have been exploring cross-sectoral AMR project priorities.

5.1 Concepts of biosecurity

Biosecurity is the protection of the economy, the environment, social amenity, or human health from the negative impacts associated with the entry, establishment, or spread of animal or plant, pests and diseases, or invasive plant and animal species (Jeggo, 2012). Australia has an enviable

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[487] Mellor, G et al. (2019) MLA Report V.MFS.0417 Pathogen and antimicrobial resistance in ovine faeces at slaughter | Meat & Livestock Australia (mla.com.au)

[488] MLA (2018) Antimicrobial stewardship guidelines for the Australian cattle feedlot industry. mla_antimicrobial-stewardship-guidelines.pdf

[489] Australian Lot Feeders Association (2021) Australian Feedlot Industry Steps Up Commitment to Antimicrobial Stewardship (feedlots.com.au)

[490] Animal Industries Antimicrobial Stewardship R,D&E Strategy Animal Industries Antimicrobial Stewardship - AIAS (aiasrdestrategy.com.au)

biosecurity record having been free of many of the infectious diseases that are endemic in livestock in many other parts of the world. Built on its island status, Australia has for many years maintained a stringent import policy around plants, livestock, and agricultural products to ensure the protection of this status. Australia has consistently adopted a conservative policy. There is a growing appreciation that the risks being addressed now encompass environment and human health as well as animals and plants.

Biosecurity is a core principle of good AMS in Australian livestock industries, to prevent and control animal diseases to reduce the need for antimicrobials and is increasingly important for preventing incursion of AMR bacteria from external sources.

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