Final report

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Meat Industry Services

Strategic Planning and Communication

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Abstract

CSIRO has provided R&D to the Australian meat processing industry for many years and much of this has been funded through various mechanisms developed by AMPC and MLA and CSIRO. This arrangement does not allow for strategic planning nor make efficient use of resources. There is a growing requirement to address the future needs of the red meat industry by developing capabilities to meet changing needs and challenges in food safety, food security and efficient processing. The aim of this project was to develop a joint strategy between AMPC, MLA and CSIRO to cover areas of agreed priorities and capability focus. Another aspect is the rationalisation of the communication effort so that industry will be able to obtain all their technical requirements through one source. Five new projects were initiated, new information summaries and newsletters were produced and a summary of CSIRO research activities was prepared.

Executive summary

CSIRO has provided R&D to the Australian meat processing industry for many years and much of this has been funded through various mechanisms developed by AMPC and MLA and CSIRO. A technical advisory service and short-term applied research projects have also been funded under a long-running project currently known as Meat Industry Services (MIS). Under this mechanism, CSIRO and contractors published six Meat Technology Updates per year, provided a rapid-response technical advisory service, maintained a web site of technical information and provided technical advice to industry bodies and regulators and provided a resource to respond to emerging issues.

This arrangement does not allow for strategic planning nor make efficient use of resources. There is a growing requirement to address the future needs of the red meat industry by developing capabilities to meet changing needs and challenges in food safety, food security and efficient processing.

AMPC, MLA and CSIRO each have a strategic aim in servicing the Australian meat processing industry. Each organisation has clear areas of alignment of their strategic objectives and it has been agreed that these should be developed further in order to develop a joint 'mini' strategy. Communication of research results and technical information to the meat industry has in the past been multi-pronged with each organisation and MINTRAC having a role. It is proposed to streamline this process.

Specific outputs included:
Strategic planning meetings for the preparation of the joint strategy: Thirteen meetings occurred between MLA, AMPC and CSIRO for the sharing of strategies and development of a proposal for 'Transforming Meat Industry Capability". These meetings were held face-to-face and also by teleconference. The development of a joint strategy, communications and R&D projects on microbiology, meat science proceeded as five separate projects (A.MIS.1001, A.MIS.1002, A.MIS.1003, A.MIS.1004, A.MIS.1005) in the interim, whilst the three year project proposal was finalized. CSIRO shared its strategy for the meat industry in February 2012. MLA shared its strategies for Value Adding, Eating Quality and Automation in May-June, 2012. From these strategies, a list of shared priority areas was developed into a proposal and three revisions to this proposal have occurred. The early version of the proposal is attached to this report. It is recommended that the project rapidly proceed to contracting.

Complete draft of upgraded information package on dark cutting: The information package on dark cutting has been reviewed and revised and a draft developed. This is awaiting finalization by the end of January. The revised dark cutting package includes information that was not available in the previous package. It is recommended that, once the content is approved by AMPC and MLA, the package should be printed and disseminated.

Complete summary of CSIRO research activities: A summary of CSIRO research activities has been prepared and is attached to the report.

Meat Technology Updates: Two meat technology updates have been written, reviewed and distributed. The meat technology updates are on the topics of "The effect of diet on sheepmeat flavour" and "Pathogenic Shiga toxigenic *E. coli* - STEC". It is recommended that these updates

continue to be produced as a part of the communication strategy to industry in the proposed ongoing project.

Communication: It is recommended that CSIRO continue to provide its website as a source of the historical information and reports from the previous Meat Industry Services. It is also recommended that AMPC and MLA review their web-based information services and advise CSIRO on the content they would like us to assist in/provide. The review of communication services available world-wide to the meat industry highlighted the diversity of services available. As meat companies are generally proficient on the internet, it is recognised that they presently, and in the future, will seek solutions globally. CSIRO's meat industry strategy is a global meat strategy and we will continue to engage with Australian companies to assist them to trade globally.

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Background

CSIRO has provided R&D to the Australian meat processing industry for many years and much of this has been funded through various mechanisms developed by AMPC and MLA and CSIRO. A technical advisory service and short-term applied research projects have also been funded under a long-running project currently known as Meat Industry Services (MIS). Under this mechanism, CSIRO and contractors published six Meat Technology Updates per year, provided a rapid-response technical advisory service, maintained a web site of technical information and provided technical advice to industry bodies and regulators and provided a resource to respond to emerging issues.

This arrangement does not allow for strategic planning nor make efficient use of resources. There is a growing requirement to address the future needs of the red meat industry by developing capabilities to meet changing needs and challenges in food safety, food security and efficient processing.

With the gradual reduction in the number of scientists working in the fields related to the meat industry, the Australian meat industry will benefit through provision of a surety of funding for meat science within CSIRO, particularly funding of PhD and post-doctoral positions.

An aspect of this is to develop a joint strategy between AMPC, MLA and CSIRO to cover areas of agreed priorities and capability focus. Another aspect is the rationalisation of the communication effort so that industry will be able to obtain all their technical requirements through one source.

AMPC, MLA and CSIRO each have a strategic aim in servicing the Australian meat processing industry. Each organisation has clear areas of alignment of their strategic objectives and it has been agreed that these should be developed further in order to develop a joint 'mini' strategy. Communication of research results and technical information to the meat industry has in the past been multi-pronged with each organisation and MINTRAC having a role. It is proposed to streamline this process.

Project objectives

1. To develop a ‘mini’ strategy in conjunction with AMPC and MLA
2. Provide input to a focussed and targeted communication approach

Methodology

A number of meetings were held between CSIRO, MLA and AMPC to share strategies and discuss possible directions.

CSIRO and MLA negotiated the commencement of a number of projects.

CSIRO prepared communications materials.

CSIRO prepared proposals for future work.

Results

Strategic planning

The purpose was to develop a strategy and agree on a capability focus.

Thirteen meetings occurred between MLA, AMPC and CSIRO for the sharing of strategies and development of a proposal for 'Transforming Meat Industry Capability". These meetings were face-to-face and also by teleconference. The development of a joint strategy, communications and R&D projects on microbiology, meat science proceeded as five separate projects (A.MIS.1001, A.MIS.1002, A.MIS.1003, A.MIS.1004, A.MIS.1005) in the interim, whilst the three year project proposal was finalized. CSIRO shared its strategy for the meat industry with AMPC and MLA in February 2012 in a meeting in MLA, Sydney. MLA shared its strategies for Value Adding, Eating Quality and Automation with CSIRO and AMPC in meetings at MLA, Sydney in May-June, 2012. From these strategies, a list of shared priority areas for R&D and capability building was developed and is described below in Table 1. From this list, a list of agreed R&D focus areas was developed and is indicated in blue in Table 1. The people attending each meeting varied, and also although the initial contact point at MLA was Rod Coogan, this changed to Phil Franks in August. Then in October, the nominated person at MLA was changed to Alex Ball, in his new role at MLA.

Table 1: List of strategic themes and focus areas that were an discussed at the strategic planning meetings between AMPC, MLA and CSIRO. R&D focus areas in blue were those agreed to be a priority for all three organizations.

Strategic Themes	**Focus areas**
1. New pathways for assuring eating quality	- **Integrated approach to eating quality R&D** - Process control tools for metabolism - Contribution to extend the range of cattle for inclusion in the MSA database Eg. Ageing and cuts - Determining the correlation between the IMF of the different muscles in the carcase - Develop and prove off-farm technologies and processes to optimise eating quality - Utilising cuts from the carcass for MSA assured eating quality without the carcass being graded, eg. hot-boning - **Moving cuts from 'ungraded' to acceptable EQ**, maybe using HPP, possibly targeting food service
2. Adding value to secondary cuts and co-products	- **Novel intervention to increase carcase utilisation and eating quality** - **Hot boning processing effects on quality parameters*** - **Cooking kinetics*** - Hides and protein. Collagen and new uses, Industrial use of proteins
3. New healthy, nutritious, safe red meat products produced sustainably	- Convenient chilled meals (this needs to demonstrate value to the producers and processors) - **Food architecture in muscle derived products,** Low preservative levels, and microencapsulation. - Novel restructuring technologies. From secondary cuts, High connective tissue, Extrusion (bite, texture, flavour, shape, format), improve meat yield from fatty trim - Flavour enhancement of muscle products - **Food safety**

	- Shelf life – interaction of packaging, micro, formulation etc
4. Strategic planning and communication	- Meat science and analytical infrastructure - Awareness and dissemination of trends in meat science and meat value added processing technology - Food safety / contamination troubleshooting (independent) - Labelling – advice, trends - Contribution to the next steps for MSA
5. Capability building	**In CSIRO for the meat industry;** - Two new post-doctorates; - Meat Scientist, with an "omics" approach to meat - Process engineer, with protein chemistry skills - Three Ph.D. students - Meat shelf-life and safety - Process engineering and modelling (cooking kinetics?) - Muscle biochemistry and structure **In the meat industry** - Through engagement with TMiC staff - Through meat science tutorials, workshops and meat technology updates

After further discussion, a project proposal titled "Transforming Meat Industry Capability" was developed and is attached in Appendix 1. Further discussion and finalisation is now pending. CSIRO's draft global meat strategy will be shared with MLA and AMPC in early 2013 and CSIRO looks forward to the input.

Communication

Meat technology updates

Two Meat Technology Updates (MTUs) have been completed and circulated. They are titled:

- Factors affecting sheepmeat flavour, and
- Pathogenic Shiga toxigenic *E. coli* - STEC and are attached in Appendix 2.

They have been printed and distributed during July and November to a mailing list maintained and updated by CSIRO. As per previous practise, they were posted on the web site: www.meatupdate.csiro.au and emails have been forwarded to a list of people who have requested that they be advised when a new MTU is available.

Dark cutting information package

A final version of the dark-cutting package will be available by January 31 2012 and a draft is attached in Appendix 3.

CSIRO web-site inventory

The meatupdate web site has been hosted on a CSIRO server since it was established in 2001. It enables access to over 1343 pdf files of CSIRO publications relevant to the meat industry, some of which date back to 1969. The files are of Newsletters and Meat Technology Update, Meat Research Reports, papers from workshops and information packages and Information Sheets. The approximate number of each is:

Newsletters & MTUs	262
Meat Research Reports	215
Workshop proceedings & Packages	617
Intervention Package	52

Web-site search statistics

During the period 1 July 2011 to 1 March 2012, a total of 10,377 separate files were downloaded.

Information on packaging was most often requested, followed by layout of boning rooms, sheepmeat quality, meat safety, rendering, steam generation, dry ageing and tenderstretching.

The site continues to generate requests that notification of new Meat Technology Updates to be received by email. Currently there are in excess of 170 names and email addresses on the database.

Review of MINTRAC training material

Dr Alison Small participated in a technical review group that assessed a range of MINTRAC training materials for the meat industry. Each person in the group had expertise in one or more fields and they met in a room and provided input and comment on MINTRAC training materials in fields in which they were expert and non-expert. Dr Small also presented five one-day training sessions on welfare management at slaughter in conjunction with RTOs in each state. The training was organised by MLA/MINTRAC in response to a plant closure due to poor animal welfare. The training met the EU requirements to have QA officers or supervisors trained in the assessment of stunning and bleeding.

Relevant research activities within CSIRO

CSIRO was established in 1926 as the Council for Scientific and Industrial Research (CSIR) with the aim of carrying out research to assist Australian primary and secondary industries – farming, mining and manufacture. Thus CSIRO has had a long history and an ongoing involvement with improving the efficiency and product quality of the livestock and meat processing industries. The research skills within CSIRO evolve with time as the priorities of industry and government change. Currently CSIRO has research capabilities in the following areas:

CSIRO Animal, Food and Health Sciences

- Genetic and genomic sciences for the acceleration of genetic improvement of livestock production for efficiency, profitability and fitness for the livestock production environment.
- Rumen microbiology and ruminant nutrition and nutrigenomics.
- Livestock disease control and identification of new and emerging livestock pathogens, including pathogen tracking and profiling.
- Livestock management practices with increased animal welfare.
- Livestock management, property management, feed production, livestock transport, processing and packaging.
- Livestock production and growth efficiency to improve water use and reduce greenhouse gas production and environmental impacts.
- Northern Australia animal production.
- Food material science, health and sensory sciences with food chemistry and biofunctionality to develop novel (meat) foods and ingredients with enhanced nutritional or health-enhancing attributes (as related to meat products).
- Development of novel products from co-products.
- Biosecurity.
- Food microbiology, food safety and food processing engineering (as related to meat products).
- Nutritional implications of meat products.

Cross-division capabilities

- Carbon and water footprinting of livestock and meat industries.
- Optimisation of water reuse and nutrient recovery from meat processing wastewater.

Capabilities in other divisions that may be relevant for the meat industry

- Technology to intelligently manage energy usage to reduce greenhouse gas emissions.
- Technology to improve the reliability and cost effectiveness of renewable energy.
- Groundwater hydrology and resource assessment.
- Computational imaging and process visualisation.
- Development of advanced sensors and networks.
- Development of autonomous technologies to improve safety and operating efficiency.

Communication methods of research institutes

This is a summary of a study via the internet of the methods used by research institutes in the food and meat sector for communicating results of their research to their industry members and general public. The study is not exhaustive as there may be methods of communication that are not described on the organisations' web sites and some institutes that have not been included.

DMRI - Denmark

http://www.dti.dk/dmri

The Danish Meat research Institute is now part of the Danish Technological Institute.
Communication methods are:

- Newsletters. These are a 2-page brochure that is more promotional than informative.
- Online shop. www.dmri-shop.dk. This sells products developed by the institute and consulting services.
- Leaflets. These are normally 2 pages on a technical topic, e.g warmed over flavour. They are not dated but provide contact details to obtain further information.
- Photos of key personnel.
- DMRI Patent News – Meat Technology. This is a subscription publication providing 4 editions per year at a cost of €750 pa.

DMRI also communicates via Twitter, Facebook, Linkedin and RSS news feeds.

Agresearch – New Zealand

http://www.agresearch.co.nz/Pages/default.aspx

Agresearch is a multi-disciplinary group covering the full range of agricultural products from the live animal and crops through meat other food and fibre. Their main publications for industry are:

- AgResearch NOW, a printed magazine published twice a year and available online and as a hard copy. The magazine is typically 20 pages with most articles being 2 pages long and containing about one page of printed detail with the rest photos and headings.
- Intouch, a bi-monthly emailed newsletter of 8 pages that is also available on their web site. Most articles are of about half a page with a large photograph occupying the remaining space.

News updates are provided on the web site as well as an RSS news feed.

MIRINZ – New Zealand

http://www.mirinz.org.nz/

MIRINZ is a division of Agresearch and does not appear to produce any current publications. An archive of Meat Research Bulletins produced until 1999 is available on their web site.

A Meat Industry Workshop is held each year and the Powerpoint presentations from workshops from 2006 to 2011 are available online.

TNO – Netherlands

http://www.tno.nl/

TNO is the Dutch equivalent of CSIRO and has seven research themes. Food and Nutrition is an Innovation Area under the Healthy Living theme. Publications (only some in English) on a range of topics can be downloaded from the website but you must register first. Registration provides a free

subscription to TNO TIME, newsletters and allows reports to be downloaded and books to be ordered.

The web site also provides links to items of news but new items only appear to be posted about once per month.

They also provide updates through Twitter and RSS

Campden BRI – United Kingdom

http://www.campden.co.uk/

Campden BRI is a membership-based organisation with 2,100 members in 66 countries. It undertakes research and provides an information service to the food, drink and allied industries in the UK and member benefits include: technical and scientific support, discounts on contracted research, and regular information updates. They use a wide range of techniques to deliver their message:

- Newsletters. These are 4 pages with short articles on research and industry news
- Blogs. Online articles on technical topics related to food manufacture.
- Open Day. This is held annually and focuses on the site activities with exhibits and a lecture.
- Case studies. These provide a brief online summary of results of investigations.
- Current news. An online newsletter published each month containing several short articles that are more promotional than informative.
- E-mail news feeds. Latest developments at Campden BRI on a range of topics. A particular topic of interest or a number of topics can be selected, although some are only available to members.
- Podcasts. A large number are provided on a range of topics and are generally 2 to 8 minutes in duration.
- Press releases. There are generally 1 to 5 per month and they are promotional as well as providing some technical information.
- Videos. Downloadable videos of 3 – 5 min duration are available on a range of techniques but are also promotional.

They also provide links to social media such as Facebook, LinkedIn, Twitter and Youtube.

TEAGASC - Ireland

http://www.teagasc.ie/

Teagasc is the agricultural and food development authority in Ireland providing research, advisory and training services with its main focus being on agriculture. They use a number of methods for disseminating their message.

- Magazine. TResearch is a magazine published four times per year and is typically about 30 pages with articles up to 2 pages long.

- Food Newsletter. TEAGASC Food Innovator consists of 4 pages published 3 – 4 times per year and contains 8 – 10 short articles on research activities and people.

- Training courses. Courses of 1 – 3 days are run in the fields of food safety, food quality and technology & product development.

- Factsheets. Occasional publications of 2 pages on a particular topic.

- Technology Updates. A summary in 3 pages of results of a research project.

- EOPR. Report on a research project but none available online since 2009.

- Videos. A number of videos on a number of topics and for promotion are available.

TEAGASC can also be followed on Facebook, Twitter, LinkedIn and YouTube.

INRA France

http://www.international.inra.fr/

The French National Institute for Agricultural Research is a public research institution established in 1946 and with a permanent staff of over 8,000 researchers and technicians, conducts research in the fields of agriculture, food, nutrition and food safety, environment and land management.

The INRA web site provides access to a publications database of their research papers. Regular updates of research results are provided by press releases, news feeds and a newsletter that is distributed every 2 months via email.

Max Rubner Institute – Germany

http://www.mri.bund.de/

The institute was formed in 2008 with the merger of the Federal Dairy Research Centre in Kiel, the Federal centre for Cereal, Potato and Lipid Research in Dortmund and Munster, the Federal Centre for Meat Research in Kulmbach and the Federal Research Centre for Nutrition in Karlsruhe plus the fish quality section of the Institute for Fisheries Technology and Fish Quality to form the Max Rubner-Instutut. The institute communicates through:

- Max Rubner Conference, held annually.

- International Summer School on Meat Research. The first one held in 2011 focussed on ageing and packaging of meat.

- Press releases.

Nofima – Norway

http://www.nofima.no/en

Nofima is the Norwegian Institute of Food, Fisheries and Aquaculture Research. The web site provides several means of obtaining information including:

- Publications database. This is a searchable database of over 5,000 publications.

- News items. Posted regularly (up to 8 per month), they summarise the progress or results of the Institute's research projects.

- Events. These include Symposiums, courses, workshops and networks. Nofima administer a network program for the food industry in which employees from 5-10 companies meet 3 or 4 times for theory, practical trials and exchange of information. Between meetings each company works on its own project with assistance from an expert consultant

Nofima can also be followed on Twitter, Facebook and YouTube.

Texas A&M University – USA

http://animalscience.tamu.edu/academics/meat-science/index.htm

Department of Animal Science, Meat Science program, conducts courses in meat science, undertakes research and provides extension programs.

- Reports – Comprehensive reports on a range of topics.

- Prime Cuts Newsletter – 4 pages covering several topics but appear to be now discontinued.

- Extension programs – Extension officers for meat science as well as livestock.

Social media: Facebook

Discussion

The sharing of strategies between AMPC, MLA and CSIRO resulted in a 3 year proposal for a jointly funded project titled "Transforming Meat Industry Capability". It is recommended that the project rapidly proceed to contracting.

CSIRO's draft global meat strategy will be shared with MLA and AMPC in early 2013 and CSIRO looks forward to the input.

The revised dark cutting package includes information that was not available in the previous package. It is recommended that, once the content is approved by AMPC and MLA, the package should be printed and disseminated.

Two Meat Technology Updates were produced and it is recommended that these Updates continue to be produced as a part of the communication strategy to industry in the ongoing project.

It is recommended that CSIRO continue to provide its website as a source of the historical information and reports from Meat Industry Services. It is also recommended that AMPC and MLA review their web-based information services and advise CSIRO on the content they would like us to assist in/provide.

The review of communication services available world-wide to the meat industry highlighted the diversity of services available. As meat companies are generally proficient on the internet, it is recognised that they presently, and in the future, will seek solutions globally. CSIRO's meat industry strategy is a global meat strategy and we will continue to engage with Australian companies to assist them to trade globally.

Conclusions/recommendations

"Transforming Meat Industry Capability" is recommended to proceed to contracting.

The revised dark cutting package should be printed and disseminated.

Meat Technology Updates should continue to be produced as a part of the communication strategy to industry in the ongoing project.

It is recommended that CSIRO continue to provide its website as a source of the historical information and reports from Meat Industry Services.

Appendix

Strategic Planning Outcome - project proposal on Transforming Meat Industry Capability

Purpose and description

VISION: Australia is the leading supplier of high quality meat from all cuts in the carcass (beef and lamb)

Aim: To develop a strategic partnership between CSIRO, AMPC and MLA to develop capability for a sustainable meat industry

Background

CSIRO has provided R&D to the Australian meat processing industry for many years and much of this has been funded through various mechanisms developed by AMPC, MLA and CSIRO. A technical advisory service and short-term applied research projects have also been funded under a long-running project known as Meat Industry Services (MIS). Under this mechanism, CSIRO and contractors developed and published several publications each year, provided a rapid-response technical advisory service, maintained a web site of technical information, provided technical advice to industry bodies and regulators and provided a resource to respond to emerging issues. This previous arrangement no longer meets the needs of the industry nor allows for strategic planning. A new partnership has therefore been established that will deliver value back to the meat industry through 3 Strategic Themes, described below.

AMPC, MLA and CSIRO each have a strategic aim to service the Australian meat processing industry. Each organisation has clear areas of alignment of their strategic objectives and these have been developed into a joint strategy which comprises the project. This project is a three-year partnership between AMPC, MLA and CSIRO with the purpose of building capability in key areas that are currently underdeveloped in the meat science community whilst also servicing the future needs of the red meat industry. The development of meat science capability will be addressed by training and developing of current CSIRO staff and employing and developing a post doctorate fellow and PhD students.

In order to meet the needs of the red meat industry in the areas of food security, food processing and food safety, the project will deliver back to the meat industry through three strategic themes: 1) Muscle Food Architecture, 2) Processing Technologies for Increasing Value and 3) Strategy Development. There will be focus areas and projects under each theme. These focus areas will be reviewed and adjusted as required each 12 months to ensure that the project continues to meet industry needs.

Strategic Theme 1 focuses on muscle food architecture in order to understand muscle structure and mechanisms and how they relate to eating quality. This theme will review muscle architecture and composition and how this alters during heating. The strategic theme will have a consumer focus, so CSIRO's expertise in meat quality will support the development of capability building in muscle architecture.

Strategic Theme 2 focuses on the development of processing technologies for novel value add red meat opportunities (increasing value of non-primal cuts). This theme will investigate processing technologies that will seek to deliver lower value cuts with higher quality traits. CSIRO's expertise in food safety and microbiology will underpin this muscle processing theme.

Strategic Theme 3 is a planning activity between CSIRO, MLA and AMPC that will ensure that the project is aligned to meeting industry needs and that it continues to develop capability in the areas identified by the industry.

Outcomes

Through the strategic partnership the project will develop capability and capacity in meat science and process engineering in relation to muscle architecture and value adding. The capability will be utilised to identify a process system(s) to provide step change in improving the texture of red meat muscles, while ensuring safety and quality.

Objectives

The Research Organisation will achieve the following objective(s) to MLA's reasonable satisfaction:

- Develop a fundamental research program to enhance our understanding of muscle structure and mechanisms underlying eating quality and to build capability in these areas
- Develop a fundamental research program using innovative approaches to identify and develop technologies for adding value and to build capability in these areas
- Identify a process system(s) to provide step change in improving the texture of red meat muscles, while ensuring safety and quality.

Two Meat Technology Updates

MEAT TECHNOLOGY UPDATE

Cutting edge technology for the meat processing industry

Meat technology update

1/12 – July 2012

The effect of diet on sheepmeat flavour

- The vast majority of pastures and feeding systems produce sheep meat of highly acceptable quality and flavour.
- There are some pastures or feeding systems that can directly, or indirectly, have a positive or negative influence on sheepmeat flavour. These need to be identified and processes put in place to ensure consumers in Australia, and overseas, always have a good eating experience.
- In order to minimise any off-flavour associated with sheep fed brassica crops, sheep should be removed from brassica crops for 2 weeks prior to slaughter.
- Grazing sheep on pastures high in protein (e.g. clover, lucerne) can increase the occurrence of 'pastoral' flavour in meat. The perception of 'pastoral' flavour as unacceptable may depend on habituation and prior experience.
- Consumer acceptance of the flavour of 'mutton', or 'pastoral' flavour could be assisted by masking the flavour with seasoning such as herbs and spices.

Introduction

Flavour is an important sheepmeat quality trait. Flavour is comprised of aroma (volatile) and taste (non-volatile) compounds. Aroma is perceived during eating by olfactory receptors in the nose, and taste is perceived by receptors in the mouth and throat. Fresh, uncooked meat is quite bland; it is only as a result of cooking that meat flavour develops. The resulting characteristic flavour is regarded as typical for a given species, e.g. lamb, beef, pork etc. During cooking, the non-volatile components of lean and fat tissues undergo a complex series of heat-induced reactions that generate a large number of volatile aroma products. The compounds formed are mainly derived from two distinct reactions that occur during the cooking process: Maillard reactions between amino acids and reducing sugars; and thermal degradation of the lipid components to produce volatiles.

Historically, most attention has been given to undesirable sheepmeat flavour attributes, such as 'mutton' and 'pastoral' flavours. 'Mutton' flavour, associated with the age of the animal, is more common in cooked meat taken from older sheep; while 'pastoral' flavour has generally been related to the pasture diet fed to the animal pre-slaughter. Branched chain fatty acids are recognised as the main compounds which contribute to 'mutton' flavour, while 3-methylindole ('skatole', also a contributor to 'boar' taint in pigs) and 4-methylphenol (p-cresol) are the main compounds which have been implicated in 'pastoral' flavour. Diet can also have other effects on the flavour of sheepmeat, aside from pastoral flavour. This MTU discusses the overall effect of different pre-slaughter diets on sheep flavour.

AMPC

mla MEAT & LIVESTOCK AUSTRALIA

Sensory evaluation

Sensory evaluation of cooked sheepmeat is usually performed with either consumer panels (untrained or naive) or trained sensory panels. Consumer panels rate the cooked meat based on their experience of the product quality. Some of the factors that consumers assess include tenderness, juiciness, liking of the smell and overall flavour. Consumers can give an 'opinion' of the meat, which will be based on their experience. A trained sensory panel is used as an objective measurement tool where the panellists are taught to identify and quantify specific sensory attributes (aroma, flavour, texture and mouthfeel) and rate them in the cooked meat product. It is an objective process that can quantitatively measure complex flavour attributes, which may not be easily measured using conventional instrumental techniques. A trained panel, by the nature of the training involved, cannot be used to give an 'opinion' on the meat. Meat Standards Australia runs consumer panels where the product is linked between tasting sessions, and a standard cooking and presentation approach is used for all tasting sessions, thus providing objectivity.

Chemistry and linkage to sensory

Volatile compounds are measured using gas chromatography-mass spectrometry (GC-MS). Volatile analysis involves extraction and concentration, chromatographic separation,

detection and quantification. Considerable effort has been made to characterise the volatile compounds associated with cooked sheepmeat. Despite reports of hundreds of volatile compounds in the literature, few studies have demonstrated which of them are important to the aroma. In fresh food products, there are usually only a small number of the total volatile compounds that actually contribute to the aroma. In order to identify the 'odour-active' volatiles, a more specialised technique is required: gas chromatography-olfactometry (GC-O). In GC-O (Figure 1), the volatile extracts are subjected to chromatographic separation and instrumental detection; and also simultaneously 'sniffed' by a human assessor and the odour intensity is rated. Ideally, GC-O is performed by a panel of assessors (similar to using a trained sensory panel) to account for human variability in sensitivity for different aroma compounds. The aim of this type of research is to identify which volatile compounds are the most significant contributors to the cooked meat aroma.

Effect of diet on cooked meat flavour

The use of pasture-based finishing diets, compared to grain-based, can impact on the sensory properties of the cooked sheepmeat (Table 1). Pasture diets, in comparison to grain, may introduce different flavours to the final product which are often perceptible by trained sensor and consumer panels. Depending on the consumer (cultural background, prior lamb consumption, habituation to meat from pasture or grain-fed animals), the flavour of cooked pasture-fed sheep may be described as typical 'sheepmeat' or 'lamb', or unfamiliar and potentially unacceptable.

Some differences have been described for the meat flavour of sheep grazing on different pastures and forages. For example, in comparative trials of different pasture species, unacceptable flavours have been found by trained panels for white clover, lucerne, phalaris, rape (Brassica sp.) and related brassica feeds (see Table 1). Other studies have reported no differences in sensory panel assessments between meat from sheep grazing forage species such as tropical legumes vs grass and chicory vs lucerne. The stage of growth for pasture species and also time of year can influence the water-soluble carbohydrate content, crude protein % and digestibility, all of which can potentially impact on the occurrence of off-odours and flavours in ruminant meat. Importantly, the majority of pastures and feeds do not create flavour or odour problems in the meat; however, and of equal importance, the forages that have potential to impact on product quality need to be identified, in order to minimise any risks of the consumer getting a poor eating experience.

In some instances, the impact of pasture species on sheepmeat flavour can be significant. One example is forage rape or canola (Figure 2) and anecdotal evidence suggests that certain Brassica crops in common use may impart negative flavour attributes in lamb. A diverse range of Brassica species is available and used in Australia, which naturally vary widely in glucosinolate and protein content. There is speculation that Brassica with high glucosinolate content may impact on flavour, through sulphur-containing breakdown products, although this still needs to be proven. In addition, pasture diets with high protein content have been implicated with the pastoral flavour notes found in lamb. Grain-finishing diets are also increasingly used, although how grain-fed lamb flavour differs from other diets requires clarification.

Effect of diet on aroma (volatile) compounds

Lactones are important aroma and flavour compounds that are found in many natural products. Higher levels of γ-lactones have been found in the meat taken from grain-fed sheep, and are believed to be derived from the free fatty acids that are present in the grain. δ-Lactones have been reported to be high in the meat obtained from pasture-finished animals. Different synthetic pathways exist for the formation of the γ- and δ-lactones.

Both 3-methylindole and p-cresol have been implicated as the main contributors to 'pastoral' flavour. Pasture has a high protein-to-readily fermentable carbohydrate ratio, and the protein from pasture is more readily digestible in the rumen compared to that available in grain and concentrate diets. Additionally, substantial degradation of feed protein to amino acids occurs in the rumen, which allows a higher availability of peptides and amino acids for absorption, which cannot be fully incorporated into microbial protein since insufficient energy is released from carbohydrate metabolism. Tryptophan and tyrosine, both amino acids, are transformed by rumen bacteria to form 3-methylindole and p-cresol, respectively. Usually, these compounds would be metabolised by the liver after release into the blood supply from the intestine; but, when in excess, some will escape liver metabolism and be released into the blood supply resulting in deposition into fat tissue.

Table 1. Impact of feeding regimes on sheepmeat flavour

Feeding system	Impact on flavour
Pasture compared to concentrates	
Pasture vs grain concentrate	'Lamb' flavour higher in concentrate
Pasture vs lucerne or maize concentrate	'Sheepmeat' higher for pasture
Ryegrass vs concentrate	'Off' odours/flavours in ryegrass-fed meat
Mixed pasture vs grain-based or poor quality dry feed	No difference between pasture vs grain
Pasture vs concentrate vs pasture/concentrate	Lower acceptance of pasture-fed animals
Other comparisons	
Rape vs pasture	Stronger, less acceptable flavour for rape
Perennial ryegrass + other grasses vs grain-based	'Sheepmeat' higher for pasture than grain
Saltbush vs barley/lupin/hay	No difference

Diet has also been implicated in the formation of branched chain fatty acids (BCFAs), regarded as the main contributors to 'mutton' flavour. Higher concentrations of these compounds have been observed in animals receiving a grain-based finishing diet prior to slaughter. This has been attributed to carbohydrate availability in the diet since higher amounts are associated with grain and concentrates compared to pasture-based diets. Although it might be logical to assume that grain-dominated diets result in increased 'mutton' flavour in the cooked meat, cereal grains differ in their propensity to generate BCFAs, so some care is required in extrapolating this observation.

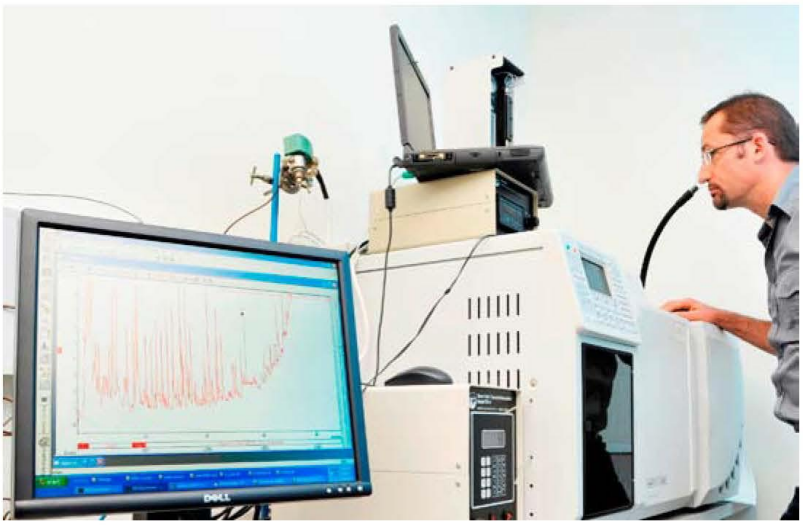

Figure 1: Sniffing aroma on a GC-olfactometer

Taste compounds in meat

To date, research relating to non-volatile taste compounds in lamb meat specifically, and meat in general, has been fairly limited; but, in recent years, interest in this area of research has been increasing. There is a wide range of compound classes that can contribute to the taste of meat and related products. These are, namely: organic acids (e.g. lactic and succinic acids); compounds derived from lipid precursors (short-chain fatty acids); sugars (such as glucose and fructose); peptides and free amino acids (produced from enzymatic hydrolysis of muscle proteins); nucleotides; and Maillard reaction products.

Low molecular weight, water-soluble compounds (namely sugars, amino acids and other nitrogenous components) are important as:

(a) background basic taste attributes (sweet, sour, salty, bitter and umami) as well as complex sensations such as mouth-fullness; and
(b) precursors of the characteristic aroma (meaty flavour) of cooked meat.

Other indirect effects

Components of the diet that change the final pH, intramuscular fat, or antioxidant status of muscle can also affect the final flavour characteristics. For example, carnosine, the most abundant dipeptide in skeletal muscle, and vitamin E, a lipid-soluble vitamin derived from pasture, both decrease lipid oxidation. Lipid oxidation in muscle post-slaughter causes deterioration in meat flavour, including the unacceptable 'warmed-over' flavour. Carnosine also has a positive influence on the thermal generation of pyrazines, a class of compounds that contribute to 'meaty' aromas. Differences in diet can impact on other factors which will influence the final flavour characteristics of the meat product. For example, meat from concentrate-fed animals undergoes lipid oxidation more readily compared to that taken from pasture-fed animals, which impacts on the amount of lipid-derived volatiles during cooking. Pastures and feeding systems which allow the adequate deposition of muscle glycogen and also intramuscular fat, by providing adequate energy and protein, will also result in more acceptable flavour in the meat.

Saltbush-fed lamb has been anecdotally reported to have a superior flavour, although the studies comparing saltbush-fed lambs to pasture-fed lambs have found no difference. As saltbush appears to impart higher levels of antioxidants to the muscle, it is possible that the superior taste is associated with prevention of the off-flavour associated with oxidation.

A consumer perspective

An estimated world total of about 1 billion sheep exist for wool and milk production, and slaughter for meat, skin and wool. The largest number are in China, about 130 million, followed by Australia (70 m), India (65 m), Iran and Sudan (50 m each), Nigeria, New Zealand and the UK (30 m each). Most of the sheepmeat produced in China is intended for local consumption. Australia, by contrast, has a high local consumption and, along with its neighbour New Zealand, is a major sheepmeat exporter. In both Australia and New Zealand it can be assumed that a significant fraction of the native population accept the characteristic flavour of locally produced sheepmeat as 'normal'. These populations can be described as habituated to the local product.

The source of sheep meat for processed foods is usually older ovines, typically mutton, which is a cheaper source than lamb. In these processed foods the meat is usually comminuted, which eliminates any problem of toughness due to muscle origin and animal age; however, mutton is more strongly flavoured and, due to the negative perception by some consumers, its inclusion into meat products is not routinely promoted, e.g. mainstream sausages prepared with mutton are often labelled 'beef-flavoured sausages' to avoid consumer misapprehension. Conversely, this is why 'mutton-flavoured sausages' are never seen.

The aversion to meat taken from older sheep was highlighted in a consumer survey in New Zealand that tested the association between

Figure 2: Canola (brassica) field in Temora, New South Wales (from en.wikipedia.org)

consumer perception of different types of red meat (lamb, mutton, beef, venison) and their perceived taste, quality and healthiness. Consumers were asked to rate expected quality with no actual meat eaten or on view. The perceptions of hogget and mutton were lower compared to the other meats, which included lamb. Whilst a negative perception for mutton might be reasonably founded on flavour differences due to the presence of higher BCFAs, a lower rating for hogget, where the animal may only be older than a lamb by one day, suggests that the mere name hogget has an unfortunate marketing consequence.

Different consumer populations around the world vary in their liking of sheepmeat. In many cases this relates to lack of exposure, familiarity and traditional use of sheepmeat in the local culture and cuisine. Sheepmeat consumption is greater in Australasia than in Japan, and this is reflected in product habituation. Researchers, in a comparative study between female Japanese and New Zealand consumers, spiked beef samples with zero, low and high concentrations of mixed BCFAs and of skatole to simulate nine flavour combinations of sheepmeat fed on pasture, designed to represent a range of sheepmeat typically available to New Zealand consumers. For the Japanese consumers, there was a strict linear decrease in liking as BCFA concentration increased. In contrast New Zealand consumers on average liked a low level of added BCFAs best, similar to those found in young lamb suggesting an effect of habituation and familiarity. The results for skatole were more complicated, but the highest concentration was clearly most disliked by both populations.

Consumers not familiar with the flavour of sheepmeat are likely to be less accepting of this product and so it will remain a challenge to overcome the negative perceptions, whether due to the inherent presence of a 'natural' lamb flavour, or due to the presence of BCFAs which contribute to the 'mutton' flavour. In order to overcome the barriers in these populations, masking lamb flavour with herbs and spices is an obvious path to take. Each culinary tradition has well-defined 'flavour principles' that could be utilised to produce an acceptable meat product suitable for unhabituated consumers. Development of optimised feeds, which impart desirable flavour attributes or, alternately, mask less desirable qualities, may also be an effective strategy for the sheepmeat industry.

Prepared by Dr Peter Watkins with contributions from Drs Damian Frank and Tanoj Singh, and Assoc. Profs Owen Young (AUT University, Auckland) and Robyn Warner.

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MEAT TECHNOLOGY UPDATE
Cutting edge technology for the meat processing industry

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Meat technology update

2/12 – October 2012

Pathogenic Shiga toxigenic *E.coli*—STEC

- Some *E. coli* strains can produce Shiga toxin and are termed Shiga toxigenic *E. coli* or STEC.
- Some of these STEC strains can cause serious gastrointestinal illness, and even death, in humans.
- The US has declared six STEC other than *E. coli* O157:H7 to be adulterants i.e. *E. coli* O26, O45, O103, O111, O121 and O145.
- USDA/FSIS has commenced testing Australian meat imports for these organisms.
- The prevalence of these STEC in Australian beef is low, but likely higher than *E. coli* O157:H7.
- Interventions on the farm, and particularly at the abattoir, are effective in minimising the prevalence of STEC in the final product.
- Isolation of STEC is technically challenging and it may take up to 5 days for a confirmed result to be available.

Background

Escherichia coli are commonly found among the natural microbial flora of the intestinal tract of warm-blooded animals. The majority of *E. coli* strains are not considered pathogenic, but some strains such as *E. coli* O157:H7 can cause serious human illness. *E. coli* O157:H7 is a member of a group of *E. coli* that produce a Shiga toxin referred to as Shiga toxin-producing *E. coli* (STEC). Some STEC can cause gastroenteritis, which in some cases progresses to life threatening complications such as haemolytic uraemic syndrome (HUS). These STEC are known as enterohaemorrhagic *E. coli* or EHEC. The most common EHEC strain is *E coli* O157:H7. Only a small number of *E coli* O157:H7 bacteria are required to cause illness, and children and the elderly are particularly susceptible. Cattle have been identified as a major reservoir of *E. coli* O157:H7 and historically disease was associated with the consumption of beef products. More recently disease has been linked to products such as green leafy vegetables that have been contaminated by cattle faeces. The incidence of *E coli* O157:H7 infections in humans varies between countries with Australia having a notification rate of approximately 0.12 cases per 100,000 per year[1] while in the USA it is 1.5[2] and in Scotland 4.3[3] cases per 100,000 per year.

In September 1994, following a large outbreak in the US in 1992–93 due to consumption of undercooked hamburgers,

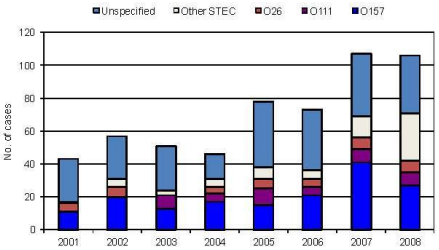

Figure 1: Disease estimates of E. coli *O157 and non-O157 in the USA*

the United States Department of Agriculture, Food Safety and Inspection Service (FSIS) declared *E. coli* O157:H7 to be an adulterant of raw ground beef and commenced a testing program. The FSIS required raw-beef establishments to reassess their HACCP plans in 2002 to determine if *E. coli* O157:H7 was a hazard reasonably likely to occur and, if so, to implement critical control points (CCPs). The FSIS utilised sampling of raw ground beef and later ground-beef components to verify the establishment's HACCP system was functioning as intended. In response to this, the Australian meat-processing industry, in partnership with DAFF, implemented a sampling and testing program that lead to a reduction in the amount of import testing conducted by FSIS. The Centers for Disease Control (CDC) in the US showed that six STEC serotypes of *E. coli* (O26, O45, O103, O111, O121 and O145) accounted for over 80% of all non-O157:H7 isolates associated with human disease between 2003 and 2006 (Figure 1). As a consequence of this the FSIS declared these STEC adulterants in ground beef and ground-

beef components. As a consequence of this the FSIS has implemented regulatory testing for all 7 STEC strains in raw manufacturing beef trimmings and other ground beef components.

FSIS and DAFF policies

The Australian Government Department of Agriculture Fisheries and Forestry (DAFF) and the Australian industry have identified that all 7 STEC serotypes are hazards that are likely to occur in Australia and, therefore, they should be addressed in an establishment's HACCP plan. As all the serotypes have similar growth characteristics, the effectiveness of interventions is expected to be the same for all serotypes. Critical control points (CCPs) identified for *E. coli* O157:H7 are expected to adequately control the other serotypes; however, the ecology of the serotypes in animals may mean that certain types of stock are more at risk of contamination.

Australia produces high-quality product through careful attention to pre-slaughter and processing practices and does not generally rely on interventions such as decontamination to control hazards on meat. While DAFF continues to highlight that there are fundamental differences between the Australian and USA meat industries and a lower level of microbial hazards on Australian meat, product may be occasionally contaminated with STEC and this contamination detected during port-of-entry (POE) testing.

FSIS began testing lots of manufacturing trim at POE for the seven STEC (O157:H7, O26, O45, O103, O111, O121 and O145) on 4 June 2012. Testing is limited to product with a slaughter date on or after the 4 June 2012. DAFF has provided some initial feedback to the FSIS on actions Australia is taking to address STEC. These actions include:

- undertaking of a regulatory baseline survey;
- industry testing of US export lots;
- increased verification testing;
- industry reassessment of their HACCP programs for control of STEC.

Once the FSIS position on STEC testing is known, DAFF will seek an equivalence arrangement with FSIS to ensure that actions taken by the FSIS in the advent of a port-of-entry (POE) detection are limited to the tested lot.

The Australian industry has delayed implementation of any regulatory STEC program as the FSIS has placed a 90-day (from 4 June 2012) moratorium on follow-up action taken in the event of a regulatory detection (including POE detections) of any of the STEC under investigation. During this time the FSIS will conduct testing on domestic and imported product. Any product in which STEC is detected will be declared adulterated. It is not clear how FSIS will consider microbiological independence of adulterated lots. FSIS collect follow-up samples for STEC testing in the event of a positive verification test result. This implies that a POE STEC detection will be treated in the same manner as an *E. coli* O157:H7 POE detection.

During the FSIS 90-day moratorium Australian industry must determine if their HACCP plans control these STEC. DAFF will publish a Meat Notice detailing the requirements of any testing program for STEC on its website once the results of the 90-day trial and FSIS's final position on STEC are known. It is likely that such a program will simply be an expansion of the current *E. coli* O157:H7 program to include testing for the other six serotypes.

Australian establishments are testing lots of manufacturing trim exported to the US for STEC under a Market Access Advice issued by DAFF. This program is not under DAFF supervision and product is not certified by DAFF as having been tested for STEC. DAFF continues to work with industry to determine the most suitable disposition of product tested under this program. While the prevalence of STEC in manufacturing beef appears to be lower in Australia compared to the US, it is higher than the incidence of *E. coli* O157:H7 at around 1%. This means that detection at POE is possible even when STEC has not been detected during sampling and testing in Australia.

STEC through the slaughter process

Little is known about the ecology of non-O157 STEC. The following information applies to O157. As with other *E. coli*, pathogenic STEC originate in the intestinal tract of sheep and cattle and they are as likely to occur in grass-fed and organically produced stock as in grain-fed animals. They tend to be more associated with faeces than rumen fluid and may be transferred to the hide and fleece and oral cavities of stock by contact with faeces, water troughs, the general environment and grooming. There is then the potential for organisms to be transferred to the carcase surface during the slaughter and dressing process. Occasionally, an individual animal may carry a very high load (10,000 cfu/g or greater) of O157 in its faeces. This animal, known as a 'supershedder', is more likely to contaminate the hide and oral cavities of other members of its group and provide the greatest risk for meat contamination. When this group is processed through the abattoir, there is a higher chance of dressed carcases being positive for O157. The reasons why some animals on occasion shed high numbers of O157 are unknown, but reducing these numbers will lead to lower contamination of meat and meat products and reduce the risk to human health.

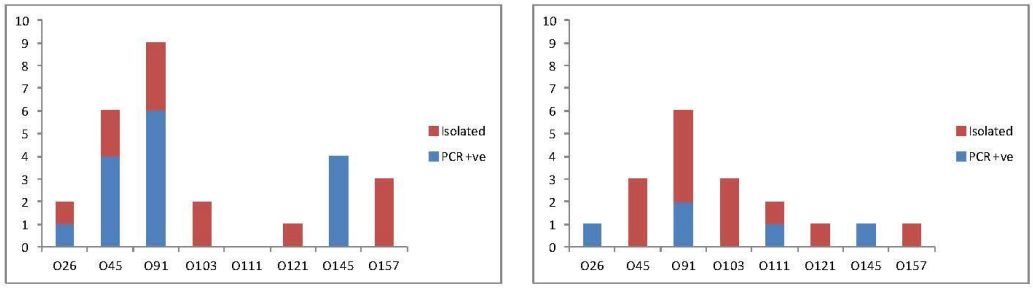

Figure 2: Number of grain-fed (left panel) and grass-fed (right panel) samples testing positive or yielding isolates of the target serotypes

Limited data exists on the prevalence of STEC in cattle and even less in other species. In a study in Australia over an eight-month period in 2008 and 2009, faecal samples were collected from the rectal end of the intestinal tract of 300 grass-fed and grain-fed cattle at slaughter. Of the 300 faecal samples, 30 tested positive for the presence of a Shiga toxin gene, an additional virulence marker, *eae* and for the presence of at least one STEC serotype using real-time PCR. Figure 2 shows the number of grain-fed and grass-fed samples testing positive or yielding isolates of the targeted serotypes. Importantly, however, none of the isolates harboured the necessary combination of virulence markers (i.e. *stx* and *eae*) and were not classified as STEC.

A study in 2011–2012 was conducted to provide an initial estimate of the prevalence of non-O157 STEC strains in Australian manufacturing beef, and to gain an understanding of the performance of commercially available screening tests. From 1,029 samples of beef trimmings (375g) only one positive screening test was confirmed to contain STEC (*E. coli* O26). One sample with a negative screening test result was also confirmed to contain a STEC (*E. coli* O26). The prevalence of non-O157 STEC strains in Australian beef was estimated to be approximately 0.2%. In a US study, 4,133 ground-beef samples were collected from 18 commercial processors, and pathogenic STEC were isolated from 0.2% of samples.

In the Australian baseline survey conducted in 2004, *E. coli* O157:H7 was recovered from one beef carcase from 1155 samples (0.1%) and from 6 out of 1117 sheep carcase samples (0.6%). No *E. coli* O157 were detected in 1082 samples of frozen manufacturing beef and one from 557 samples of frozen sheep meat (0.2%). Results from the 2011 baseline survey indicated a similar prevalence of 0.3% on sheep leg samples and 0.2% on shoulder samples and no *E. coli* O157:H7 on frozen beef primals.

Dairy cattle and calves may be more significant reservoirs of STEC. This is relevant as the meat from culled cows and calf trimmings is mostly used for processing into ground beef. Studies of dairy cattle in the US have reported prevalence of non-O157 STEC in faeces of up to 22%. A study of animals on a dairy farm in Australia over a year showed a low prevalence of *E. coli* O157 in faeces for most of the year, but a sudden increase in one month. If cattle from this farm had been slaughtered during this outbreak, there would have been a higher chance of carcases being contaminated.

The rate of faecal shedding of STEC by dairy cattle can vary markedly between farms and between cattle of different ages. Calves have a higher incidence than milking cows and the general herd, and weaned calves have a higher incidence than pre-weaned calves (Figure 3). The stress of weaning and diet change, an immature immune system and intensive housing of weaned calves are thought to be the main factors leading to a higher incidence of STEC shedding in this group.

Interventions

Over the last 10–15 years, a large amount of research has taken place into means of reducing *E. coli* O157 in livestock and in ensuring that, if it is present, it is not transferred to the carcase during dressing, or allowed to survive on the chilled carcase. The majority of the research focussed on *E. coli* O157:H7, but the results are assumed to be equally applicable to control of non-O157 STEC. Below is a list of on-farm and in-plant interventions that have been considered worldwide.

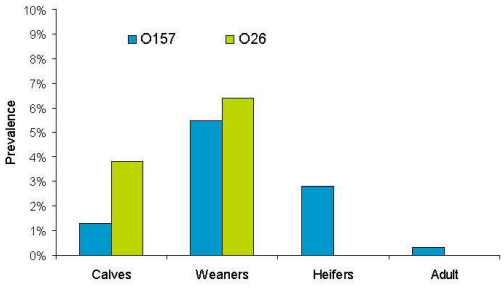

Figure 3: Faecal shedding of E. coli *O157 and O26 in Australian dairy herds*

On-farm

Methods to control O157 in livestock have met with varying degrees of success, being effective under some conditions, but not others. This is not surprising given the range of production systems and practices in use. Methods trialled have included the following.

- Manipulation of diet to alter the volatile fatty acids and pH in the rumen may reduce the chance of colonisation and shedding.
- Vaccines have been developed for the control of *E. coli* O157:H7. While showing promise, none of the vaccines has been completely successful in eliminating the carriage of this pathogen. Vaccines for a specific STEC serotype are unlikely to be effective in controlling other serotypes.
- Probiotics, which are live microorganisms that can confer a health benefit, have been administered via the feed.
- Bacteriophages (viruses which infect and kill specific bacteria), have also been administered to target *E. coli* O157:H7. Again this technology is likely to be serotype specific.
- Chemicals such as sodium chlorate have been administered to animals.

In-plant

A wide range of methods have been developed and applied to the control of *E. coli* O157 during slaughter, dressing and further processing. Many of these are general antimicrobial techniques have been refined for use in the meat-plant environment and tested on pathogenic *E. coli*. These interventions are not meant to be replacements for good hygienic practices and will only provide incremental benefits to the final carcase hygiene. Interventions include:

- stock cleaning by de-dagging and water washing to reduce visible soil and microbial numbers on hides;
- steam vacuuming after hide removal, especially along cutting lines;
- pre-evisceration systems such as acid spray washes;
- carcase decontamination on completion of dressing by:
  - hot water
  - steam
  - radiation
  - antimicrobial chemicals and organic acids;

- effective chilling of the carcase to prevent microbial growth (drying of carcase surfaces during chilling is an effective control for bacterial growth and survival).

One of the most effective methods of minimising microbial levels on carcases is to follow good manufacturing practices (GMP). This can include ensuring animals are clean, facilities are properly cleaned and sanitised, hand and equipment cleaning facilities are adequate and correctly used, and most importantly that staff are trained in hygienic hide removal and evisceration procedures, trimming and observation/removal of zero-tolerance defects (faeces, ingesta, urine and milk) and in operation of equipment.

The interventions listed above have been found to be effective in reducing the prevalence and the numbers of E. coli O157 on carcases and final product. In most cases a series of rigorously tested and approved treatments used in combination have been shown to reduce the risk associated with these pathogens, but not entirely eliminate them. In evaluating an intervention suitable for your plant, you should consider:

- effectiveness of the intervention (how much reduction in microorganisms can be expected);
- effect on product quality (colour, taste, residues, etc.);
- capital cost;
- operating costs;
- environmental considerations such as water and energy use, and chemical and biological waste;
- acceptability to customers.

A package providing summaries and assessments of a large number of interventions is available on the web site www.meatupdate.csiro.au.

Testing for *E. coli* O157 and STEC

E. coli O157:H7 and STEC all have two key virulence markers that are utilised during the screening and confirmation process. The screening process utilises PCR (a molecular-based detection system) to test for the presence of the Shiga toxin genes and an additional virulence marker known as eae. Information about the serotypes present in the sample is generated by PCR or is implied following immunomagnetic separation (IMS) for the serotypes of interest. IMS uses magnetic beads coated with antibodies to the specific *E. coli* serotypes to separate target organisms from the enrichment broth. Once the presence of a Shiga toxin gene, eae, and a gene for serotype O157 or target STEC has been detected in an enrichment broth, then it is deemed a potential positive and should be sent to a confirmation laboratory for further analysis. Confirmation laboratories will use IMS and PCR to determine if the enrichment broth contains *E. coli* of the appropriate serotype carrying a Shiga toxin gene and eae. Confirmation of STEC isolates is technically challenging and may take up to five days for a result to be confirmed. A number of commercially available systems for conducting in-plant screening for *E. coli* O157 and STEC have been approved for use by DAFF. Further information about these systems can be found on the DAFF website (http://www.daff.gov.au/aqis/export/meat/elmer-3/approved-methods-manual/summary).

CSIRO acknowledges the assistance of Ian Jenson of MLA and Paul Vanderlinde of DAFF in preparation of this publication.

Further reading

CSIRO *Meat Technology Update* 6/03, *E. coli*, *E. coli* O157 and Salmonella.

Draft risk profile for pathogenic non-O157 Shiga toxin-producing *Escherichia coli* (non-O157 STEC). USDA food Safety and Inspection Service, May 2012, available at: http://www.fsis.usda.gov/PDF/Non_O157_STEC_Risk_Profile_May2012.pdf.

Pathogenic Shiga toxin producing *E. coli* (pSTECs) other than O157 (non-O157 STECs) in manufacturing beef. Baseline survey and method comparison. MLA, Feb 2012.

1 Vally et al. 2012, BMC Public Health, 12:63
2 Gould et al. 2009 Clin Infect Dis 49:1490
3 Pearce et al. 2009 BMC Microbiology 9:276

Final *Meat Technology Update*

This edition of the *Meat Technology Update* is the final in the series distributed by CSIRO. In the future, technical information will be distributed to the Australian meat industry through the resources of the Australian Meat Processor Corporation and Meat & Livestock Australia.

Past editions of the *Meat Technology Update*, *What's New*, *Fact Sheets* and various other scientific reports will continue to be available online.

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Meat Industry Services is supported by the Australian Meat Processor Corporation (AMPC) and Meat & Livestock Australia (MLA).

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MEAT TECHNOLOGY UPDATE
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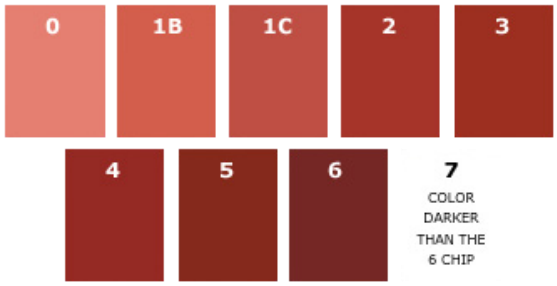
Dark Cutting Package

On-farm guide

What is dark cutting?

Dark cutting meat usually has a very high pH which makes the meat appear dark. Because consumers prefer 'bright-cherry' coloured meat, dark-cutting carcases are often heavily discounted (up to $0.45/kg hot carcase weight, or up to $200 for a carcase. In Australia the incidence of dark cutting is almost 10% in beef. That equates to a potential loss for the industry of almost $36 million per year! In sheep and lambs the figures are even higher – an estimated 15% of sheep and lamb carcases are classified as high pH.

Some classes of livestock tend to be more susceptible than others. Dark cutting is more prevalent in pasture-fed cattle than feedlot cattle, in milk-fed vealers compared to weaned vealers and sucker lambs compared to carry over lambs. Heifers in season, bulls, and cattle treated with hormonal growth promotants and freshly shorn sheep in cold weather may also be especially susceptible to dark cutting.



In addition to the unacceptable dark colour, high-pH meat has the following features:

- A coarse texture
- Higher water holding capacity (therefore the meat loses a lot of moisture during cooking)
- Reduced shelf life (bacteria grow more rapidly due to the higher pH and moisture)
- It appears undercooked
- Reduced tenderness at pH ranges 5.7 – 6.2
- Stronger flavour in sheep

High-pH beef (above pH 5.7) is excluded from many meat brands, MSA, food service operations and markets such as the valuable Japanese trade.). In order to be eligible for MSA grading, beef carcasses must be graded as having an AUSMEAT colour score of 3 or lower (see AUSMEAT colour scores pictorial standards below). Furthermore, the ultimate pH of the striploin at grading must by <5.7. Dark-cutting meat is ultimately rejected by consumers at the retail level on the basis of its colour.

Key message:

The good news is that high-pH meat can be prevented! And it's worth it. By improving the handling and care of livestock, there are benefits such as:

- reduced bruising
- improved animal welfare
- reduced carcase weight loss

Tip

There are many terms used to describe dark cutting. These include high-pH and DFD (dark, firm, dry) meat.

Meat quality and pH

pH is a key factor in meat quality. The potential for good quality meat only occurs over a relatively small pH range, between 5.4 and 5.7 as shown in the following table. The table also shows that the pH values resulting in dark-cutting meat can occur over a wider range, and compares meat with living muscle and other common household products.

pH value	Description
14	STRONG alkaline
12-23	Bleach
9-12	Common household detergents
7.1	Living muscle
7	Pure water
5.8-6.9	**Meat classified as 'Dark Cutting'. Shelf life decreased, not suitable for vacuum packaging, generally darker and tougher.**
5.4-5.7	**Meat with good visual appeal and potentially, good eating quality.**
4-5	Orange juice, beer
2-3	Vinegar
0	Battery acid

How much the pH declines after slaughter is dependent on how much muscle **glycogen** the animal has in reserve.

In simple terms, glycogen is the reserve energy tank in muscle. The tank is used during stressful events, during excessive physical activity, or after the death of the animal, where the availability of oxygen to the muscle is reduced or removed.

When the animal is slaughtered, glycogen is utilised as the primary energy source. This in turn produces lactic acid, which lowers the pH of the meat.

The final pH is achieved when the conversion of all muscle glycogen to lactic acid is complete and is known as the ultimate pH of meat. By measuring this pH we can determine the potential quality of the meat.

Filling the glycogen bucket

The key to achieving an ultimate pH below 5.7 (the pH for good meat quality) is to ensure the glycogen levels in the live animal are high before slaughter.

High-pH meat or Dark Cutting Meat is due to inadequate levels of glycogen in muscles at the time of slaughter

Glycogen can only be restored in the animal through good nutrition, but can be easily lost through factors such as stress or strenuous activity.

Unlike humans, sheep and cattle can't quickly replace their muscle glycogen levels. Neither can glycogen be added to a carcase after slaughter.

A simple way to consider glycogen is to think of it as a bucket. A full bucket means a normal ultimate pH (and the potential for good meat quality) will be achieved. Once the level in the bucket falls below half, there is insufficient glycogen (resulting in high-pH meat). A bucket that is less than half full means the meat will be dark cutting. It takes at least seven days to refill the bucket once emptied.

Causes of dark cutting

The biggest influence on ultimate pH levels is the management of animals in the few days prior to slaughter. Stress and/or physical activity are the primary factors causing muscle glycogen loss. During the pre-slaughter phase it is therefore essential that both stress and physical activity be minimised.

While there are steps that transporters and processors must take to reduce dark cutting, it is on-farm that many of the problems can first occur.

It is important to fill the glycogen bucket on farm and in the feedlot and then to keep it full.

Action that fills the glycogen bucket

- Ensure animals are gaining weight prior to marketing by providing good nutrition (quality pasture, grain supplementation) during the 7-14 days prior to despatch.

Actions that empty the glycogen bucket (avoid or minimise)

- Physical activity (e.g. mustering, yarding, transporting, loading, unloading).
- Emotional stress (e.g. mixing/separation, excessive noise, unfamiliar environments, dehydration, weaning).
- **Poor nutrition leading to loss of condition (low-energy pasture can result in lowering of muscle glycogen).**
- Other (e.g. sudden climatic changes – especially cold snaps, shearing during cold weather, inappropriate use of HGPs, oestrus in heifers disease/parasites).

In reality, cattle and sheep will always lose some muscle glycogen between farm and slaughter. Thus the challenge is to ensure the bucket of muscle glycogen is full, through good nutrition, prior to despatch from the farm.

Guidelines for preventing dark cutting meat

Management practices for sheep and cattle production vary widely within Australia – from intensive feedlot systems to extensive grazing systems based on a range of pasture conditions. However, in all cases, a reduction in dark cutting can be achieved.

The following guidelines are the result of all the relevant research undertaken in Australia and overseas. All the recommended practices have a scientifically valid and tested reason.

You may be surprised to learn that some past practices or recommendations on dark cutting no longer apply. For instance researchers have found that when nutrition is good, breed is not a significant factor. Only when ineffective pre-slaughter practices are used do differences occur, such as between merino and crossbreed sheep for example.

How to use these guidelines

STEP 1: Review past performance. Assess your on-farm management and handling practices

- Talk to your local abattoir or review past feedback sheets (look at variation in meat colour scores).
- Identify financial losses or penalties you have previously incurred for dark cutting.

STEP 2: Assess your current on-farm management and handling practices

- Using the guideline tables in this publication, tick off those practices you routinely follow. Take note of those which you are not following. Cross out the ones that do not apply to your operation.
- Summarise and prioritise the practices which you need to follow. Develop an action plan (what you need to do and by when).

STEP 3: Change your practices

- Plan your marketing operations carefully.
- Incorporate procedures in your on-farm quality assurance system or management practices.
- If necessary, talk to your local advisors processor or to Meat & Livestock Australia for further advice.
- Monitor improvements by comparing new feedback sheets with historical ones.
- Look at the improvements to your bottom line.

On-farm management and marketing

	Recommended practice	Why?	How?	✓ or ✗
1.	Select stock on temperament as well as performance characteristics	Animals with poor temperament are stress susceptible and can disturb others within a mob	There are several tests that can be applied to determine temperament. Advice may be sought from your local Department of Agriculture advisor. Flight speed is a heritable character and can be included in breeding programs. **Minimise variation in flightiness across the herd by culling wild animals as they potentially stir up calm animals.**	
2.	Familiarise animals to handling and human contact.	Animals exposed to frequent positive handling and training move more easily and are likely to be more resilient to pre-slaughter stressors.	Familiarising means frequent and gentle handling and movement of your stock, and getting your animals used to yards and transport. Yard weaning is one way to achieve familiarity and cell grazing may also benefit. Try exposing animals to different stimuli (in a positive way) such as motor bikes, people on foot and people on horses.	
3.	Ensure stock are on a rising plane of nutrition prior to marketing.	Good nutrition keeps the glycogen bucket topped up. A low plane of nutrition will begin to deplete the glycogen level even before you muster them.	Assess the quantity and quality of food available to the animal and use animal growth rate to verify this assessment. Feed intake should be above maintenance value such that growth rate is better than 0.5 kg/head/day for cattle and 100 g/head/day for sheep. High growth rate indicates high energy intake so a high level of muscle glycogen can be expected. This is particularly important for the two-week period prior to slaughter. Note: fat cover does not necessarily indicate high muscle glycogen.	
4.	Consider pre-slaughter pulse feeding of high-energy diets for animals susceptible to dark cutting or when markets stipulate low incidence of dark cutting.	Certain classes of stock are more likely to have low muscle glycogen and produce dark-cutting meat. Included are bulls, freshly shorn sheep in cold weather, stock mustered long distances, sucker lambs, vealer	Feed forage/grain rations for 1-2 weeks prior to slaughter taking care to avoid acidosis (grain poisoning) on introduction.	

		calves, lactating females and any stock finished on low-quality pasture.	
5.	Use magnesium oxide to assist with stress management.	Adrenaline released by stress will empty the glycogen bucket. Magnesium blocks the action of adrenaline hence tempers the action of stress on muscle glycogen. This effect is not complete so magnesium oxide is a useful aid but no substitute for good nutrition and stock management.	Add magnesium oxide to the feed at the rate of 1% for four days prior to marketing for slaughter. Usage for greater than four days causes the effect to wear off.
6.	Preferably consign direct to abattoirs.	Marketing animals via saleyards means further handling of stock and longer delays off-feed and therefore a higher risk of dark cutting.	Talk to your local agent or abattoir about direct consignment.
7.	Where possible exclude heifers in oestrus from slaughter consignments.	Heifers in oestrus will encourage mounting activity.	Separate heifers showing signs of oestrus from consignments.
8.	Market bulls separately.	Bulls are at a higher risk of dark cutting due to their mounting and fighting activities.	Don't market bulls, including mickey bulls, or rams with other animals.
9.	Don't market for slaughter too soon after purchase.	Stock need time to adjust to their new surroundings and herd mates.	Don't market newly purchased stock within four weeks of purchase.
10.	Minimise drafting off livestock just prior to transport.	Extra movement and disturbance of animals causes glycogen	Draft stock into slaughter lines at least two weeks prior to slaughter where livestock have to be mixed. Livestock selected for slaughter from within a

		depletion especially when rushed	management group should be drafted as close to transport time as practicable.
11.	Comply with manufacturer's instructions regarding HGPs.	Research has found that cattle consigned while under the influence of HGPs are at a greater risk of dark cutting. The risk increases even more in heifers.	Check the label for the properties of the HGP and ensure cattle are not consigned while the HGP is still active. (Note: chemical withholding periods must always be adhered to.)
12.	Avoid marketing, particularly trucking, during very cold or very hot weather.	Sudden climatic changes can increase the risk of dark cutting. This risk is particularly evident during periods of cold, wet weather.	Avoid marketing in extreme weather conditions (very hot, very cold, raining, or stormy) or when there is the potential for sudden climatic changes (particularly cold weather).
13.	Avoid or take extra care marketing shorn sheep.	Shorn sheep require more energy in cold weather than unshorn sheep. Cold exposure will empty the glycogen bucket and cause dark cutting. Shearing close to slaughter may also cause carcase bruising.	Time shearing to be at least four weeks prior to marketing or pulse feed high energy diets to shorn sheep two weeks prior to sale. Use magnesium oxide in feed supplements four days prior to slaughter to counter stress.
14.	Be aware of the effects of sheep genetics.	Sheep with a higher proportion of merino genetics have been have been shown to be more sensitive to stress.	Pay particular attention to nutrition or use pulse feed forage/grain supplements two weeks prior to slaughter. Use magnesium oxide in supplement four days prior to slaughter to counter stress.
15.	Only market healthy animals for slaughter.	Animals with visible signs of disease, or those recovering from disease or trauma are at high risk of dark cutting. (Marketing animals with	Ensure sick animals are treated, well rested and recovered before marketing.

		obvious signs of disease/trauma is also in breach of the code of practice for the welfare of animals.)	
16.	Use well-designed and constructed facilities for slaughter stock preparation.	Animals do not move easily through poorly designed yards. Additional force and contact is often required to shift animals and this increases the potential for stress and bruising.	Use yards built to a good standard and designed around stock behavioural traits. Consider implementing on-farm QA programs such as CATTLECARE™ or FLOCKCARE™, which address bruising and dark cutting risk factors.
17.	Use only reputable transport companies.	Poor transport conditions increases stress levels.	Use transport companies operating under a quality assurance scheme and utilising good animal handling practices (e.g. TruckCare™)

18.	Muster and assemble stock as quietly and efficiently as possible	Livestock have sensitive hearing. Unexpected loud or foreign noises and unnecessary movement can be highly stressful to livestock.	Refrain from using excessive and unnecessary yelling and whip cracking. Use skilled and trained cattle and sheep handlers. Work within the flight zone and utilise the point of balance.
19.	**Avoid excessive force when driving calm stock.**	**Clam cattle can be more at risk of dark cutting than flighty cattle.**	**Handle calm cattle with greater care and habituate them to change and human interaction.**
20.	Avoid running livestock to assembly areas.	Running uses up glycogen at a much faster rate than walking. Trotting animals 4 kilometres can empty the glycogen bucket from full to half full, which is critical for dark cutting. Once depleted, muscle glycogen can only be replaced by feeding the animal for 2-3 days which is impossible immediately prior to slaughter.	Set aside ample time for mustering. If mustering from a very long distance move stock closer to yards at least a week beforehand to allow feeding after mustering and prior to marketing.
21.	Minimise use of dogs.	Cattle and sheep view dogs as predatory animals. Dogs can create stress, especially in confined spaces.	Try using noise or drafting flags to move cattle.

22.	Keep animals in their social groups and don't mix mobs of unfamiliar animals.	Cattle and sheep become stressed or agitated when separated from their herd or flock. Lone animals are more difficult to handle. Similarly, mixing unfamiliar animals results in fighting to establish a new social order.	Avoid mixing unfamiliar mobs in holding paddocks prior to transport. If mixing of stock is unavoidable, do so at least one month prior to marketing and then re-muster. Try to avoid isolating any animal. Don't draft just one or two animals from a herd to fill and order.
23.	**Consign animals to abattoirs in large lots.**	**Cattle from large groups have a lower probability of becoming dark cutters.**	**If possible, consign animals in groups of 60 or more.**
24.	Reduce or eliminate the use of electric prodders and other goads.	As well as risking bruising, excessive use of jiggers and prodders will cause additional stress.	Use techniques such as working the point of balance and flight zone. Try using flappers, rattles or drafting flags instead.
25.	Be patient and allow time and space for livestock to move through the yards.	Hurrying animals can increase stress and deplete glycogen levels.	Use trained and skilled stock handlers familiar with quiet and efficient handling. Make sure gates are open before attempting to drive livestock in that direction.
26.	Use well-designed loading ramps.	Loading ramps, if not designed correctly, can impede animal movement and even cause injury.	Loading ramps must be non-slip and less than 25° slope, preferably with stepped incline. Provide double-decked facilities if two-deck transports are loaded regularly.
27.	Avoid dehydrating animals.	Dehydration can lead to stress, glycogen loss and carcase weight loss. When stock are kept off feed they lose about 0.1% of carcase weight per hour (0.5 kg per 20 kg lamb carcase per day).	Keep curfew times on farm to a minimum and make sure water is available to all stock before they are trucked. Make stock familiar with small water troughs as these are used in lairage. Consider using electrolytes.
28.	Feed electrolyte mixes prior to	Helps to maintain muscle glycogen	Supplement cattle with a commercial electrolyte 24 hour prior to transport.

	transport to slaughter.	concentration prior to transport.	These mixes are generally added to either the feed or the water.

Remember

The process of marketing animals for slaughter causes stress for cattle and sheep.

Stress and too much physical activity reduce glycogen levels and therefore increase the risk of dark cutting.

High ultimate pH has a detrimental effect on meat colour, texture, keeping ability and sometimes tenderness.

The following summary steps can help reduce stress in livestock prior to slaughter:

- Ensure livestock have good nutrition prior to slaughter.
- Muster and assemble stock as quietly and efficiently as possible.
- Handle livestock with care and avoid excessive force and noise.
- Familiarise animals to handling and train stock persons in handling skills.
- Maintain animals in their social groups.
- Preferably, consign direct to abattoirs.
- Ensure livestock have access to water at all times prior to consignment.

Meat Processor Guide

What is dark cutting?

Dark-cutting meat has a very high pH (typically above 5.8), which makes the meat appear dark.

In Australia, the incidence of dark cutting, or high pH meat, is almost 10% in beef. That equates to a potential loss for the industry of almost $36 million per year! In sheep and lambs the figures are even higher - an estimated 15% of sheep .and lamb carcases are classified as high pH.

Some classes of livestock tend to be more susceptible than others. Dark cutting is more prevalent in pasture-fed cattle than feedlot cattle, in milk-fed vealers compared to weaned vealers and sucker lambs compared to carryover lambs. Heifers in season, bulls, cattle treated with hormonal growth promotants and freshly shorn sheep are also especially susceptible to dark cutting.

The **ultimate pH** is a term used to describe the pH reached in the meat after rigor. It is now quite commonly used as an indicator of meat quality in the industry because:

- it provides an indication of meat quality - tenderness, texture, keeping quality, and suitability for vacuum packaging or further processing; and
- it provides an indication of the pre-slaughter treatment of animals.

High-pH meat is excluded from many meat brands, food service operations and markets such as the valuable Japanese trade. It is ultimately rejected by consumers at the retail level because of its colour.

Key message:

The good news is that high-pH meat can be prevented - and it's worth it. By improving the handling and care in marketing livestock, other benefits accrue, such as:

- reduced bruising
- improved animal welfare
- reduced weight loss ,and carcase shrink.

TIP

There are many terms used to describe dark cutting. These include high-pH and DFD (dark, firm, dry) meat.

Meat quality and pH

pH is a key factor in meat quality. The potential for good quality meat only occurs over a relatively small pH range, between 5.4 and 5.7 as shown in the following table. While the range may seem quite narrow, it is possible to consistently achieve this target. The table also shows the pH values that result in dark-cutting meat can occur over a wider range, and also compares meat with living muscle and common household products.

pH value	Description
14	STRONG alkaline
12-23	Bleach
9-12	Common household detergents
7.1	Living muscle
7	Pure water
5.8-6.9	**Meat classified as 'Dark Cutting'. Shelf life decreased, not suitable for vacuum packaging, generally darker and tougher.**
5.4-5.7	**Meat with good visual appeal and potentially, good eating quality.**
4-5	Orange juice, beer
2-3	Vinegar
0	Battery acid

How much the pH declines after slaughter is dependent on how much muscle **glycogen** the animal has in reserve.

In simple terms, glycogen is the reserve energy tank in muscle. The tank is used during stressful events, during excessive physical activity, or after the death of the animal, where the availability of oxygen to the muscle is reduced or removed.

When the animal is slaughtered, glycogen is utilised as the primary energy source. This in turn produces lactic acid, which lowers the pH of the meat.

The final pH is achieved when the conversion of all muscle glycogen to lactic acid is complete and is known as the ultimate pH of meat. By measuring this pH we can determine the potential quality of the meat.

The rate and chilling conditions under which the pH declines are important for meat processors in terms of meat tenderness.

Causes of high-pH meat

A low level of muscle glycogen in the live animal prior to slaughter is the cause of high pH and dark cutting. Management of animals in the few days prior to slaughter probably has the greatest influence on these levels. In particular, pre-slaughter nutrition, physical activity and stress are the primary factors associated with glycogen depletion and high-pH meat.

Glycogen can only be restored in the animal through good nutrition, but it can be easily lost by factors such as stress or excessive physical activity.

Unlike humans, sheep and cattle can't rapidly top up their muscle glycogen levels. Neither can glycogen be added to an animal after slaughter.

While there are important steps that producers and transporters must take to reduce dark cutting, the same equally applies at the abattoir. The risk factors at lairage and leading up to knocking are:

- time in lairage
- fasting or dehydration
- mixing or isolation
- poor lairage design
- poor handling and excessive use of electric prodders
- pre-slaughter washing
- excessive physical activity, such as mounting behaviour, fighting, slipping and falling
- animals that are more susceptible to the stress of lairage such as sucker lambs, baby beef, and lactating females.

Key message:

Good lairage means no further loss of glycogen.

Guidelines for preventing dark-cutting meat

While lairage pre-slaughter practices vary from abattoir to abattoir, the principles of good management remain the same. The following guidelines are a result of all the relevant research undertaken in Australia and overseas. All of the recommended practices have a scientifically valid and tested reason.

It is recommended that these guidelines be actively adopted in your operation by becoming part of your quality system or operational procedures.

Carcase weight loss

Stock can lose about 0.1% of carcase weight for every hour fasted (0.5 kg per 20 kg lamb carcase per day). However the rate of loss is fastest during the first 48 hours of the fasting period, which starts on farm. To minimise carcase loss the fasting period should be kept to a minimum. However slaughter directly of the truck (tailgate slaughter) may increase dark cutting in some classes of stock and should be avoided. Animals need at least four hours to recover from transport before slaughter. Water should be freely available in lairage to avoid dehydration and restore liveweight lost during transport. Water additives such as electrolytes (e.g. Nutricharge ™ and Glucotrans™) and soluble carbohydrates can help with rehydration. Glycerol/propylene glycol is a soluble carbohydrate mixture that will supply energy and increase water intake during the lairage period.

The efficacy of electrolyte treatment prior to slaughter

Several commercial electrolyte treatments have been tested under Australian conditions. The 'in-feed' supplement Nutricharge™ has received considerable attention after work in Canada demonstrated reduced liveweight and carcase weight loss, increased interstitial water space, and reduced incidence of dark cutting at slaughter. Experiments in Australia have shown that when the product (Nutricharge™ overnight pellets) is fed during extended lairage periods (i.e. 40 hours) the loss of muscle glycogen is reduced and dressing percentage is increased. Feeding Nutricharge™ market ready pellets 'on farm' also increased muscle glycogen concentration at slaughter, although this effect disappears after 20 hours lairage unless animals continue to be supplemented at the abattoir. It should be noted that the effects of the Nutricharge™ supplement were small and highly variable, the variability possibly the result of poor palatability of the product. A water-borne supplement (Glucotrans™) was also tested during lairage, and also produced a small increase in muscle glycogen concentrations at slaughter.

Guidelines for prevention

Recommended practice	Why?	How?
1. Stock should be moved as quietly and quickly as possible.	Gentle handling and quiet movement of livestock reduces stress.	Use skilled and competent stockmen with knowledge of natural animal movement (e.g. flight zone and point of balance). Animals should be inspected and assigned to lairage pens as soon as possible after arrival. Move animals as little as possible following penning, and if possible, pen them away from areas of activity and disturbance. Allow races to become half-empty before attempting to move cattle into them. They can be filled more easily and effectively utilising the animal's natural following behaviour. Make sure gates are open before attempting to drive the livestock. Closed gates will cause the animals to baulk. Air-operated gates should have mufflers to reduce noise. Fit rubber stoppers to gates.
2. Treat injured animals immediately.	In addition to this being an animal welfare issue, injured animals are more likely to become stressed leading to increased pH levels after slaughter.	Provide immediate veterinary inspection and, if required, arrange emergency slaughter.
3. Calm cattle can be more at risk of dark cutting than flighty cattle.	**Flighty cattle appear to deal with changes in environment better than calm cattle.**	**Treat calm cattle with greater care and do not use excessive force to move them.** **Do not mix flighty cattle with calm cattle as they can stir up the calm animals.**
4. Don't mix groups of unfamiliar livestock.	There is greater activity and fighting amongst groups of unfamiliar cattle. Also, cattle isolated from their mob can become highly distressed.	Maintain animals in their consignment groups.
5. Place valuable cattle in a quieter are of the lairage.	**A greater loss of value will be experienced if high-value cattle are dark cutters.**	**If processing a mixture of cattle, place cows or lower value animals next to high-traffic lanes. Locate MSA or high-value export cattle where they have minimal contact with humans and other cattle.**

6.	**Milk-fed vealers are susceptible to dark cutting**	**Separation form mother and a new environment are stressful.**	**Treat milk-fed vealers with extra care.**
7.	**Grass-fed cattle are more susceptible to dark cutting during late summer and autumn in southern Australia.**	**At the end of the green flush, the pasture contains reduced amounts of metabolisable energy leading to low glycogen levels in muscle.**	**Cattle handlers at the abattoir should be aware of the seasonable differences and handle stock with extra care during this period.**
8.	Water should be available at all times. Feed must be provided if stock are kept for longer than 24 hours.	Fasting and dehydration can lead to high pH meat, particularly in sucker lambs, and lower carcase weights in all classes of stock. Provision of feed leads to restoration of muscle glycogen levels and will also provide some comfort to hungry animals. (It should be noted that even under ideal conditions, it will take 2-3 days for muscle glycogen levels to be replenished.)	Provide good-quality hay for stock that are held for extended times (over 24 hours and weekends) or for stock that have been off-feed for 36 hours or more. Have clean, fresh water available to all stock in lairage.
9.	Feed electrolyte mixes during lairage prior to slaughter.	Helps to maintain muscle glycogen concentration prior to slaughter, and may increase carcase yield.	Supplement cattle with commercial electrolyte mix during lairage. These mixes are available in pelletised form or as a water supplement.
10.	Supplement glycerol and propylene glycol prior to slaughter.	Reduces muscle ultimate pH and markedly increases water intake during lairage.	Mix 3.5% glycerol and 1.5% propylene glycol in the drinking water of cattle in lairage.
11.	Yard design should consider comfort and welfare of animals.	Correct yard design can minimise stress and physical exertion as well as reduce bruising and fighting.	Locate the unloading area well away from pens to minimise disturbance as other cattle are unloaded. The recommended stocking density in lairage pens is at least 1.9 m^2/head (so cattle can all lie down at one time). Sheep require at least 0.6 m^2/head. Ensure yards are well drained and sheltered. Dry dirt floors are preferable if bogging is not a problem, otherwise use non-slip flooring.
12.	Make lairgae as restful as possible.	Lairage is beneficial as it allows animals to rehydrate and recover from transport.	Provide rest periods in lairage depending on the transport history of the animals, the abattoir and State/Territory requirements. It is recommended that at least some period of rest (4-6 hours) be allowed prior to slaughter.

			After long journeys (above 24 hours) animals will require rest of 18 hours or more.
13.	Eliminate all unnecessary procedure, such as live weighing, washing and hosing unless codes of practice necessitate their use.	Washing can expose the animal to further stress and may cause shivering in cold weather. Hosing can be highly stressful for cattle because of the noise and pressure.	Consider the cleanliness of the cattle and observe local regulators (and DAFF Biosecurity) whether washing is required and avoid where possible.
14.	Assembly yards, races and ramps should be well designed and managed in a manner that ensures a smooth flow of livestock.	Well-designed facilities can lead to calmer animals that can be moved more easily with less stress and physical activity.	Ramps and races should have solid outer fences to minimise distractions to the animals and should not contain obstructions such as internal posts. No objects should be hanging over the races. Use light to encourage animals to move forward (livestock will move willingly into a well-lit area from a dim area). Install non-slip flooring in laneways and forcing yards. Do not leave individual animals isolated in the races or lead-up ramps. Ramps to the stunner should not exceed 15° slope and should be curved to facilitate ease of cattle movement. Ensure the flooring of ramps and races has a non-slip surface. Grooved stair steps are recommended on concrete ramps since they are easier to walk on when concrete becomes worn. Provide a level surface at the top of the ramp prior to entry to the stunning box.
15.	Minimise use of electric prodders.	The use of jiggers and prodders can cause stress as well as increasing the risk of bruising.	Canvas or leather flappers, soft polythene pipes, rattlers or inflated plastic bag are recommended to aid stock movement. Electric prodders should only be used to move animals up to the knocking box and then only if the animal is baulking and has a clear path ahead.
16.	Do not leave livestock on ramps during breaks.	It can be stressful for an animal to remain isolated in the race for an extended period.	Clear all livestock from ramps before stopping for breaks and breakdowns.
17.	Only competent and trained operators with cattle handling	Incorrect stunning has animal welfare implications and can cause animal stress.	Train operators in correct stunning. Use an effective and well-maintained stunning device/system and ensure it is applied in an effective manner.

	skills should be used for stunning.		Follow the manufacturer's recommendations for cleaning and maintaining the stunner.
18.	The stunning box should be quiet in operation and have firm, non-slip flooring.	A slippery floor can make stunning difficult as the animal moves about in an attempt to maintain a secure footing. Noise will further unsettle animals.	Install non-slip floors. Install mufflers on air-operated gates and use rubber stoppers to reduce noise.
19.	Do not leave cattle isolated in the stunning box or restrainer during breaks or delay stunning when in the knocking box.	Cattle will become stressed and restless when isolated leading to the possibility of dark cutting and bruising.	Clear cattle from the stunning box and restrainer prior to breaks. Delay moving another animal into the knocking box until you are sure the rest of the chain is ready.
20.	Position lamps above the head of cattle in the box.	Cattle are attracted to light and hence may look up at any lighting.	Install even and diffuse lighting but ensure it is not glaring in their eyes.

Moving cattle easily: The flight zone

Cattle have wide-angled vision in excess of 300 degrees. They are surrounded by what is termed the 'flight zone'. Different animals will have different flight zones depending on tameness and how handlers approach them. To move cattle easily, handlers should work the edge of the circle. To make the animal move, penetrate the flight zone. To stop it moving, retreat from the flight zone.

The point of balance at the animal's shoulder should also be used in moving cattle. Approach an animal from behind the point of balance and it will be inclined to move forward. Approach it from the front and it will move backwards.

TEMPLE GRANDIN PCTURE

Remember

High ultimate pH has a detrimental effect on meat colour, texture, keeping quality and sometimes tenderness.

Stress and excessive physical activity will reduce glycogen levels and therefore increase the risk of dark cutting.

The following steps can help reduce stress in livestock at the abattoir leading up to slaughter:

- Handle livestock with care
- Keep animals in their familiar consignment groups
- Ensure livestock have access to water (and feed for extended lairage times)
- Use the animal's natural behaviour to move them
- Ensure good yard, pen and race design
- Use effective, well maintained stunning equipment and trained staff

Publications on dark-cutting

(1) Chrystall BB, Channon HA, Hofmeyr CD, Warner RD, Egan AF, Ferguson DM, et al. Meat quality: how well do we monitor and assure quality? Proceedings of Australian Society of Animal Production 1998;22:55-60.

(2) Cummins LJ, Knee BW, Butler KL, Warner RD, Walker PJ. Stocking pressure and seasonal influences on muscle glycogen levels in beef cattle. Asian Australasian Journal of Animal Sciences 2000;13 (Supplement):237.

(3) Dunshea FR, D'Souza DN, Pethick DW, Harper GS, Warner RD. Effects of dietary factors and other metabolic modifiers on quality and nutritional value of meat. Meat Science 2005 Sep;71:8-38.

(4) Eldridge GA, Warner RD, Winfield CG, Vowles WJ. Pre-slaughter management and marketing systems for cattle in relation to improving meat yield, meat quality and animal welfare. Melbourne, Australia: Department of Agriculture and Rural Affairs; 1989.

(5) Eldridge GA, Barnett JL, Warner RD, Vowles WJ, Winfield CG. The handling and transport of slaughter cattle in relation to improving efficiency, safety, meat quality and animal welfare. Melbourne, Australia: Department of Agriculture and Rural Affairs; 1986.

(6) Ferguson DM, Warner RD, Walker PJ, Knee B. Effect of cattle marketing method on beef quality and palatability. Australian Journal of Experimental Agriculture 2007 Jul 2;47:774-81.

(7) Ferguson DM, Warner RD. Have we underestimated the impact of pre-slaughter stress on meat quality in ruminants? Meat Science 2008 Sep;80:12-9.

(8) Ferguson DM, Warner RD. Pre-slaughter stress in ruminants and its relationship to meat quality. Symposium on Meat Science and Muscle Biology: Impact of pre- and post-slaughter handling on meat quality. Joint Animal Meeting of ADSA, PSA, AMPA, CSAS.Denver, Colorado: 2010.

(9) Knee BW, Cummins LJ, Walker PJ, Kearney GA, Warner RD. Reducing dark-cutting in pasture-fed beef steers by high-energy supplementation. Australian Journal of Experimental Agriculture 2007 Oct 18;47:1277-83.

(10) Knee BW, Cummins LJ, Walker PJ, Warner RD. Seasonal variation in muscle glycogen in beef steers. Australian Journal of Experimental Agriculture 2004 Sep 20;44:729-34.

(11) Pethick DW, Ferguson DM, Gardner GE, Hocquette JF, Thompson JM, Warner RD. Muscle metabolism in relation to genotypic and environmental influences on consumer defined quality of red meat. In: Hocquette JF, Gigli S, editors. Indicators of milk and beef quality. EAAP Publication No. 112. 1 ed. Wageningen, Netherlands: Academic Publishers; 2005. p. 95-110.

(12) Pethick DW, Ferguson DM, Gardner GE, Hocquette JF, Thompson JM, Warner RD. Muscle metabolism in relation to genotypic and environmental influences on consumer defined quality of red meat. WAGENINGEN: WAGENINGEN ACADEMIC PUBLISHERS; 2005.

(13) Shorthose WR. Dark-cutting in beef and sheep carcasses under the different environments of Australia. In: Fabiansson SU, Shorthose WR, Warner RD, editors. Dark-cutting in cattle and sheep. Proceedings of an Australian Workshop.Sydney, Australia: Australian Meat and Livestock Research and Development Corporation; 1988. p. 68-74.

(14) Stevenson CR, Knee B, Philpotts AC, Warner RD. Investigation into the occurence of dark cutting in beef carcasses. Proceedings of Australian Society of Animal Production 1996;21:147-50.

(15) Tarrant PV. Animal behaviour and environment in the dark-cutting condition in beef. In: Fabiansson SU, Shorthose WR, Warner RD, editors. Dark-cutting in cattle and sheep. Proceedings of an Australian Workshop.Sydney, Australia: Australian Meat and Livestock Research and Development Corporation; 1988. p. 8-18.

(16) Walker PJ, Warner RD, Weston PA, Kerr MG. Effect of washing cattle pre-slaughter on glycogen levels of M *semintendinosus* and *semimembranosus*. International Congress of Meat Science and Technology, 1999;45:298-9.

(17) Walker PJ, Warner RD. Pre-slaughter handling and management of cattle at Q-Meats Ipswich. Report to Brismeats Pty Ltd (QLD) follwoing review of pre-slaughter cattle handling procedures. Werribee, Victoria.: Victorian Institute of Animal Science; 1995.

(18) Walker PJ, Warner RD, Pethick DW, Gardner GE, Cummins LJ, Knee BW. Reducing dark-cutting in beef. Australian Association of Cattle Veterinarians Hamilton Conference Proceedings 1999;11-14 November:132-8.

(19) Walker PJ, Warner RD, Kerr MG, Payne AM, Weston PA, Knee BW. Saleyard marketing of cattle can reduce muscle glycogen content. Asian Australasian Journal of Animal Sciences 2000;13 (Supplement):179.

(20) Warner RD, Truscot TG, Eldridge GA, Franz PR. A Survey of the incidence of high pH beef meat in Victorian abattoirs. International Congress of Meat Science and Technology, Brisbane, Australia 1988;34:150-1.

(21) Warner RD, Ferguson DM, Cottrell JJ, Knee BW. Acute stress induced by the preslaughter use of electric prodders causes tougher beef meat. Australian Journal of Experimental Agriculture 2007 Jul 2;47:782-8.

(22) Warner RD, Walker PJ, Eldridge GA, Barnett JL. Effects of marketing procedure and liveweight change prior to slaughter on beef carcass and meat quality. Proceedings of Australian Society of Animal Production 1998 Aug;22:165-8.

(23) Warner RD, Greenwood PL, Pethick DW, Ferguson DM. Genetic and environmental effects on meat quality. Meat Science 2010;86 (1):171-83.

(24) Warner RD, Pethick DW. Reducing the incidence of dark-cutting beef carcasses in southern Australia. TR.001. Final Report. Sydney, Australia: Meat and Livestock Australia; 2000.

(25) Warner RD, Eldridge GA, Barnett JL, Halpin CG, Cahill DJ. The effects of fasting and cold stress on dark-cutting and bruising in cattle. Proceedings of Australian Society of Animal Production 1986;16:383-6.

(26) Warner RD, Greenwood PL, Ferguson DM. Understanding genetic and environmental effects for assurance of meat quality. In: Joo ST, editor. Control of Meat Quality.Kerala, India: Research Signposts; 2011.