final report

Project code: V.RMH.0110

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Date published: 30 August 2020

PUBLISHED BY
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Review of emerging (food industry) clean technologies for potential high value red meat opportunities

Meat & Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Executive summary

Clean label and free from trends have continued to evolve across the food industry as consumers continue to show a preference for more natural and less processed foods which contain no undesirable additives. This has created challenges for the food industry as they expand into new clean label product lines that are perceived as nutritious, wholesome and fresh, while also achieving desired shelf-life and maintaining quality. The meat industry is also facing increased competition from the growth in plant-based meats, which are perceived as being better for health and wellbeing and with a lower environmental footprint. In recent years, red meat and processed meats have been subjected to negative press, such as being classified as a carcinogenic risk to humans – specifically attributing this risk to additives such as nitrites. Hence, this study will review suitable food processing technologies that have potential in the development of clean label processed meats and in doing so, identify potential high value red meat opportunities for ready meals, chilled offal, deli style meats, cooked sausages and trail mixes containing jerky, nuts and dried fruits. This desk-based study included a design-led approach, reviewing scientific and commercial literature, previous MLA project reports, CSIRO's internal knowledge on novel technologies and CSIRO's ON Prime type learnings (an innovation and entrepreneurship program designed to fast-track research and technology into high impact outcomes) , to develop a value proposition for each product.

The findings from the study indicated that a combination of technologies and natural ingredients could be used to achieve clean label meat products as indicated:

1. Chilled ready meals - novel technologies such as high pressure thermal processing (HPTP) could negate the use of any additives in ready meals without impacting on quality and achieving extended shelf-life.
2. Chilled offal (liver) – high pressure processing (HPP) and very fast chilling (VFC) could be used to increase the chilled shelf-life of liver, creating opportunities in the chilled offal export market.
3. Cooked sausages – depending on the targeted ingredient/additive for removal, for example, nitrite or phosphate or reduced salt, a combination of natural ingredients and technologies like HPP and HPTP can be used to produce a cleaner label cooked sausage.
4. Deli style meats – these whole muscle, sliced meats could also be produced with a clean label, using natural ingredients and technologies (HPP and HPTP).
5. Trail mix snacks including jerky – ultrasound assisted drying techniques and natural ingredients could be used to produce clean label jerky products. HPTP could be used as a surface decontamination method eliminate *Salmonella* prior to drying.

The red meat industry needs to invest in scientific research to validate the opportunities identified in this study and further explore scale-up towards commercialisation. Hence, it is recommended that the red meat industry consider investment in the following areas, in collaboration with CSIRO:

- Commercialisation of the canister technology such that current HPP (cold units) could be modified to undertake HPTP.
- New product development using HPP and HPTP to understand the benefits of these technologies and to improve the functionality and safety of clean label meat products.

- Evaluation and validation of the natural nitrite replacers (e.g. Prosur Natpre T-10 and others) in cured red meat products to determine if 'nitrite free' processed meats could be produced without impacting on quality and safety (*Clostridium botulinum*).
- Investigate the suitability of ultrasound assisted drying technology for dried meats applications such as jerky.

The red meat industry is currently facing strong competition from plant-based meats and there is a perception that processed meats are unhealthy. Addressing these consumer concerns through the development of clean label value-added red meats, including ready meals, processed meats and meat snacks will reflect positively on the industry while meeting the needs of the consumer. This is also an opportunity for the industry to shift from trading meat as a commodity to value added meat products manufactured in Australia. The other benefits could be achieving a premium price through provenance claims, a more cohesive domestic supply chain, increased employment in the industry and maintaining labour and skills in Australia.

Table of contents

1. Background

1.1 Clean Label Foods

1.1.1 Definition and Interpretation

The definitions and interpretations of clean label food products are constantly evolving, and it can mean different things to different people. For example, a 'clean' ingredient list generally means packaged foods with a short ingredient list, made up of recognisable ingredients that are perceived as wholesome and sourced from nature, as opposed to a label that has ingredients with e-numbers and long/confusing/chemical sounding names that are unfamiliar to consumers. 'Clean label' can also include words such as natural, organic, free from artificial additives, GMO free, low salt, low sugar, ethically produced/sourced and sustainable.

For the purposes of this study, 'clean label' was defined as free from artificial additives. The focus of this review was on how novel processing technologies could be utilised to develop meat products with a clean ingredient declaration on the label which will create opportunities for the red meat industry.

1.1.2 Clean Label Trend in the Meat Industry

Clean label and free from trends have continued to evolve across the food industry. There is also a trend towards eating a more plant-based protein diet, in the form of meat substitutes. The global market for meat substitutes is expected to reach a total value of US$5.5 billion by 2021 (Technavio 2016). People are consuming these products because they believe that plant-based diets are better for their health and wellbeing as well as being more sustainable i.e. having a lower environmental footprint. In recent years, red meat has been subjected to negative press, such as when the World Health Organisation classified red meat as Group 2A (probably carcinogenic to humans) and processed meat as Group 1 (carcinogenic to humans) (WHO 2015). In the case of processed meats, additives such as nitrite were targeted. However, many of these additives serve important functions in processed meats such as preservation (including food safety assurance), emulsion stability, water-holding and improved eating quality. Consumer preference towards natural and less processed food has resulted in the growth of the clean label trend. Therefore, the meat industry needs to address these clean label issues in order to maintain their customer base and ensure the continued growth and viability of the industry. However, the clean label trend has created challenges for the industry as they expand into new clean label product lines that are perceived as nutritious, wholesome and fresh, while also achieving desired shelf-life, without the use of undesirable additives.

Novel processing technologies have been shown to reduce the requirement of salt and other additives in many foodstuffs. In this project, at least 5 technology solutions were reviewed against a matrix of at least 5 value added red meat products. Mechanical and physical disruptive technologies used in other food sectors to replace chemical additives to produce (and market) cleaner labelled products were explored and the technical feasibility of these technologies for application to the Australian red meat products were evaluated. At the beginning of the project, CSIRO and MLA mutually agreed to consider platforms such as Shockwave, High Pressure Processing (HPP), Pulsed Electric Field (PEF), Ultraviolet light (UV), and cold plasma for/against value propositions in product categories selected by MLA which were chilled offal, cold deli style meats, smoked sausages/frankfurters and products that combine red meat with other produce such as ready meals with rice and/or vegetables and trail mixes with jerky and nuts and dried fruits.

Using design-led thinking, case studies were developed to rank and understand different technologies in the context of the product/technology matrix. These case studies were used to identify products and services that the respective technology might unlock for the meat industry. In doing so, potential target markets and investment opportunities for the Australian red meat industry were identified, as well as potential research gaps in the clean label space for the red meat industry. The findings from this desk-top study will equip the industry with the knowledge required to identify a strategic portfolio of growth opportunities and future investments.

This report will add to the knowledge from MLA's other project on 'clean label trends' V.RMH.0107 and it is envisaged that the findings from the two reports could be combined as a pitch to the industry for a potential Meat Donor Company project with CSIRO as the service provider should there be sufficient commercial interest in the development of new products and/or process using one of the technologies described in this project.

2. Project objectives

- Overview of several clean technologies in selected red meat product applications and their value propositions. Includes identification of suitable food processing technologies in the clean label space to support the development of commercial strategy for partnerships to drive demand for red meat and identification R&D gaps.
- Final report summarising the key findings as well as all the information/data collected during the project.
- A short presentation (5-10 slides) on the key findings that can be used by MLA for industry engagement on strategies for developing clean label higher value red meat products.

3. Methodology

This project comprised a desk-based study of selected red meat product categories. In doing so, a current market status of the selected products is provided, including current ingredients declarations and challenges with removal of functional additives. With a view to innovating these products towards cleaner labels and healthier processed meats, we provide case studies for food processing technologies and clean label strategies that could be applicable to producing clean label red meat products that improve or maintain high food safety and high levels of quality, flavour and texture, with minimal or no additives. The selected products evaluated in this study were:

- Chilled offal (liver) for export markets;
- Chilled ready-to-eat meals (with meat, sauce, vegetables and pasta/rice);
- Smoked/steamed/cooked sausages;
- Trail mix snacks, such as beef jerky (with nuts/seeds/dried fruit);
- Roast beef (cold and hot), cold sliced and shaved deli meats.

This review focused on novel technologies and already available solutions for clean label processing applicable to the red meat industry. These technologies and solutions are highlighted through case studies, under the principles of the value proposition canvas, i.e. what product and service that the technology might be able to unlock which addresses customers (i.e. the red meat industry) jobs, pains and gains. This approach may unveil benefits that might not have been considered using the traditional method for evaluating a novel technology, which is generally not from a customer perspective.

CSIRO’s market analysis team were engaged to review the ’clean technologies’ space which included leveraging CSIRO’s relationship with Euromonitor Scientific literature, in the form of journal papers accessed using CSIRO’s databases to support the recommendations for technology and solutions, for the selected products. Reports from previous projects funded by MLA in this space were also accessed to provide background and market information. The internet was also searched extensively to obtain ingredients and technology information for the selected products. ON Prime type approach which is an innovation and entrepreneurship program designed to fast-track research and technology into high impact outcomes, design-led thinking and the value proposition canvas were utilised to rank and review different food processing technologies and identify market opportunities for clean label meat products throughout the red meat value chain, i.e., technologies to produce clean label processed products that meet the needs of discerning consumers of today.

The initial phase of the project included market analysis of the various processing technologies that have been utilised by the food industry to minimise or eliminate the use of ’undesirable’ ingredients in order to produce clean label foods e.g. cold pasteurisation of fruit juices using high pressure processing (HPP). These technologies were collated, as shown in Figure 1, and studied utilising ON Prime approaches, which included developing a value proposition. In this context, each of the five products selected for this study were assessed to identify product and services the technology might unlock for the meat industry. Subsequently, a product and technology matrix was developed to determine the suitability and relevance of the five technology solutions to the five selected products. Based on this, the ingredients (where relevant) and technology solutions were investigated in detail to identify potential research gaps and investable opportunity in the clean label space for the

Australian red meat industry. This was to the industry with the knowledge required to identify a strategic portfolio of growth opportunities and future investments.

Technology solution	Products
Shockwave	Chilled meals
HPP	Chilled offal (liver)
PEF	Cooked sausages
UV	Roast beef and deli meats
Cold plasma	Trail mix – beef jerky

Figure 1: Selected technology solutions and products for assessment in this project

4. Results

4.1 Chilled ready meals and components

4.1.1 Product and Market information

The Australian market for ready meals is emerging and has the potential to grow significantly, especially when compared to the more diverse range of similar products in countries like the United Kingdom (Wunsch 2020). The current ready meals market in Australia is worth $900M annually (Parry 2016). According to Mintel estimates (Food and Beverage news 2020), the Australian prepared meals market grew 4.6% CAGR (compound annual growth rate) in 2014-18 but is expected to slow down to 3.5% over 2019-23. Chilled prepared meals contributed 31% of the market value in 2018. Consumer demand for convenient meals with fresh-like characteristics is now out-growing demand for frozen meals (Wunsch 2020). In response, beef processors are innovating towards value-add opportunities which position them closer to the demands of the consumer in the supply chain. Teys recently launched a ready meals range for Woolworths under the 'Simply Heat' brand. The range includes full meal options such as Beef Ragu (8-hour slow cooked beef with carrots and potatoes in a sauce) or ready-to-heat meats such as Butterflied Beef in gravy and sticky BBQ ribs. In response to consumer demand for convenience and healthy meals, brands like My Muscle Chef and YouFoodz are offering convenient ready meal delivery service. The meat component is often slow cooked to ensure consistent tenderness. In addition, due to the multiple food components (sauces, vegetables, rice, potatoes), the ingredient declarations often appear lengthy, which is unfavourable from a clean-label perspective. Although many 'fresh-like' and clean label options are available, some other products contain additives.

The current approach to ensure the quality, microbiological safety and stability of these products is to use food additives and thermal processing (Table 1). Food additives are added to processed foods for a specified techno-functional purpose e.g. colour (e150), flavour enhancer (e635), antioxidant (e330), thickeners (e466), emulsifier (e451), acidity regulator (e500) and gums (e415). Ready meals are typically low-acid foods (i.e. pH >5.0) and support the growth of a broad range of vegetative and spore-forming microorganisms. The control of these microorganisms is primarily achieved using thermal processing, the degree (or thermal lethality) of which will result in varying degrees of microbial inactivation, and therefore, shelf-life (Table 1). However, as process thermal lethality increases, so too does the negative impact on favourable product attributes like taste, colour, texture and nutrients. Preservatives may also be required to assist with shelf-life extension (e.g. nisin), however, such preservative use is inconsistent with consumer preferences and manufacture's desire to have a clean label.

Chilled ready meals and components are routinely processed in accordance with Process 1 and 2 in Table 1 and seldom rely on preservatives as a sole hurdle for controlling pathogenic and spoilage microorganisms; i.e. the thermal process is the critical control point. Process 3 is not relevant for chilled foods but is adopted for producing shelf-stable ready meals.

Currently, preservative free and minimally processed (i.e. 70°C/2 min for *Listeria monocytogenes* control), chilled ready meals should carry a maximum safe shelf-life of 10 days. Shelf-life greater than 10 days can only be safely assured with thermal processing and/or preservatives that provide adequate control for non-proteolytic *C. botulinum* (Cox and Bauler, 2008). Supermarkets have traditionally preferred extended shelf-life products (~30-40 d) given Australia's extensive distribution networks, however, consumers are becoming more conscious (suspicious) of perceived, unnaturally long shelf-life, particularly where preservatives have been added, and supermarkets are therefore adjusting their expectations on shelf-life to be more aligned with these consumer expectations ('Meals by Design' ON Program interview data).

Table 1: Thermal processing categories for low-acid foods (i.e. pH >5.0), including target microbiological hazards and safe shelf-life conditions (Cox and Bauler, 2008., CSIRO, 2010.)

Process type	**Process**	**Packaging method**	**Shelf-life duration at specified temperature**	**Process target microbiological hazard**	**Estimated reduction ($\log_{10}$ cfu/g)**	**Post-process contamination risk?^**
1	**Pasteurisation** **70°C for 2 min or equivalent**	Sous-vide; processed in-pack, under vacuum	≤10 d at ≤5°C (>10 d at <3°C)[#]	*L. monocytogenes*	6	Unlikely
		Hot filled (≥85°C)	≤10 d at ≤5°C	*L. monocytogenes*	6	Yes
		Processed in-pack	≤10 d at ≤5°C	*L. monocytogenes*	6	Unlikely
2	**Pasteurisation** **90°C for 10 min or equivalent**	Hot-filled (≥85°C)	≤10 d at ≤5°C (>10 d at <3°C)[#]	Non-proteolytic *C. botulinum* spores	6	Yes
		Processed in-pack	>10 d at ≤5°C	Non-proteolytic *C. botulinum* spores	6	Unlikely
3	**Sterilisation** **121°C for 2.8 min or equivalent**	Processed in-pack / hermetic seal / canning	>1 y at ambient	Proteolytic *C. botulinum* spores	12	Unlikely

^ Where product is not processed in-pack, there is an increased risk of post-process contamination during the filling process, including re-introduction of the hazard the thermal process was targeting. Therefore, consideration needs to be taken regarding the likelihood of this occurring

4.1.2 Clean Technology Solutions

The two clean technology solutions for ready meals are:

1. High pressure thermal processing (HPTP)
2. Microwave (MW)

4.1.2.1 High pressure thermal processing (HPTP)

Although conventional high-pressure processing (HPP) has been successfully implemented as an alternative to heat-based technologies, it is still limited in its ability to safely preserve all foods;

specifically, it cannot be used to extend the safe shelf-life of low-acid chilled products because HPP cannot inactivate bacterial spores. This becomes problematic for growing product categories like ready to eat/heat meals and meal components where shelf-life extension (beyond 10 days) is critical for national and export markets. HPP is therefore not discussed in reference to RTE meals.

Hybrid high pressure thermal processing combines the benefits of pressure with milder thermal processing to bridge this gap and deliver products with fresh-like attributes, extended shelf-life, and a reduced requirement for chemical preservatives and harsh thermal processing. During processing, high pressure (~600 MPa) and heat (~80-125°C) can be simultaneously applied to inactivate pathogens, cook/modify the product and increase shelf-life.

HPTP can be used for a variety of applications, including for the preservation and shelf-life extension of foods and beverages, but also for modulating the texture of foods, including the tenderisation of low-value meat cuts and the toughening of oily fish. The benefits of HPTP for ready meals, from quality and shelf-life perspective are summarised in Table 2.

CSIRO have previously developed concept products with MLA and using recipes from CSIRO's Total Wellbeing Diet program.

Table 2: Potential benefits of HPTP for chilled ready meals compared to a thermally processed product

Characteristic	Function of HPTP	Potential benefit
Flavour	HPTP affects molecules responsible for flavour less than heat, thus preserving natural flavour	Reduced requirement for salt and flavour enhancers
Colour	HPTP affects colour molecules less than heat, thus preserving natural colour	Reduced requirement for artificial colourings
Shelf-life and food safety outcomes	Inactivation of pathogenic and spoilage spore-formers achieved with a reduced thermal load	Extended shelf-life with improved 'fresh-like' characteristics
Meat tenderness	High pressure, when combined with moderate-high temperature, can lead to rapid tenderisation of meat	Accelerated processing, ability to tenderise low-value cuts
Nutrients	HPTP affect vitamins and minerals less than heat	Increased nutritional value

Current status of HPTP technology

While there are a handful of pilot-scale HPTP systems around the world (one of which is located at CSIRO Werribee), to date, no commercial scale system capable of delivering a HPTP process is available. Indications from HPP equipment manufacturers are that they do not intend to build such a HPTP machine in the foreseeable future. If demand would increase for the technology, this could change, but costs of a HPTP system would most likely be prohibitive.

In the absence of any commercial scale solutions, CSIRO has developed a processing canister (patent granted in Australia and Europe, pending in other jurisdictions) enabling the use of existing, cold HPP systems for HPTP. This 'drop-in' innovation will transform HPP from a technology with limited applications, to one that will unlock new and exciting market opportunities in food processing with massive appeal and growth potential.

The canister has been validated at pilot-scale, and validation at commercial scale is being undertaken at the largest HPP equipment manufacturer, Hiperbaric (Spain). Further collaborative and commercial activities are being explored, including concept development for an automated handling and pre-heating system for process integration in established HPP lines.

Challenges

Developments necessary to enable commercial adoption of HPTP include engineering developments to make available commercial-scale HPTP systems (as above), including temperature monitoring during processing and handling systems, as well as a need for translation of fundamental research regarding spore inactivation into tangible information that underpins the development of safe commercial-scale processes. An additional hurdle to the commercial application of HPTP has been the identification of suitable packaging materials that not only withstand the process itself but provide suitable barrier properties throughout the shelf-life of the product.

4.1.2.2 Microwave (MW)

Microwave processing is an alternative, rapid method for the thermal processing of pre-packaged food and beverages and heats food by direct or volumetric heating, rather than by typical conductive/convective methods. Microwaves are electromagnetic waves (measured in frequency, Hz) that, when passed through a material, cause polar and ionic molecules to rotate, resulting in friction and the subsequent generation of heat. This volumetric heating rapidly generates heat within the product itself as opposed to conductive heating approaches where the heat slowly permeates through food from the outside, in. This rapid heating is exploited to deliver standard pasteurisation and sterilisation thermal processes with less overall exposure to heat (i.e. lower thermal load) and therefore results in better quality product. Unlike HPTP, which is also a rapid heating method, there is no synergistic effect of MW heat on the inactivation of microorganisms, and as such, normal thermal processing principles apply when determining the processing parameters required to achieve food safety objectives.

The primary benefit of MW heating is the rapid and efficient heating it affords, with claims that processing time and thermal load can be reduced by between 25-90% compared to conventional heating approaches (e.g. retorting), also reducing energy use by ~70% given that most of the energy required is dissipated directly into the product.

Current status of MW technology

Microwave processing has been successfully commercialised at industrial scale for the purposes of processing food, and ready-to-eat meals. For industrial food processing MW application, the typical operating frequency of machines is ~2450 or 915 MHz, the latter of which has a greater wavelength and can therefore penetrate deeper into materials. There are several MW system manufacturers, and the design of the system will dictate its processing scope. For example (Fig. 2), the Micvac MW system can only pasteurise product (chill-stable foods), while the 915 Labs MATS (microwave assisted thermal sterilisation) system is capable of maintaining moderate pressurisation within the MW processing chamber, meaning higher temperatures can be reached and maintained, facilitating sterilisation (shelf-stable foods).

In Australia, there are known to have been two industrial microwave systems in operation, both for the purposes of manufacturing pasteurised, chilled meals (one of which is a Micvac system). More recently, the Australian government invested in the purchase of an R&D or pilot-scale MATS B system from 915 Labs that facilitates the manufacture of sterilised foods; this unit is located at the Department of Defence Food and Nutrition Centre in Scottsdale, Tasmania.

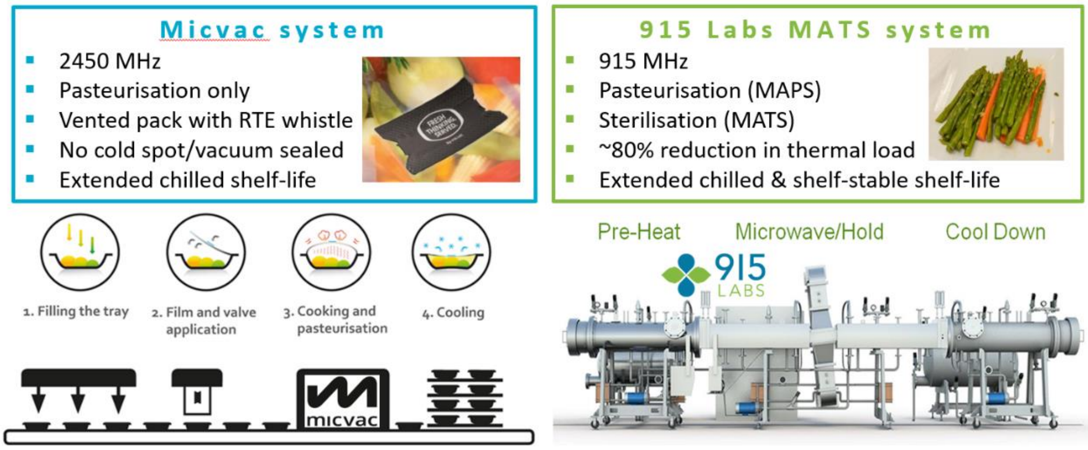

Figure 2: Examples of industrial microwave systems

Challenges

The primary challenge with MW processing is related to the non-uniform heating that occurs as a result of the complex interaction of the electromagnetic waves with multi-component/multi-property foods. Whilst rapid heating is enabled by the direct interaction of MWs with the ionic and polar compounds in foods, in a multi-component food there is also a great variability in dielectric, and other thermophysical properties (e.g., thermal conductivity, specific heat capacity, density etc), and therefore, the products will heat at different rates across that product leading to non-uniform heating patterns. The product packaging can also play an important role in this, where packaging can be designed such to optimise or offset some of these challenges. Because of the variability in response of different foods and packaging designs to MW, each processing run must be carefully mapped to understand the distribution of heat throughout a process so that the slowest heating point can be identified and monitored during a process for food safety/HACCP purposes.

4.1.3 Value Proposition

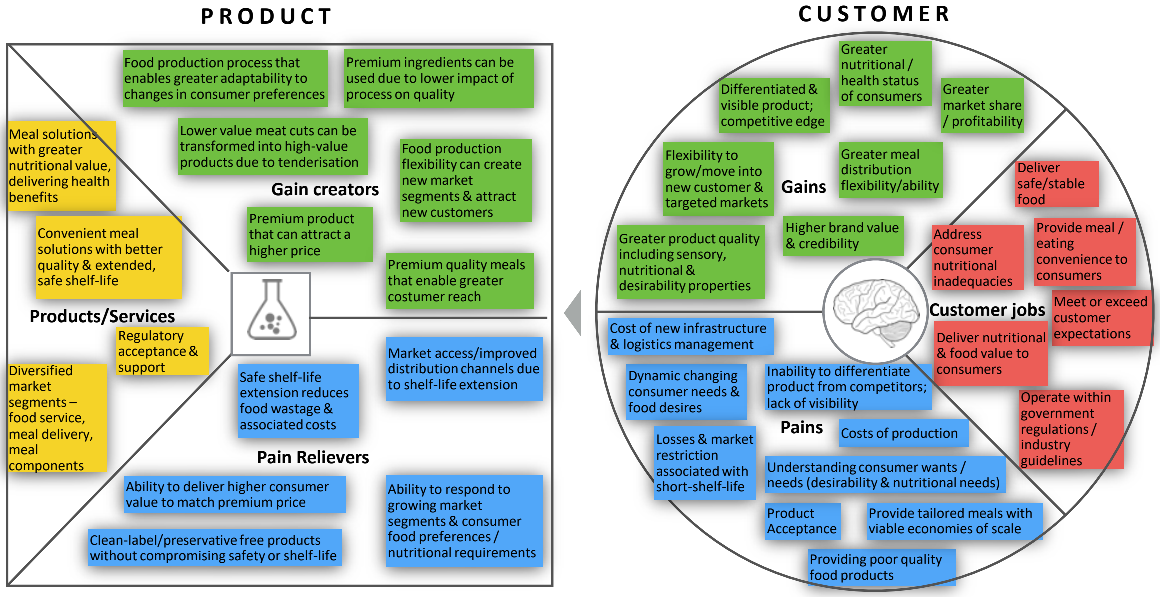

Figure 3: Value proposition canvas for the application of emerging technologies in the manufacture of cleaner labelled ready meals (product) in the red meat industry (customer)

4.2 Chilled offal (liver) for export markets

4.2.1 Product and Market information

The production of edible offals from beef carcasses represents a valuable source of income for the meat industry. About 45% of the live weight of an animal is handled as co-products (edible offal, rendering and pet food) (MLA 2009). A large percentage of Australia's offal is exported around the world, with Indonesia, South Korea, Japan and Hong Kong comprising the top overseas markets for beef offal, and Hong Kong and Saudi Arabia being the highest markets for sheep offal, by volume (MLA Australian offal exports April 2020). In the last year (2019), 94% of beef offal products were exported frozen. The biggest chilled categories were for skirt and tongue products. Although liver consists of approximately 16% of the total beef offal products exported, less than 1% (0.9%) is packaged as a chilled product, mainly to countries of the Arabian Peninsula (Dubai, Abu Dhabi and Qatar). The largest markets for frozen liver products were Egypt, South Africa, Indonesia and Kuwait. Some of these countries, for example, Egypt, may have technical restrictions preventing chilled product.

Apart from seasonal demand, prices paid for offal depends on market access and packaging style (Spooncer 2012). Premium pricing is available for chilled offals but only a small percentage of exported offal is in chilled form. MLA collects co-product price information via monthly surveys, and these are end-market specific prices. In the latest report (MLA Co-product market report May 2020), liver prices averaged $1.20/kg.

While meat companies appreciate the value of investing in offal recovery, the systems for ensuring the appropriate quality expected by customers, are generally not as well developed as they are for boneless meat. It is generally considered that offals are necessarily of poor hygienic quality, prone to rapid spoilage and with a high incidence of pathogenic organisms. Hence, offals have a shorter shelf-life than fresh meat, and when cooking preferences are considered, offals may also present an increased food safety risk. This poor microbial shelf-life can arise from two sources: (1) a high initial bacterial load; and (2) the temperature history of the products during the 24 hours after evisceration. The nature of the spoilage microflora is affected by offal composition and storage conditions. Non-muscle tissues, such as liver, are also degraded by autolytic activities. Control of microbial spoilage alone might be insufficient to preserve offals in an acceptable condition during extended periods of chilled storage.

Freezing of edible offals extends shelf-life but this commands a lower price on the market than fresh offals. The freezing of offal impairs the offal structure and releases exudates which negatively affect the visual aspect and quality of the product after thawing. Vacuum packaging can be used as a means of extending offal shelf-life, to be able to market the products as fresh, rather than frozen, but results in only a moderate increase in shelf-life. Several non-thermal processing methods for food preservation have been investigated as alternatives to conventional thermal methods; for example, irradiation and HPP, with the potential of being applicable for edible offal products.

Currently offals are often packed and chilled in bulk to minimise cost. The chilling rates vary, depending on whether a pre-cooling step is included, the dimensions of the cartons, and the type of cooling system used. Liver receives minimum preparation (e.g. treatment or trimming) prior to packing.

All edible offal must comply with chilling criteria (refrigeration index guidelines: IIR 2006, IIR 2000), and liver and heart are pre-cooled in water or ice to achieve this. The general view is that offals should be cooled to 7 °C within about 7 h of slaughter and stored at less than 5 °C for food safety reasons (Barnes 1996). Vacuum packed chilled offal is also pre-chilled to improve presentation.

Offals exported frozen (-18°C) have a shelf life of around 12 months, whereas the storage life of vacuum packed offals at 0°C is 3–4 weeks (Meat Technology Update 2002).

Therefore, the development of a clean process that can extend the shelf life of chilled offal products via the reduction of initial microbial loads, will enable the Australian meat industry to retain current volumes in higher-end markets, as well as tap into more opportunities and markets by the expansion of the product range. Although edible offals will be considered in general, this study will focus on chilled liver for export markets.

4.2.2 Clean Technology Solutions

The two clean technology solutions for offals (liver) are:

1. High pressure processing (HPP)
2. Very fast chilling (VFC)

4.2.2.1 High pressure processing

High pressure processing (HPP) is a well-established non-thermal technology used for the extension of shelf-life of many chilled food products. HPP effectively inactivates the vegetative cells of microorganisms without the use of heat or preservatives and involves pressures of up to 600 MPa at ambient temperature for a few minutes. Pressures lower than 400-500 MPa are generally unsuitable for the inactivation of microorganisms and would certainly be limited in their ability to achieve food safety objectives that require a 5-6 log_{10} reduction in vegetative pathogens. Because HPP does not eliminate all microorganisms in food, products still require chilled storage to manage the growth of surviving microorganisms (typically spoilage microorganisms) and increase shelf-life.

The primary benefit of HPP is the fact that high pressure does not affect covalent bonds, therefore, the small molecules in food that are responsible for colour, taste and nutritive content are generally unaffected by HPP, which is in contrast to thermal processing which damages these molecules.

Current status of HPP technology

HPP has been in commercial use in Australia for 15 years, with approximately 15 industrial-sized units situated across the eastern states. HPP is primarily used for the manufacture of chilled fruit juices or other, acidified products (i.e. pH <4.5), because these products do not require a control for microbial spores. Low-acid products produced using HPP with a chilled shelf-life greater than 10 days have either added preservatives or some other control for non-proteolytic *Clostridium botulinum*.

Challenges

The obvious challenge for extending shelf-life of offal products such as fresh liver, is the effect of HPP on other quality aspects, especially colour. High pressure unfolds proteins which can lead to a cooked appearance in animal proteins. This makes it challenging to market these products as raw. Therefore, an initial step would be to investigate the optimum conditions for microbial kill whilst maintaining quality/raw appearance and whether the targeted micro-organisms are inactivated. In addition to microbiological deterioration, autolytic activities will proceed rapidly at warm temperatures in biochemically highly active tissues such as liver. Autolysis can lead to loss of texture and the development of progressively stronger liver-like and bitter flavours. Therefore, the effects of HPP on the inactivation of these enzymes will need to be ascertained.

4.2.2.2 Very fast chilling

The biggest challenge in the current processing of edible offal is to reduce the initial temperature of the product (37 °C) to around 1 °C in the most clean, efficient, time-sensitive and cost-effective manner. This is particularly important for liver, being the largest (weight/volume) of the edible offals. Very fast chilling (VFC) involves reducing muscle temperature to -1.5 °C within 5 h of slaughter. Under this regime, the chilling process is completed before rigor commences (pH 6). In a metabolic sense, offals such as heart, skirt and tongue could be expected to respond to VFC in a similar way to skeletal muscle. This would include a fast rate of pH decline, prevention of cold shortening, similar or higher ultimate pH, improved protein functionality, and improved yield. For liver, the effect of pre-slaughter management, particularly the length of the fasting period, is well known and has greater effects on yield (weight) and glycogen concentration than for muscle. Pre-slaughter management might need consideration if quality and yield is to be optimised for liver using either VFC or conventional chilling. Several offals, such as heart, liver and tongue, are removed as discrete organs and generally become available for processing within an hour of slaughter. This should mean that VFC regimes are more easily achieved with offal than skeletal muscle.

Chilling faster and storing at lower temperatures than done currently by using VFC could improve shelf-life of chilled offals by reducing microbial activity and changing post-mortem metabolism.

Current status of VFC technology

Research has shown that several advantages exist with VFC of muscle, such as prevention of cold shortening, accelerated tenderisation, improved yield, facilitation of hot boning and reduced chilling space. Despite these favourable findings, VFC has been used in only one commercial application to date, which is to produce high ultimate pH meat for sausage making (Beak and Johnston). This process improves colour, flavour, texture and water holding capacity of sausages.

Challenges

The optimisation of the rate of VFC to achieve appropriate temperature profiles and to balance 'freezing' and quality would need to be considered. This would include the process of chilling (e.g. mode and format), as well as the elucidation of the effect of VFC on liver metabolism, and hence eating quality of fresh liver. Consistent early chilling of the product is essential, and the effect of VFC on microbial loads, also plays a role in the final quality and storage life of the product.

4.2.3 Value proposition canvas

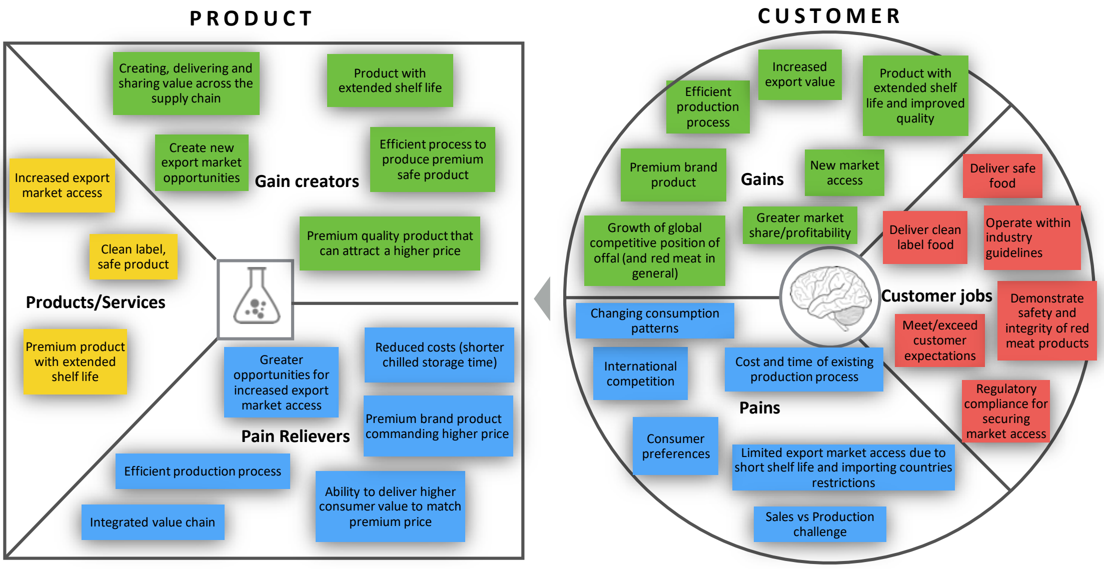

Figure 4: Value proposition canvas for the application of emerging technologies in increasing the shelf-life of chilled offal (product) for the red meat industry (customer)

4.3 Smoked/steamed/cooked sausages (Hot dogs)

4.3.1 Product and Market information

Hot dogs, also known as frankfurters, wieners and cooked sausages, are a popular processed meat product in Australia. They are typically composed of minced/comminuted meat mixed with salt, preservatives and seasonings and enclosed in a casing. Traditional sausage making involves filling the emulsion (batter) into sheep or pig casings (small intestines) with a diameter of 22-24 mm (Feiner 2008). However, it is now more common for sausage emulsion to be filled into edible (e.g. collagen) and inedible (e.g. plastic, cellulose) casings. The key difference between raw and cooked sausages is that sulphite is used as a preservative in raw sausages to achieve a shelf-life of up to 18 days, whereas in cooked sausages, nitrite is used as a preservative which can achieve a shelf-life of up to 43 days when vacuum packed and stored chilled at 2 °C (Battistella et al. 2011). There are many varieties of cooked sausages, differing in protein source (beef, pork, lamb etc.), diameter, casing, herbs and spices. Some cooked sausages, like hot dogs, are also smoked. Smoking involves cooking the product in a smoke-filled chamber, which imparts flavour and extends shelf-life through the presence of anti-microbial organic compounds and dehydration (Škaljac et al. 2014). Other key characteristics of hot dogs are the salt and fat content, with the Australian Food Composition Database showing a cooked frankfurter typically contains 19.9 g/100 g fat and 770 mg/kg of sodium (FSANZ 2020).

It is also common that the ingredient declaration for cooked sausages, like hot dogs, is long (>10 ingredients) and contains e-number additives. Although additives serve important techno-functional purposes, such as safety and quality, they are unfamiliar to consumers and therefore, do not fit with the clean label trend. Along with long ingredient declarations, the preservatives found in hot dogs are often controversial. For example, nitrite which is used to preserve hot dogs is commonly associated with carcinogenic molecules, nitrosamines. There are also challenges associated with nitrite removal due to its multiple functions in the formulation. Firstly, it is an antimicrobial that is effective against spore-forming bacteria, notably *Clostridium botulinum*, which is the key safety target for control in these types of products. Furthermore, as it dissociates, the nitrosyl cation (NO^+) binds to myoglobin to create nitrosyl-myoglobin, the molecule responsible for the characteristic pink colour of cured meats. In addition, by reducing carbonyl groups, nitrite acts as an indirect antioxidant while also creating a unique cured meat flavour. Due to its multi-functional purpose (preservation, colour, flavour and antioxidant), nitrite is not easily replaced in meat products, however the desire for its removal remains topical. Coupled with this, hot dogs which are smoked are also at risk of containing polyaromatic hydrocarbons (PAHs); compounds which can be harmful to human health in certain circumstances. In fact, the World Health Organisation, declared that processed meats were in the same risk category as tobacco and asbestos (WHO 2015). This classification was based on many studies which resulted in a recommendation that eating just 50 g of processed meat per day increased the risk of colorectal cancer by 18%. This was attributed to heterocyclic molecules in processed meats, including n-nitroso- compounds and PAHs.

Although not as controversial as nitrite and by-products of the smoking process (PAH), there are other e-number additives commonly found in hot dogs which do not fit the clean label trend. They vary by brand but some of the most common can be found in Table 3.

Table 3: Techno-functional additives in Australian retail sausages where novel technologies could have a role

Type of sausage	**Additive (e-number)**	**Techno-function**
Cooked sausage (Hot dog)	Nitrite (e250)	Preservation- Stops spore forming bacteria i.e. *Clostridium botulinum.* Acts as an indirect antioxidant and forms cured colour and flavour by binding to myoglobin.
Fresh uncooked sausage and cooked sausage (hot dog)	Triphosphate (e451)	Acidity regulator/emulsifier- works in synergy with salt leading to protein solubilisation, water entrapment and emulsion stability. Also gives a springy texture and juiciness.
Fresh uncooked sausage and cooked sausage (hot dog)	Sodium erythorbate (e316), sodium citrate (e331), sodium ascorbate (e301)	Antioxidant – stops rancidity and discolouration

Cooked sausages, such as hot dogs could offer a key opportunity for growth for meat processors as they have a long shelf-life meaning that export markets could be reached. A 2017 overview of the hot dog market estimated that the market would return a revenue of more than US$81 billion by 2021, as hot dogs appeal to millennials who want convenience and cost-effectiveness (Technavio 2017). They also present a key export opportunity to Asia, with a 2016 study finding that more innovation is needed to develop packaged ready-to-eat sausages in order to compete with the USA and UK (Coriolis 2016). Nonetheless, it was stated that growing health-consciousness would drive innovation towards healthier hot dog varieties. For example, an Australian brand, Cleavers, launched an organic clean-label hot dog claiming to have 'no synthetic chemicals, no added hormones, no GMOs and no antibiotics' (Cleavers 2017).

4.3.2 Clean Technology Solutions

The three clean technology solutions for cooked sausages are:

1. Ingredients - through reformulation to reduce salt, phosphate, nitrite, fat and PAHs
2. Process and packaging modifications
3. HPP and HPTP technologies

4.3.2.1 Ingredients

Ingredient innovations to replace nitrite with natural alternatives is complex and dependant on the legislation in a country. This is because there are many natural sources of nitrate, a precursor to nitrite which can be converted to nitrite by a bacterial culture. Often sodium nitrate is added to cured meat products that require longer curing time, e.g. Wiltshire cured ham, where a bacterial culture in the cure solution will convert nitrate to nitrite so that a desired shelf-life is achieved while factoring in long immersion curing times. However, this process can also take place in the human body. For example, beetroot, celery and spinach are some of the vegetables which are naturally high in nitrate and it is estimated that every 100 mg of nitrate ingested is converted to 20 ppm of nitrite, by bacteria on the tongue (Bedale et al. 2016; Spiegelhalder et al. 1976). When ingested, it dissociates into nitric oxide which is used in many physiological processes such mitochondrial respiration, estrogen receptors and blood flow of cardiac muscles (Alahakoon et al. 2015). It is estimated that only 5% of ingested nitrate and nitrite is from processed meats (Milkowski 2011). Despite this, the trend for its removal from meats has led to the development of commercial pre-cultured versions of natural sources of nitrate. Most commonly used for curing meat is cultured celery due to its mild flavour and colour contribution, however it too, is becoming unfavourable from a clean-label perspective due to its allergenicity. Its use is dependent on the legislation of a country. In the US, the USDA denote that any product containing sodium nitrite has a label stating 'cured'. Therefore, in a marketing advantage, products containing cultured celery (a natural source of nitrite), are labelled as 'uncured'. Consumers seeking nitrite-free meats often select these products without realising they contain the same chemical. In other countries, legislation differs. For example, in Europe, the EU Commission state that any ingredient used for a technological purpose (e.g. preservation) must appear on the additive directive (Regulation (EU) No. 1333/2008) and therefore, vegetable extracts do not fit with this and are currently not permitted (FSAI 2019). A Spanish company, Prosur, have developed a fruit and spice extract alternative to nitrites, namely, Natpre T-10, (ProsurInc. 2018), and while robust validation studies that are product and process specific are still required, this could offer a nitrite-free solution for hot dogs. Investigations by CSIRO of a similar Prosur product, T4-N (which are commercial-in-confidence), suggest these plant extracts are effective in preventing the outgrowth of non-proteolytic *C. botulinum* under certain conditions. There have also been studies which suggest the use of fruit, juice, spices, herbs and tea could assist towards reducing PAH development during smoking (Iko Afé et al. 2020). Other ingredient strategies for PAH reduction, discussed in the review by Iko Afé et al. (2020) include marination in beer, tea, red wine pomace and potato juice.

There has also been research into the reduction of salt and phosphates in cooked sausages to make them healthier and fit with the clean label trend. Phosphates (e50-452) are commonly added to meat products in quantities up to 5000 mg/kg. Phosphorous pentoxide (P_2O_5) dissociates the actomyosin complex and thus works in synergy with salt to improve water-binding, juiciness and yield. It also acts as an indirect antioxidant and is slightly bacteriostatic. Due to its unique mechanism, no alternative with the same functionality exists. Studies have been conducted to replace phosphates with fibres, starches and proteins but this often results in a loss of quality, as these ingredients can bind water but will not dissociate actomyosin. Therefore, it is challenging to achieve good distribution in the meat, leading to poor visual appeal and mouthfeel.

Comprehensive reviews on ingredient strategies to remove nitrite (Alahakoon et al. 2015), phosphates (Thangavelu et al. 2019) and PAH formation (Iko Afé et al. 2020) in processed meats have been published. For nitrite and phosphate, the reviewers conclude that no natural ingredient can act as an alternative to these compounds in meats but rather a hurdle approach could provide a solution, where natural ingredients when combined with novel technologies (such as high pressure processing) can achieve desired product quality and shelf-life. Likewise, it is likely that a combination of measures including ingredients (marination), process steps (pre-heating, filtering, fat collection, product washing) and packaging could lead to PAH reduction (Iko Afé et al. 2020) and these are discussed further in the following sections.

Challenges

In terms of replacing artificial additives with clean label ingredients, the challenges are cost, potential losses in quality, reputational risk and regulations in target destination market, as legislative restrictions apply in some countries. It is common for clean-label ingredients with specific techno-function to cost significantly more than the artificial alternative. For economy style products like hot-dogs, which must meet a price point to remain competitive, reformulation towards clean label is often cost prohibitive. In addition, the clean label alternative, does not always match the techno-functionality of the additive. For preservatives, validation studies are required, both from a consumer safety and reputational risk perspective, which are often costly. Furthermore, as clean-label ingredients often do not match the techno-functionality of clean label alternatives (e.g. clean label alternatives to phosphates which may not distribute evenly in meat leading to poor appearance and reduced yield), costly R&D is required to optimise quality. Finally, clean-label alternatives are not always permitted in target markets. In Ireland, for example, ingredients with a technological function must appear on the EU additive direction, as explained in the previous section.

4.3.2.2 Process modifications

There are several measures that could be taken to reduce the formation of nitrosamines and PAHs but these are mostly during consumer preparation stage. Given that these occur post purchase, these interventions are beyond this report's scope but are included to create some awareness for the reader. For example, studies have shown that boiling (lower heat) or microwave (indirect heat) produces fewer n-nitroso-compounds than direct heat application by deep-frying and pan-frying of dry-cured raw sausages (Li et al. 2012). The reader is directed to other reviews if there is interest in this area. Likewise, PAH content is not something that appears on a retail label, as the amount, if any, depends on several factors during the smoking process such as wood type and moisture content, smoke temperature, oxygen and ventilator velocity (Kafouris et al. 2020). However, in the interest of developing healthier processed meats, manufacturers could consider several steps in the manufacturing process to reduce PAH formation. Selection of wood types, such as beech, neem, copper pod, earleaf acacia and eucalyptus have been shown to maintain PAH concentrations below the EU maximum limits in smoked sausages (Iko Afé et al. 2020, Malarut and Vangnai 2018). It has also been suggested that pre-heating the fuel and preventing excessive drip i.e. juices dropping into embers, reduces PAH content (Lee et al. 2016).

Challenges

The challenge for manufacturers to develop processed meats which do not produce PAHs and n-nitroso-compounds lies with the fact that this is a very difficult process to control that is affected by numerous factors, including consumer product preparation and lack of identification on the label. Therefore, there is no incentive from a clean-label perspective. Nonetheless, in the interest of developing healthier processed meats, further research is required to fully develop an optimal approach for PAH reduction at both manufacturer and consumer level.

4.3.2.3 HPP and HPTP technologies

Several novel technologies have been discussed for applications in meat processing and detailed reviews exist (Lyng and Cummins 2017, Toldrá and Nollet 2018). Although the technologies have specific applications (e.g. tenderisation, surface decontamination), only some are suited to hot dogs. For example, light-based technologies and cold plasma are surface decontamination technologies and, therefore, will not penetrate a hot dog where internal preservative effects are required. The ability of power ultrasound (US) to act as a hurdle, with natural ingredients, for phosphate replacement in processed meats, was discussed by Thangavelu et al. (2019); however, in terms of microbial inactivation, US is likely to achieve around 1.0-1.5 log CFU reduction which is not sufficient for hot dogs (Toldrá and Nollet 2018). In terms of a technology which could have multiple benefits to create healthier and cleaner-labelled hot dogs, HPP has the potential to reduce salt content and reduce or remove phosphates. In addition, HPTP could offer further improvement by allowing for nitrite removal. Both technologies have been discussed in previous sections 4.1.2.1 and 4.2.2.1, so the following sections discuss them in terms of applicability to hot dogs.

As shown in Table 4, HPP and HPTP could have several benefits in the development of cleaner-labelled hot dogs. Previous work completed by the CSIRO has demonstrated that HPP (up to 400 MPa for 2 min at 10 °C) can reduce salt content by up to 50% in beef sausage batters and result in reduced cook loss and increased sensory acceptance (Sikes et al. 2009). HPP has also been shown to reduce the requirement for phosphate additives by 50% in breakfast sausages (O'Flynn et al. 2014). HPP as an end-of-process pasteurisation step has already been commercialised for many processed meats and many studies have been published on its application to meat. For example, HPP at 400 MPa has been shown to reduce *L. monocytogenes* to <10^2 CFU/g for 61 days, when combined with the bacteriocins, pediocin, sakacin and enterocin (Garriga et al. 2002). However, its application for spore inactivation is ineffective alone and requires simultaneous combination with moderate heat, as previously discussed (section 4.1.2.1 on HPTP). The ability to replace nitrite in meat by implementing HPTP remains theoretical and studies on this direct comparison would be interesting. There are a multitude of publications that demonstrate the significant effect of HPTP on spore inactivation. Of relevance here, where the inactivation of non-proteolytic *C. botulinum* spores would be the objective, commercially viable processes (i.e. < 5 min) have been investigated by CSIRO which have shown that an equivalent amount of inactivation of Type E spores can be achieved by HPTP (600 MPa, 90 °C, ~3 min) as would normally be achieved by a standard 90 °C/10 min thermal process (Legan, Chapman and Bull 2008). Irrespective of the effectiveness of HPTP from a food safety point of view, it would still likely need to be complemented by natural ingredients to provide the characteristic cured colour and flavour of nitrite.

Table 4: Theoretical applications of HPP and HPTP in the manufacture of cooked sausages

Application	**HPP**	**HPTP**
Salt reduction	✓	✓
Phosphate removal	✓	✓
Nitrite removal		✓
Shelf-life extension (end of pack pasteurisation)	✓	✓

Challenges

The challenges associated with HPP and HPTP use can be found in sections 4.2.2.1 and 4.1.2.1, respectively. In summary, they include engineering developments to make safe commercial-scale processes and challenges associated with selection of suitable packaging materials, that can withstand the process, maintain the required shelf-life and do not have detrimental effects on product quality. In the context of smoked cured hot dogs, the packaging challenge is unique in that product shape needs to be maintained during processing. This depends on the process and objective. For example, if HPP is applied to cooked sausages as an end of process pasteurisation step, the products are cooked and can be placed in vacuum packaging. However, if the objective is to apply HPTP to the products as a cooking/pasteurisation process, there could be a challenge with vacuum packing the sausages while preventing tearing/ripping of the casing and spillage of contents. Another challenge with HPP and HPTP for clean-label hot dogs could be establishing processing parameters. For example, if the objective is to remove nitrite, those parameters which lead to inactivation of *C. botulinum* may negatively affect texture/colour/juiciness if salt and phosphates are also removed. Optimisation trials would be required for quality, while validation trials would be required for safety and shelf-life.

4.3.3 Value Proposition

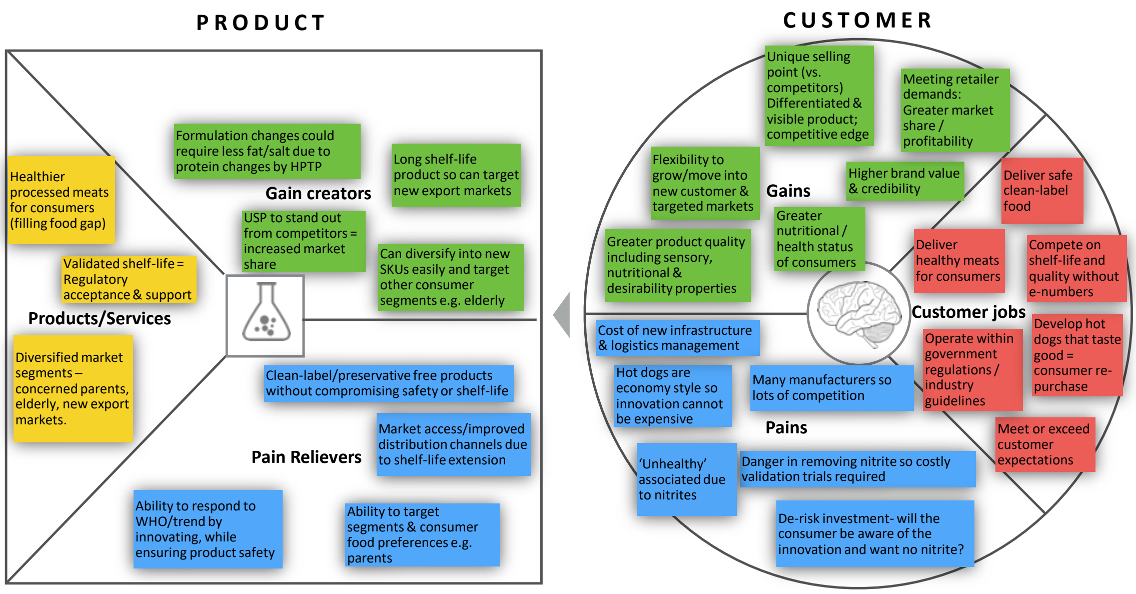

Figure 5: Value proposition canvas for the application of emerging technologies in the manufacture of cleaner labelled cooked sausages e.g. hotdogs (product) in the red meat industry (customer)

4.4 Roast beef, cold sliced and shaved deli meats

4.4.1 Product and Market information

The deli-meat counters in supermarkets are dominated by pork-based products such as hams, bacon and value-added chicken products (Parry 2016). The market share of red meat in the deli space was only 2% on 2016. MLA had indicated that if market share could be increased by 1%, it would return a benefit to the industry by approximately $10M (Fortune 2018). The red meat in the deli-counter is predominantly represented as rare roast beef and corned beef, and more recently as hot roast beef, from the roast chicken counter. In 2016, Woolworths, in conjunction with Teys, launched the hot corned and roast beef, and together with the respective cold version of those meats, aimed to take 5% of deli space (Beef Central 2016). Market analysis found that BBQ-roast chicken was valued at $932.6m in 2014 in Australia, and that 25% of chicken buyers indicated purchase intent for a beef alternative, which was projected to raise a profit of ~$5.5m due to increased demand for beef outside flats (Smith 2016). When the hot beef roasts were launched, there was a price war and the major supermarkets reduced the price of roast chicken from $11 to $8 (Heffernan 2016), whereas the hot beef roast prices ranged from $13 - $15 – reinforcing that red meat was a premium product.

Both hot and cold roast beef and corned beef are generally injected with a salt and phosphate brine to retain the moisture during cooking and reduce cook loss. Salt impacts on the flavour and shelf-life of these products. Corned beef also contains added nitrite which gives it it's characteristic colour and flavour. As mentioned in Section 4.3.2.1, nitrite is used as preservative to control *Clostridium botulinum* and it's also an antioxidant which results in improving the shelf-life of these products. The rare roast beef that can be purchased chilled from the deli counter does not contain salt or phosphate (Table 5); however, it does contain a range of acids (acetic, lactic and citric), potentially as preservatives. The ingredient list of hot and cold roast beef and corned beef contain a significant number of e-numbers, as thickeners, gelling agents, preservatives and antioxidants as shown in Table 5. For example, current Australian deli hot corned beef is manufactured to contain 125 ppm of nitrite and <1090 ppm salt, resulting in a 50 days shelf-life in vacuum packed, chilled storage (Smith 2016). These hot corned and roast beef products are pre-cooked and held chilled and are re-heated in the in-store ovens at 200 °C for 10 mins (Smith 2016). They can also be held in a Bain Marie hot box carousel at 80 °C for a maximum of 4 hours, which may explain the addition of various e-number ingredients to maintain product quality and shelf-life. However, these are against the clean label trend and the consumer demand. In general, in deli counters, the ingredient list is not visible to the consumer, however it can be easily obtained through supermarket websites. The ingredient list is available on the pre-packaged format of chilled roast and corned beef.

The primary food safety concern with respect to deli meats (including modified atmosphere packages (MAP) meats) is *Listeria monocytogenes* and non-proteolytic *Clostridium botulinum,* both of which can grow under refrigerated conditions and with extended shelf-life. Because these hazards may be present anywhere on the entire surface of the product, any formulation preservative must be uniformly distributed through the whole product. Traditional formulation hurdles include:

L. monocytogenes (Food Standards Code 1.6.1-4; FSANZ, 2016)

a) the food has a pH less than 4.4 regardless of water activity (a_w); or
b) the food has a a_w less than 0.92 regardless of pH; or

c) the food has a pH less than 5.0 in combination with a a_w of less than 0.94; or
d) the food has a refrigerated shelf-life no greater than 5 days; or
e) the food is frozen (including foods consumed frozen and those intended to be thawed immediately before consumption); or
f) it can be validated that the level of *L. monocytogenes* will not increase by greater than 0.5 log_{10} colony forming units (cfu)/g over the food's stated shelf life.

Non-proteolytic *C. botulinum* (Cox and Bauler, 2008)
a) the food has a refrigerated shelf life no greater than 10 days; or
b) the food is stored at ≤3°C; or
c) the food is chilled (5–10°C) and the pH is ≤5 throughout; or
d) the food is chilled (5–10°C) and the salt (NaCl) concentration is ≥3.5% in the water phase throughout; or
e) the food is chilled (5–10°C) and the a_w is 0.97 (using NaCl) or 0.94 (using glycerol) throughout; or
f) the food is chilled (5–10°C) and receives a thermal process equivalent to 90°C for 10 minutes.

In addition to these controls, other preservatives may be used if adequate evidence (challenge test data, peer-reviewed journal data) in support of their effectiveness can be provided (e.g. nitrites).

Table 5: Ingredient list of cold and hot corned and roast beef from the deli counter

Type of roast	Ingredients list
Cold rare beef roast^	Beef (99%), Colour (e150a), Dextrose (from Maize), Acidity Regulators (Acetic Acid, Lactic Acid), Lemon Juice Concentrate
Cold corned beef^	Beef (80%), Water, Sugar, Salt, Thickener (e1414, 407, 415, 412), Acidity Regulator (e451, 450), Soy Protein, Dextrose(Maize), Dehydrated Vegetables (Onion, Garlic), Gelling Agent (e508), Antioxidant (e316), Preservative (e250, 260, 270), Maltodextrin (Maize), Herb and Spice Extracts, Soy Sauce Powder, Natural Flavour Lemon Juice Concentrate
Hot beef roast*	Beef (80%), Water, Salt, Acidity Regulator (e451, 325,262), Thickener (e1414, 415, 412), Dextrose (from Maize), Soy Sauce Powder, Herbs, Onion Flavour, Yeast Extract, Canola Oil, Vegetable Extract (Celery), Acidity Regulators (e260, 270), Colour (e150a), Lemon Juice Concentrate
Hot corned beef*	Beef (85%), Water, Salt, Thickener (e1414, 415, 412, 407), Sugar, Acidity Regulator (e451, 450, 260, 270), Soy Protein, Gelling Agent (e508), Antioxidant (e316), Maltodextrin (from Maize), Preservative (e250), Canola Oil, Herbs and Spices, Lemon Juice Concentrate

*Smith, 2016
^Woolworths website

In the deli counter, meat products are often displayed in trays containing pre-sliced meats, or as whole pieces where the deli staff members can cut/slice the product according to the customer's request. Hence it is difficult to determine how the bulk packs of sliced and whole meats are packaged and stored prior to being delivered to the supermarket and how they are stored once the pack has been opened. According to Parry (2016), packaging innovations from the fresh meat sector such as vacuum packing, modified atmosphere packaging, skin packing etc. are being applied to the deli products for clean label and differentiated products. However, there is limited information about the packaging innovations in the deli counter product space.

4.4.2 Clean Technology Solutions

The two clean technology solutions for deli meats are:

1. Ingredients
2. HPP and HPTP technologies

4.4.2.1 Ingredients

As explained in section 4.3.2.1, replacement of nitrite in corned or cured products is difficult as nitrite is a preservative (against *Clostridium botulinum*), an antioxidant and it gives corned beef its typical pink colour and cured flavour. In corned beef, nitrite can be replaced with natural ingredients like celery powder or fruit and spice extracts, like Natpre T-10 (Prosur Inc. 2018). Challenge studies would be required to validate the effectiveness of these ingredients from a food safety perspective.

The thickeners and gelling agents can be potentially replaced with ingredients like soy protein, starch, fibres and gums, but some of these ingredients do not dissolve in the injection brine. This can lead to issues with settling of these ingredients during injection and poor distribution in the product itself, which can result in pockets of gel within the cooked product, impacting in the texture and appearance of the sliced product.

Salt and phosphates are crucial in injected products due to their techno-functionality from a texture and water binding perspective. However, as mentioned in section 4.3.2.3, meat products high in salt are perceived negatively from a clean label trend. These can be partially replaced using HPP.

Challenges

As described in section 4.3.2.1, replacement of artificial additives with clean label ingredients have costs, quality, reputation and legislative challenges. As mentioned previously, the clean ingredients may cost significantly more and may not have the techno-functionality of the artificial alternative. Corned and roast beef are both injected products hence there is a challenge to find ingredients that are soluble in the brine and distributed evenly throughout the products. These injected products also need to meet the criteria for core temperature hold-time (see Table A2 in the Appendix) to ensure food safety.

4.4.2.2 HPP and HPTP technologies

HPP and HPTP technology would have the same application benefits in deli meats for clean label as those described in Table 4 for cooked sausages from a microbiological point of view, where HPP can inactivate vegetative microorganisms, and HPTP must be used where spore control is desired. Roast beef, both hot and cold, does not contain nitrite, hence post cooking temperature control and storage is critical in maintaining product safety, especially with extended shelf-life beyond 10 days. Since a storage temperature of <3 °C would be required to prevent non-proteolytic *Clostridium botulinum* growth in a chilled low-acid food that has no other hurdles, other mitigation strategies are required and HPTP could be one approach that could yield the desired spore inactivation. As mentioned before, the hot roast and corned beef are vacuum packed and chilled, like cold beef roast. Hence, both these products would benefit from the application of HPP as a post pack pasteurisation step to reduce the risk of any post cook contamination by *Listeria monocytogenes* especially. The hot roast and corned beef have a final cook or kill step hence they can be considered low risk from a food safety perspective. However, the food safety of cold beef roast could be improved by using HPTP. As mentioned in section 4.3.2.3, HPP has been shown to reduce salt and phosphates in comminuted products; however, the research on the applicability of HPP for salt reduction in whole muscle, injected meats like corned and roast beef is limited. Tamm et al (2016) found that application of HPP after tumbling and in combination with 0.2% potassium chloride resulted in a low salt (1.1% salt) ham that had acceptable texture and water retention.

Challenges

As there is limited research supporting the use of these technologies to produce low salt whole muscle products, further research is needed to determine the applicability of the HPP and HPTP technology for salt and phosphate in such products. HPP could be utilised as a 'processing aid' to solubilise the proteins, however this would need to be applied prior to cooking. Commercial HPP units are currently used for post pack pasteurisation purposes, hence there would be a need to have two units – for raw and cooked product. Although these technologies could potentially result in a clean label product, it may be cost prohibitive.

4.4.3 Value Proposition

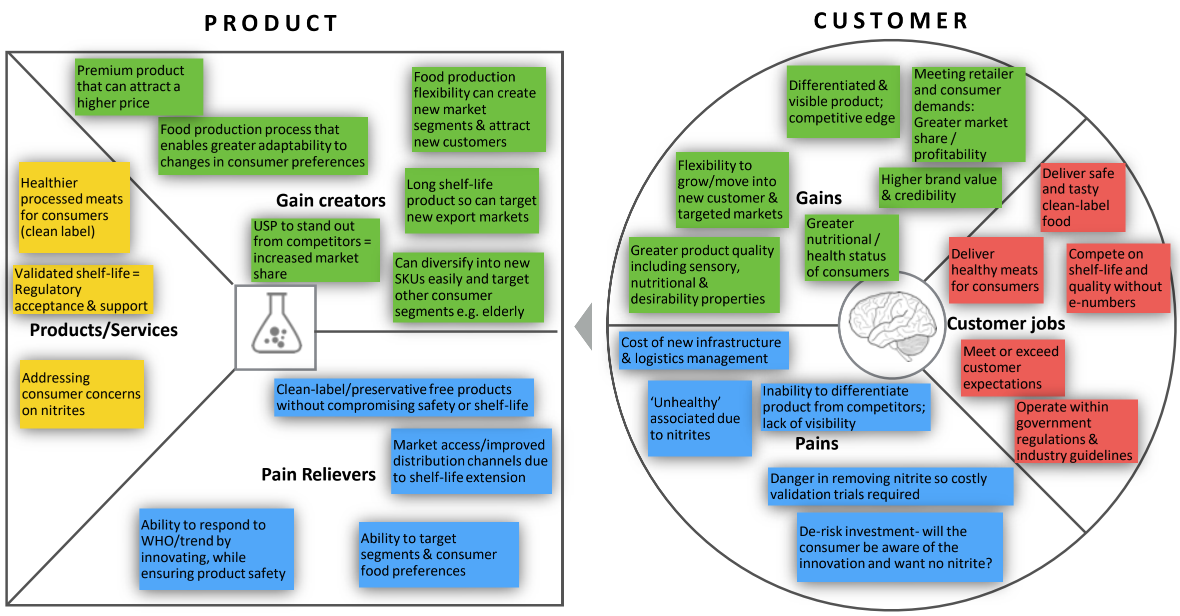

Figure 6: Value proposition canvas for the application of emerging technologies in the manufacture of cleaner labelled deli meats (product) in the red meat industry (customer)

4.5 Trail mix snacks, such as beef jerky with nuts/seeds/dried fruit

4.5.1 Product and Market information

Snacks represent one of the fastest growing segments of the food industry as they are highly accessible, convenient, portioned foods that appeal to people on the go, seeking to satisfy short-term hunger (Kumar et al. 2019). This has resulted in the 'snackification' trend where consumers are replacing traditional meals with 'on the go' snacks. Foods with high protein are also a growing market segment, appealing to image- and health-conscious consumers such as young active people interested in muscle building and also, ageing/elderly consumers seeking health maintenance and prevention of sarcopenia (age-related loss of muscle mass) (Kessler et al. 2019). Due to the high energy density and presence of essential nutrients, meat snacks have potential to avail of the growing protein snack trend. The meat snack market, composed of product classifications such as jerky, sticks, bars and others, is valued at $7.4 billion and is expected to reach $11.3 billion by 2026 (Thomas and Deshmukh, 2019). A recent project, conducted by CSIRO and MLA through the ON Prime process, validated that gym-goers were interested in low-sugar, clean-label meat bars as an alternative to current sweet protein bar offerings. Key insights also revealed that snack consumers were interested in consuming this mid-afternoon for satiety and that bars were preferred over protein balls due to the ease of consumption. According to Thomas and Deshmukh (2019), the largest trend in meat snacks will be the availability of organic meat snacks that cater to targeted consumer cohorts. Current meat snacks are commonly preserved through salting, drying, seasoning, smoking etc. as without preservation, meat snacks represent a high moisture and favourable pH environment for spoilage microbes (Kumar et al. 2019). However, this often results in a product with high salt content and e-number additives, such as nitrite, which are unfavourable from a health and clean label perspective. Jerky accounts for the highest market share in 2018 of meat snacks (Thomas and Deshmukh, 2019) and consumption levels have surpassed potato chips in the United States (Serra et al. 2019). However, it has been recommended that additional research is conducted to establish proper dietary recommendations of beef jerky as current food processing procedures may alter the molecular composition and result in health effects (Serra et al. 2019).

Per capita, Australians consume 92.6 kg of meat per year (OECD 2020), of which beef and lamb make up 18.3 kg and 7.2 kg respectively. Although Australia has one of the highest meat consumption rates in the world, there is still low uptake of meat snacks (Minotto 2017) and this provides a significant opportunity for value adding to the red meat industry. Countries like US and UK have seen growth of over 50% in meat snacks between 2011 and 2016 because meats snacks have undergone a transformation to meet the consumer's needs i.e. high in protein, low in sugar and salt, natural (additive free) and portable (Minotto 2017). The Australian meat snack market is still dominated by jerky and biltong type products, which are high in salt, sugar and preservatives like nitrite. In a recent report commissioned by MLA, Wiskar (2018) indicated that beef jerky needs to be redeveloped to create a meat snack that delivers 'the outcomes consumers are really looking for'. Hence jerky could be innovated to be incorporated with other foods, such as nuts, seeds and dried fruit as a snack offering with a balanced nutrient profile. However, novel processes could be utilised to create healthier jerky for trail mix inclusion.

Jerky is one of the few shelf-stable meat products available in the Australian market that is portable and can be used on the go. There are no microbiological limits on dried meats, but to prevent mould growth and maintain product quality and safety, it is recommended that that packaging material have low oxygen and water transmission rates, and that it contains an oxygen scavenger (MLA 2015). These advances in packaging has resulted in jerky type products being available at petrol stations and in vending machines (Leroy & DeGreef 2015).

Raw meat can be naturally contaminated with pathogenic bacteria including *Salmonella, Escherichia coli*, C*ampylobacter* and *Listeria monocytogenes*, and handling can further introduce *Staphylococcus aureus (*Brown 2000). Prior to drying meat to yield jerky products, meat should be treated to reduce or eliminate these pathogens. Typically, this would be achieved using thermal processing, and current advice suggests that processes designed to achieve a 7 $\log_{10}$ reduction of *Salmonella* are required to provide an adequate level of protection (AIOE 2012). Following this critical control point for safety, meats must be dried rapidly to sufficiently low water activity to minimise the chance for microbial growth during the drying process itself (nominally, <0.85), and to stabilise against microbial growth by xerophilic microorganisms during shelf-life, particularly yeasts and moulds which can grow down to a water activity of 0.65 (Brown 2000). Pathogenic bacteria are not able to grow at water activities lower than 0.86 (lower limit for *S. aureus*); however, *Salmonella* can persist under such hostile conditions, hence it is important to ensure that it has been eliminated from the product prior to drying. Depending on the required (low) water activity of the final product, will dictate what additional measures may be required to control spoilage, such as salt, preservatives (including smoke), and refrigeration.

In order to eliminate the risk of mould growth, the water activity needs to be reduced to <0.65, which could result in a very dry jerky product, that might be difficult to chew and consume. However, fermented salami type products are shelf-stable and are available in shelf-stable packs like jerky but are not as dry. In these products, reduction of pH to < 4.5 is used as a hurdle step, together with high salt and nitrites which control pathogen growth (I.e. proteolytic *C. botulinum*) and ensure shelf stability.

4.5.2 Clean Technology Solutions

The three clean technology solutions for dried, jerky type meats are:

1. Ingredients
2. HPP, MW and HPTP technologies
3. Drying technologies

4.5.2.1 Ingredients

In clean label dried meat products like jerky and meat bars like the EPIC range (Epic Provisions 2020), celery powder is used as the natural source of nitrite. As described in section 4.3.2.1, vegetable powders together with a starter culture have been used to convert the naturally present nitrates into nitrites in these products. However, research by Sindelar et al. (2010), showed that an acceptable colour was only achieved when the beef with vegetable powder and starter culture was incubated at 40.6°C. Hence additional processes are required to convert the natural nitrates into nitrites and this has resulted in pre-cultured ingredients being available on the market, however their use is governed by country specific legislation. Natural nitrite replacement ingredients like Natpre T-10 can also be used but further studies are needed to validate its efficacy in dried meats.

4.5.2.2 HPP, MW and HPTP technologies

Given the imperative to eliminate pathogenic bacteria from raw meat prior to drying/curing, processes in lieu of traditional thermal processing that deliver the required microbial inactivation can be applied. HPP would be suffice for vegetative cell inactivation, however conditions that result in the required reductions of *Salmonella* would need to be determined. Alternatively, thermal-based novel technologies could be applied, such as HPTP and MW, as introduced earlier, for greater microbial inactivation assurance. The advantage of these technologies would need to be determined to justify the extra expense of processing that would be incurred; i.e., are there meat quality benefits to be gained by using these in lieu of traditional thermal processing?

4.5.2.3 Drying technologies

Drying is one of the oldest unit operations in food processing, and while it has been improved on over the last decades, it is still one of the most energy (and time) consuming processes. Most operations utilise hot air to evaporate the water to produce the dried product. The initial stage of drying is fast; however, once all free surface water has been removed, the drying slows down considerably. The larger the product, the slower the drying process; and depending on the product and its composition, pronounced product deterioration and damage to thermo-labile components, especially on or near the surface, can be expected. Freeze drying is a process that dries the product at temperatures below freezing, under vacuum. While this provides benefits in terms of product quality, it is even more time-consuming than traditional drying processes, and expensive due to the requirements of vacuum. This also means that it can only be operated as a batch process. New developments at CSIRO have shown that drying assisted by ultrasound (at low and high frequencies) can significantly reduce the drying time of conventional drying operations by ~ 50% (or significantly reduce the drying temperature). Overall energy savings are in the order of 60%. This approach has also been shown to enable atmospheric freeze drying (i.e., freeze drying at standard atmospheric pressure), yielding similar product characteristics to vacuum freeze drying, with the benefit of not requiring vacuum, i.e., making it a much more affordable process, which can be operated continuously.

4.5.3 Value Proposition

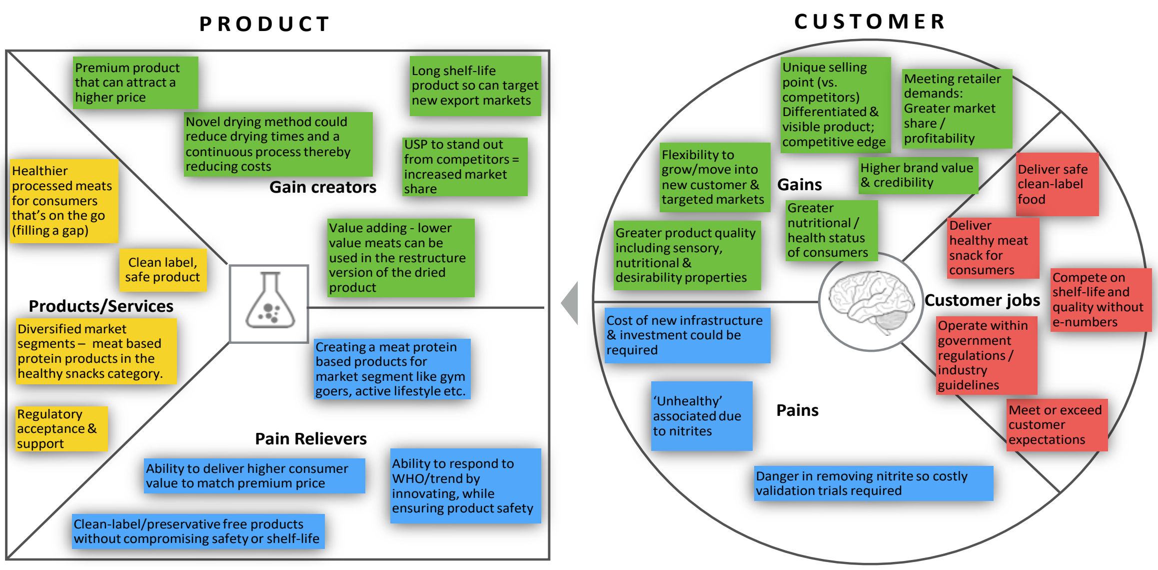

Figure 7: Value proposition canvas for the application of emerging technologies in the manufacture of cleaner labelled dried meats e.g. jerky (product) in the red meat industry (customer)

5. Discussion

According to the guidelines for the safe manufacture of smallgoods (MLA 2015), all ready-to-eat (RTE) products (e.g. roast and corned beef, cooked sausages and dried meats) are considered high risk products, as they are not cooked prior to consumption. Hence, controls need to be in place to ensure their food safety, from when the product is packaged until consumption. The most effective method is temperature control both from a product quality and food safety perspective. The permitted additives categorised as preservatives in cooked and dried meat products (NSW Retail Meat 2016) are summarised in Appendix Table A3.

In clean labelled foods where some of the permitted preservative ingredients and additives like salt and nitrite are reduced or totally replaced, it is essential that the alternative ingredient and technology solutions do not negatively impact on food safety and quality and this validation should be underpinned by scientific studies, in order to ensure consumer safety.

5.1 Clean-label strategies for selected red meat

Table 6 summarises the suitable ingredient and technology solutions in order to produce five products selected by MLA with a clean label. As can be seen, these options are dependent on the type of product; especially if it is raw or cooked and the food safety issue that needs to be overcome. Some of these solutions could be detrimental to product quality whilst it improves the food safety, hence a balance needs to be achieved where both the clean label needs of the consumer are met, and the product quality and safety are unaffected. In order to achieve this further research is required to address the challenges associated with the relevant ingredient and technology solutions.

Table 6: Ingredient and technology solutions identified for the selected red meat products

Technology Solution	**Products**				
	Chilled Ready meals	Chilled offal (liver)	Cooked sausages	Roast beef and deli meats	Trail mix – beef jerky
HPTP	✓		✓	✓	
HPP		✓	✓	✓	✓
VFC		✓			
Microwave	✓				✓
Natural Ingredients			✓	✓	✓
Drying					✓

5.1.1 Ingredients for clean-label red meats

- **Nitrite** – could be replaced with fruit extracts and natural flavourings that claim to have preservative effects, but each product and process would need to be regarded as independent and therefore challenge studies need would to be undertaken to determine the efficacy of the replacement ingredients against *Clostridium botulinum* in order to safely validate nitrite replacement. In addition, ingredients like natural antioxidants (polyphenols and carotenoids), colours and flavours may need to be added to address the antioxidant, colour and flavour contribution of nitrites.
- **Salt** – can be reduced with other ingredients like potassium chloride, however it can contribute negatively to the flavour of the products, depending on the concentration. The best clean label approach is using HPP to solubilise the meat protein, however this approach can have practical implications because HPP treatment needs to be applied to the raw product and the same unit cannot be used for post pack pasteurisation. Thus, two HPP units would be needed, one for raw materials and another for cooked and packaged products. This has cost implications for the processor as HPP units are expensive e.g. an average commercial system can cost approximately EUR2M.
- **Other additives** – Stabilisers (e.g. phosphate, modified starch, gums, etc.) and antioxidants (e.g. sodium ascorbate, erythorbate) are also common e-number additives added to meat products. While they are less controversial than nitrites, they still do not fit with the clean label trend.
  - Stabilisers: Natural ingredients such as starches, fibres and plant proteins have been tested to replace e-number stabilisers, but they can have technical (e.g. settling in the injection tank) or quality (e.g. poor dispersion in meat) issues. A promising clean label approach to replace stabilisers such as phosphates is to apply HPP since it can solubilise protein, potentially replacing that function of phosphate.
  - Antioxidants: Clean label natural ingredients, such as fruit extracts, can have anti-oxidative properties and therefore have potential to replace e-number antioxidant. However, they are often more expensive than synthetic additives.

5.1.2 Technologies for clean-label red meats

- **HPP** – improves meat protein functionality and allows for significant replacement of salt in emulsion and whole muscle products. It is also a good post pack pasteurisation technology for extension of shelf-life, but it is an expensive technology.
- **HPTP** – has the potential to achieve the required 6 log reduction in non-proteolytic *C. botulinum* spores, while maintaining flavour and texture of the product, and it significantly increases product shelf-life; e.g. up to 8 weeks shelf-life in clean label ready meals. This technology has the advantage of spore inactivation, unlike HPP.
- **Microwave** – allows for reduced processing time, energy and thermal load compared to conventional heating approaches (e.g. retorting). However, thermal distribution throughout product can be uneven so development work is needed to determine the appropriate, relevant processing parameters.
- **VFC** – chilling faster than conventional methods, and storing at lower temperatures, may reduce microbial activity and could change post-mortem metabolism, leading to improvement of shelf-life of, for example, chilled liver.

- **Drying** – assisted with ultrasound can be used to reduce the drying time for the production products like jerky, making the process affordable and continuous.

5.1.3 Technology readiness for clean-label red meats - Research needs and challenges

- **HPTP** – given this technology is not yet available at commercial scale, adoption is still not possible. CSIRO is currently in the process of commercialising a novel drop-in innovation that will see the ability to undertake HPTP using conventional HPP machines, supported by complimentary research regarding product handling systems, temperature monitoring and food safety validation.
- **HPP for post pack pasteurisation** – technology is ready and commercially available, including toll processing. Validation studies for different products would be required in the absence of relevant microbial inactivation data in the published literature.
- **HPP for improved functionality** – technology is ready and commercially available, however HPP has not been used at a commercial scale for salt and phosphate reduction in cooked meat products like sausages, roast and corned beef. Hence, further research would be required to assess the practicality of this approach for salt and phosphate reduction.
- **Ultrasound assisted drying** – this technology is currently in development by CSIRO and has shown that drying time of conventional drying operations can be reduced by ~ 50%. However, the application of this technology to dried meat products like jerky needs to be investigated.
- **Ingredients –** a range of ingredients are available; however, the cost and effectiveness of these ingredients need validation:
    - Cost: It is common for clean label commodity ingredients to be more expensive than the artificial alternative. In addition, sometimes a greater quantity is required in the formulation to achieve the desired shelf-life and quality, further increasing the manufacturing cost of the product. However, as clean label ingredients become more mainstream and ingredient suppliers continue to innovate and compete, it is likely that costs could reduce.
    - Further research or NPD required on the end-product: Depending on the ingredient, varying levels of research may be required. For example, validation studies undertaken/supervised by a qualified microbiologist experienced in challenge testing may be necessary when alterations are made to product formulations, particularly when a microbiological preservation hurdle is changed. This is necessary in order to ensure product safety and to reduce reputational risk that may arise as a result of product spoilage issues. For other changes, such as salt reduction, scale-up studies are often required to further assess the yield and eating quality of the end-product. This can have cost and time implications for processors.
    - Further research or development of ingredients: For some additives, there are very limited or no clean-label alternatives that can act in the meat matrix under the same mechanism e.g. phosphates. Therefore, fundamental research is still required towards the development of clean label ingredients for meat products.
    - Regulatory restrictions: Depending on the target market, manufacturers should ensure that any changes to additives or ingredients meet the legislative requirements and appropriate labelling changes are made.

5.2 Value proposition for the ingredients and technology solutions

- Addressing consumer needs: less additives and more clean label products
- Targeting new consumer cohorts: on-the-go protein e.g. parents, snacking
- Healthier processed meats: Delivering on nutritional and food value to the customers
- Improving the image of red meat: validation studies for safety and healthier snacks compared to current offering
- Differentiated products: longer shelf life, stable, convenient, safe, healthy
- Product safety: Delivering on nutritional and food value to the customers
- Clean label products without compromising safety or shelf-life
- Supply chain and market access: Increased shelf-life leading to improved distribution channels and market access

5.3 Implications for the industry

- Lost opportunity as untargeted market segments will continue to grow:
    - Deli and snack segments dominated by other proteins (chicken and pork)
    - Plant proteins will take some of the market share away from red meat
- Red/processed meat will be continued to be perceived as unhealthy without new clean label offerings
- Opportunity to improve supply chain cohesion:
    - MLA needs to support and encourage the Australian red meat industry to value add in Australia and slowly move away from the “commodity” mindset resulting in a more cohesive domestic supply chain.
- Make the clean label products cost effectively i.e. price competitive by
    - Investment in research to validate and understand clean label offerings and applications for red meat to encourage market uptake and therefore increase volumes for clean technology and ingredients, resulting in reduced costs
    - Value-add domestically to maintain labour and skills in Australia
    - Provenance claims for value-added premium products

6. Conclusions and recommendations

The findings from this research have shown that opportunities exist for the red meat industry to produce clean label meat products by combining natural ingredients and various technologies for the five different products evaluated in this study. However, further research is needed to optimise the combination of ingredients and technologies that results in products with clean labels. The ingredients and technologies would have applicability to other meat products beyond the scope of this project.

Future research and development that can assist the red meat industry in capturing the opportunities in the clean label space include:

- Commercialisation of the novel canister technology to allow current HPP (cold units) to be modified to undertake HPTP. This will provide the meat industry accessibility to the HPTP technology which could result in the production of clean label ready meals.
- New product development using HPP and HPTP to understand the benefits of these technologies in improving functionality and safety of meat products while resulting in clean labelled meat products.
- Evaluation of the natural nitrite replacer (e.g. Prosur Natpre T-10 and others) in cured red meat products like corned beef and cooked sausages to determine if 'nitrite-free' processed meats could be produced without impacting on quality and safety. This will also contribute towards consumer concern around the carcinogenicity of nitrite and reflect positively on the red meat industry that it is addressing consumer issues.
- Validation of the efficacy of natural preservatives e.g. Natpre T-10 or other extracts against *Clostridium botulinum* via challenge studies.
- Application of ultrasound assisted drying technology to dried meat products like jerky, needs to be investigated. The technology has the potential to reduce drying times by ~50% and make the process continuous which would have significant economic benefits for this sector.

The red meat industry needs to invest in the opportunities for scientific research identified in this report which will allow scale up, validation as well as commercialisation and extension of these activities. MLA could identify potential companies as research partners to CSIRO for the development of clean label prototype products. CSIRO has access to the technologies and expertise in meat science and food safety to bring these product concepts to fruition. Adoption of these opportunities will allow the industry to value-add in line with consumer trends for healthier and clean label foods. Other benefits include a potential shift from trading meat as a commodity to value adding in Australia. This could result in achieving a premium price through provenance claims, a more cohesive supply chain and maintaining labour skills within Australia.

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8. Appendix

Table A1: Microbial guidelines for roast beef and cured cooked meats like corned beef (reprinted from - MLA 2015)

	Number of samples (n)	Number of samples (c) allowed to be >m but <M	Limit (m)	Maximum (M)
Coagulase-positive *staphylococci*	5	1	100*	1,000*
Products in which growth of *L. monocytogenes* will not occur	5	0	100	
Products in which growth of L. monocytogenes can occur	5	0	0**	
Salmonella	5	0	0**	

* Count per gram of product
** Not detected in 25g samples

Table A2: Core temperature hold times for 6 log reduction in *Listeria Monocytogenes* counts (reprinted from - MLA 2015)

Temperature (^{o}C)	Time (min)
55	200
56	146
57	108
58	79
59	58
60	44
61	33
62	24
63	18
64	13
65	10
66	7
67	6
68	4
69	3
70-72	2
73-76	1
76 or warmer	<1

Note: A 6D process is a process which reduces the bacterial count from 1,000,000 to <1

Note: Cooling of meats (NSW Retail Meat 2016):

- Cured meats (hams, etc.) temperature must be reduced from 52°C to 12°C within 7.5 hours, and reduced to 5°C within 24 hours of completion of cooking
- Un-cured meats (roast beef/lamb/pork) temperature must be reduced from 52°C to 12°C within 6 hours, and reduced to 5°C within 24 hours of completion of cooking,

Table A3: Permitted additives and preservatives in processed meats (from NSW Retail Meat 2016) – e-numbers and usage rates

Products	**Additives & Preservatives – e-number, name, allowable usage rate**
Whole muscle processed meats (e.g. corned beef)	# 234 - Nisin (12.5 mg/kg) # 243 - Ethyl lauroyl arginate (200mg/kg) # 249, # 250 - Nitrites (potassium & sodium salts) (125 mg/kg)
Comminuted processed meats (e.g. hot dogs)	# 249, # 250 - Nitrites (potassium & sodium salts) (125 mg/kg) # 220, # 221, # 222, # 223, #224, #225, #228 - Sulphur dioxide and sodium and potassium sulphites (500 mg/kg) # 234 - Nisin (12.5 mg/kg) # 243 - Ethyl lauroyl arginate (315mg/kg)
Dried meat (e.g. jerky)	# 200, # 201, # 202, # 203 - Sorbic acid and sodium, potassium and calcium sorbates (1,500 mg/kg) # 234 - Nisin (12.5 mg/kg) # 243 - Ethyl lauroyl arginate (200mg/kg) # 249, # 250 - Nitrites (potassium & sodium salts) (125 mg/kg)