Opportunities for **packaging** and **processing machinery** and **technologies** to tackle **food waste**

Baseline Review
Insights

FIGHT FOOD WASTE Cooperative Research Centre
REDUCE - TRANSFORM - ENGAGE

Australian Government
Department of Industry, Science, Energy and Resources

Business Cooperative Research Centres Program

APPMA
Australian Packaging and Processing Machinery Association Limited

RMIT UNIVERSITY

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About this project

Across the food supply chain, the use of some technologies and processes can directly result in food waste generation, including during harvesting and processing, in customising portion sizes, through product and date labelling, shelf-life extension and product packaging. For food producers often the type of packaging and processing machinery available dictates how effectively resources are used and the volumes of food waste produced. Equipment manufacturers may not be aware of the critical role they play in reducing food waste.

Understanding how the Australian packaging and processing machinery sector can promote these technologies and services to the food industry to realise new opportunities to reduce and/or transform food waste is the challenge being addressed. The aim of this project is to consolidate the ways that Australian packaging and processing machinery can reduce and/or transform food waste and to provide equipment manufacturers with improved knowledge and understanding of the food waste challenges. In isolation, a single initiative will not address the issue at scale, however driving collaboration across the APPMA with the various packaging providers and processing companies can achieve this.

About the APPMA

The Australian Packaging and Processing Machinery Association (APPMA) was established in 1983 to promote, integrate and foster participation and development at all levels of the packaging and processing machinery industry in Australia. Within the APPMA membership there is a diverse range of technology and service providers.

The Project Partners:

RMIT UNIVERSITY

APPMA Australian Packaging and Processing Machinery Association Limited

Executive summary

This report presents a global baseline literature review across academic and industry publications for the APPMA (Australian Packaging and Processing Machinery Association) and provides a landscape study of relevant technologies and their (potential) impact on food waste and loss. The existing literature strongly recommends a strategic approach that incorporates various aspects of the food supply chain, as well as considering investment costs, sustainability impact, and industry demand in the supply chain, rather than a piecemeal approach that implements a single technology at any given point in the supply chain.

This whole system approach is used by nearly a third of the papers reviewed. A quarter of the papers explore packaging solutions; nearly a quarter explore processing and manufacturing solutions; and roughly a tenth explores solutions related to transport, distribution and logistics. Other parts of the food system – including on-farm, packing, retail, consumer and waste management – are the focus of between 2 and 6 per cent of the papers each. Much of the literature describes technologies throughout the supply chain that focus on the reduction and/or monitoring of microbial activity for extension of shelf life for the food product. An emerging trend in the literature was Industry 4.0 technologies, which are used across the food supply chain, and include digital transformation technologies such as neural networks, blockchain, Internet of Things, sensors and RFID, and robotics.

The existing literature strongly recommends a strategic approach that incorporates various aspects of the food supply chain, as well as considering investment costs, sustainability impact, and industry demand in the supply chain, rather than a piecemeal approach that implements a single technology at any given point in the supply chain.

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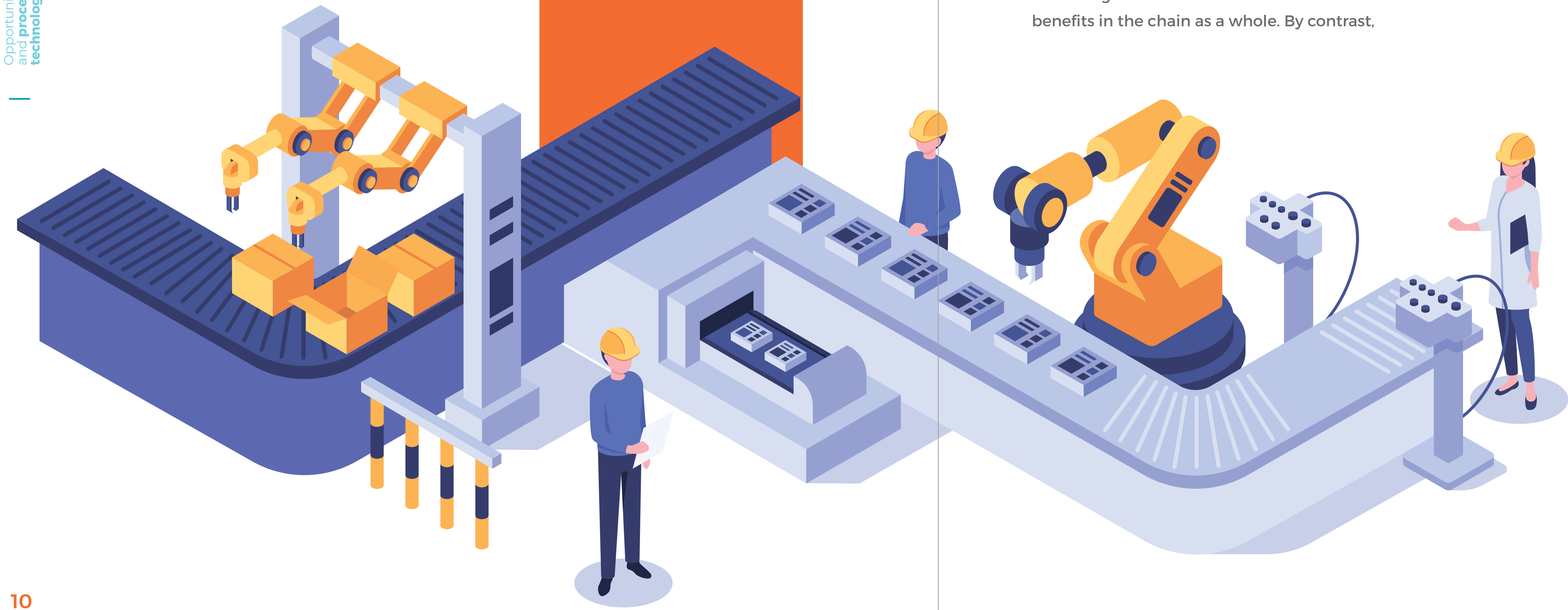
Introduction

Food waste and loss is a complex and growing problem that occurs across all parts of local and global food supply chains, including consumption, packaging and processing equipment and machinery – and a broad range of other technologies – play a direct and indirect role in addressing food waste issues. In addition, the packaging and processing industry has unique innovation capabilities that provide opportunities to further tackle the food waste problem and contribute to sustainable food waste reduction and a thriving industry.

This report presents the first deliverable of the research project – a baseline literature review across academic and industry publications from the Australian Packaging and Processing Machinery Association (APPMA) and provides a landscape study of relevant technologies (as represented by APPMA members) and their potential impact on food waste and loss.

The packaging and processing industry has unique innovation capabilities that provide opportunities to further tackle the food waste problem and contribute to sustainable food waste reduction and a thriving industry.



The APPMA was established in 1983 to promote, integrate, and foster participation and development at all levels of the packaging and processing machinery industry in Australia. The larger project is funded by the Fight Food Waste Cooperative Research Centre in partnership with APPMA and RMIT University.

This document provides a summary of key machinery and technologies relevant to the food supply chain found in the literature, spanning both established and emerging equipment and machinery. All the articles in the review have a link to food waste or loss in terms of their topic. In addition, the review illustrates some overarching strategies and management considerations to maximise the effective deployment of machinery and equipment in relation to food loss and waste. Specific case studies also demonstrate that piecemeal implementation of single technologies often fails to deliver sustainable benefits in the chain as a whole. By contrast, implementing a range of complementary technologies, such as data collection technologies, modelling and analytics, machinery and robotics, management and coordination tools, impact assessment, and efficiency or cost/benefit analytics, appears to have much potential; although the true impact was rarely measured in the literature. Finally, some articles in the review show a clear need to manage investment costs, sustainability impact, and industry demand in the supply chain simultaneously.

The following sections are structured in three parts:

- Processing and packaging machinery and technologies in relation to the food supply chain;
- Industry 4.0 technologies used to integrate and improve the food supply chain;
- The potential impact of these technologies on food waste and loss.

02

Literature Review

The technologies are listed below according to their stage in the supply chain: most importantly, processing, packaging, distribution and transport, waste management, and industry 4.0 technological innovation.

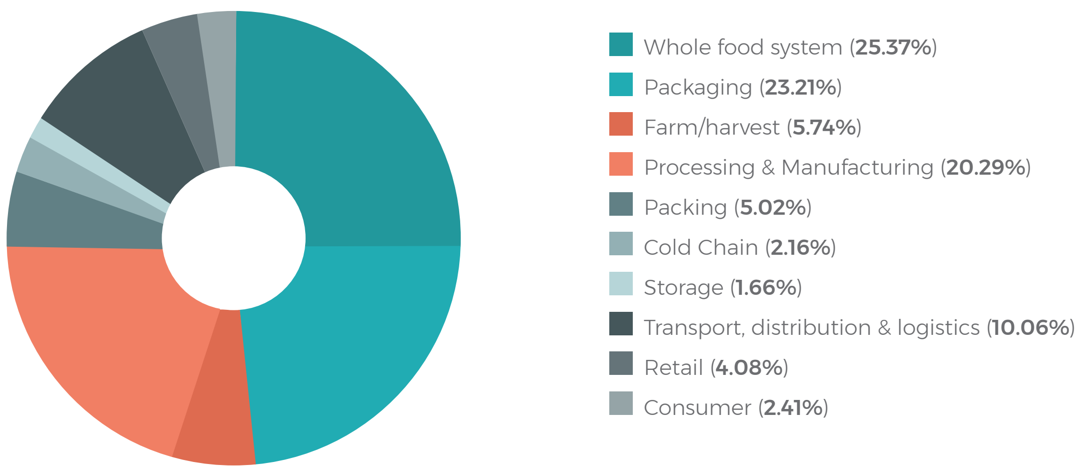
The global literature search

A series of keyword combinations were used to search academic databases for both academic literature and grey literature (industry reports) regarding existing research about packaging, machinery, and other technologies that have an impact on food loss and waste (FLW), and that are currently used or being developed for use in the food supply chain. All searches included the keywords 'food loss' or 'food waste'. The keyword combinations included variations on 'automation', 'food packaging', 'handling machinery', 'processing' or 'production', 'placement machinery', 'innovation', 'research and development equipment', 'shelf life extension', 'technology trade-offs', and 'vision systems'. These keywords were informed by an analysis that mapped the focus of organisations in the APPMA's membership base, included in the appendix (**Section 5.1**). A full list of the keyword combinations is included in the appendix (**Section 5.2**). A total of 348 relevant results were identified.

Figure 1 below shows the spread of papers across different parts of the food supply chain. This shows that the literature is focused largely on a whole food system approach, but that packaging and processing and manufacturing technologies are also a strong focus. Each stage of the supply chain (with some overlapping stages) is described below.

FIGURE 1

Percentage of papers that address different parts of the food supply chain



2.1

Processing

It has been estimated that up to 39% of the food losses in the European Union occur in food manufacturing . Overproduction is a key reason for this, with companies including farms producing 30-50% extra to compensate for unexpected losses. Mechanical damage during transit, blackouts, human error, equipment defects, experimental losses, cleaning losses, hazardous contamination, and process-related by-products also play a role. Key technologies for food loss and waste management in processing include high pressure processing, pulsed electric field, ultrasound, thermal processing, ohmic heating, and pasteurisation. Each is summarised below.

2.1.1. High pressure processing

High pressure processing involves the application of very high pressures to food in order to destroy microbial activity. It is often used in processing food like fruit juice, where harmful, spoilage-causing microorganisms can be killed by being pressurised at 400MPa at 20 degrees for just a matter of minutes.

The technology is over a hundred years old, though it is currently finding application in many new fields, such as a method for milk pasteurisation. The technology is used as a method of preservation by reducing microbial activity, dramatically improving the shelf life of raw and processed products with minimal adverse effects on their sensory quality. It decreases food loss and wastage due to microbial, chemical, or enzymatic spoilage. Adoption of this technology is limited by high investment costs, the need for a better understanding of process parameters, and challenging regulatory requirements.

2.1.2. Pulsed electric field

This technologiy involves the application of electric pulses to food in order to reduce microbial activity, extending preservation of produce. The first commercial example of this technology is from 2005 and it is being adopted slowly, with many companies preferring high pressure processing methods for achieving similar outcomes. This technology can produce a non-uniform distribution of the electric pulse which leads to an uneven result in processing, though it is possible to work around this problem.

2.1.3. Ultrasound

Ultrasonic waves are applied to a food as a non-thermal treatment. Ultrasound is an emerging technology that results in microbial inactivation, thereby extending shelf life. This technology has been effective on liquids such as fruit juice, but less so on solid food. Applications of ultrasound as a singular means of food preservation are not seen yet commercially feasible but have been shown to be effective when combined with other processes, such as emulsification, homogenisation, extraction, crystallisation, dewatering, degassing, and defoaming.

2.1.4. Thermal processing

This includes technologies such as radiofrequency heating, infrared heating, sous-vide processing, hot water treatment, and hot air treatment. These methods treat microbial issues such as pests, fungus, moulds, and other harmful pathogens, thereby extending shelf life.

2.1.5. Microwave heating

Microwave technologies are established, however there are newer emerging applications of the technology, such as drying broccoli stems for preservation and for alternative use. Heating time through these methods is greatly reduced, minimising the microwave's impact on food quality compared with other heating technologies. However, non-uniform heating remains a problem with microwave technology.

2.1.6. Ohmic heating

Ohmic heating uses electric currents to heat foods, extending shelf life by destroying microbial activity. It is an old technology that has only recently emerged in the food sector. Ohmic heating is very energy efficient compared to alternative preservation processes.

2.1.7. Pasteurisation

Pasteurisation involves heating food to a high temperature in order to kill off harmful microbial activity. It is used extensively in dairy processing, and is beneficial for food safety and extending shelf life.

2.2

Packaging

Packaging helps manage food loss and waste directly through the protection, preservation, and containment of produce and processed foods, but also indirectly through communication, information, traceability, and convenience for the consumer. Innovation in packaging technology has focussed on two areas: improving the longevity of the contained produce by reducing damage to the food and extending shelf life, and the environmental sustainability of the packaging itself via the reduction of secondary packaging, material selection, and energy and end-of-life waste.

Key innovations in packaging technology fall into three broad categories: 'smart' active packaging, 'smart' intelligent packaging, and novel food packaging. Each is summarised below.

2.2.1. 'Smart' active packaging

Active packaging technologies decrease spoilage of produce as a means of extending shelf life. They include: scavenging and absorbents, active emitters, antimicrobial agents from both synthetic sources and antimicrobial compounds of natural origin, antioxidant agents from both synthetic and natural sources, regulation functions, humidity absorbers, and ethelyne absorbers.

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2.2.2. 'Smart' intelligent packaging

Intelligent packaging technologies promote the tracking and communication of food quality throughout the supply chain and include biosensors, indictors, radio frequency identification, freshness indicators, leak indicators, time temperature integrators (TTIs), and barcodes. See **section 2.3.1** for further detail.

Both types of 'smart' packaging technologies have been successfully employed for fresh fruit and vegetables and meat. 'Smart' packaging is both an established and emerging innovation in the food supply chain, with substantial opportunity for integration with other technologies.

2.2.3. Novel food packaging

Novel food packaging is an umbrella term used to describe a variety of emerging packaging technologies that use novel materials. These include edible films and coatings which form a thin layer of material coating on food to extend its shelf life, vacuum skin packaging where a plastic film is thermoformed to the exact shape of the food to inhibit microbiological deterioration, and nanotechnology, which uses nano-sized materials to provide antimicrobial barriers and/or physiochemical reactions. Nanotechnology is also being developed as a way of detecting and identifying foodborne pathogens in real time. Novel food packaging that makes use of by-products from the food supply chain would further address food loss and waste; for example, the use of animal-based gelatine to create absorbent pads for meat packaging.

Novel food packaging is a relatively recent development and is not yet widely adopted in the food supply chain, but shows significant promise as practices develop. Its innovative nature presents some risks and concerns regarding potential regulatory and environmental concerns. However, antimicrobial and antioxidant packaging from natural-derived sources may be incomptible with biological novel packaging materials, decreasing their stability, which may prohibit European Food Safety Authority (EFSA) approval. These novel materials also often pose high up-front costs in their current form, caused by the novel machinery modifications required to manufacture them.

2.3

Distribution and transport

Development of technology in this logistics area through data collection and analysis allows for substantial improvements to the life span of produce and practical solutions for efficient and effective extension of shelf life. Key technologies for food loss and waste management in distribution and transport include sensor technology, modelling and prediction, and cooling technologies. Each is summarised below.

2.3.1. Sensor technology

Sensors for example in the cold chain allow for a better understanding of temperature fluctuations in the vehicles and storage spaces, as well as different perishables needing different temperature to remain cool. Key sensors identified are:

- Radio frequency identification (RFID) – provides fine-grained data and allows high-volume scanning. This technology can be expensive to implement on a large scale and have limited range and sensing capacities. RFID tags can be active, passive, or semi-passive. There has been wide-scale commercial adoption of RFID tags. This is further explained below.
- Time-temperature integrators (TTIs) – inexpensive smart labels currently used widely to visualise the time-temperature history in the cold chain. This technology is believed to underestimate remaining shelf life, as TTI response is not always representative of food quality changes.
- Wireless sensor network (WSN) – uses the 2.4GHz microwave band, which is widely adopted, but has issues with transmission through water and high humidity environments. Commonly implemented in conjunctions with other sensors such as RFIDs to measure, record, and monitor product temperatures in cold chains.
- Bluetooth low energy (BLE) – sensor type commonly used in telecommunication, used to communicate data to enable the monitoring and control of cold chains.
- Thermal imaging – can capture a number of data points and be used as an estimate for temperature calculations, potentially reducing the need for or number of sensors required. Can complement other existing technologies and achieve full thermal supervision of the product.

2.3.2. Modelling and prediction

Intelligent processing of sensor data allows for far more effective management processes and automated/dynamic changes to practices as required.

- Real time temperature monitoring systems – checks, measures, and reports the actual temperature in real time to help business operators make decisions, take corrective action, and evaluate their operations.
- Artificial neural network (ANN) – machine learning processes used for system classification and estimation. Assumes a nonlinear relationship between the desired temperature (inside a pallet) and the temperature source (air temperature in the container) to better model and adjust cooling processes.
- Distributed predictive control technology – an alternative for the development of distributed controllers and large-scale systems. Used to partition the process model of a cold chain in such a way that one can obtain subprocesses that represent its dynamics locally, while simultaneously observing the interaction between the other state variables and outputs with each subsystem obtained.
- Internet-of-things (IoT) – connecting sensing devices to facilitate the aggregation and analysis of data, often in real time. Provides live data that can inform decision making and be responsive to temperature events.
- Computational fluid dynamics (CFD) – the simulation of air flow dynamics in a specific environment, allowing for modelling and testing of more efficient ways to cool produce.
- Big data modelling – large scale data measurements of the cold chain to better predict shelf life of products in real world situations (e.g. the EU FRISBEE Cold Chain Database).

2.3.3. Cooling technologies

Cooling the environment during transport is an important mechanism to reduce food waste and loss. These involve specific practical measures to improve the effectiveness of food preservation. The data collection and modelling processes described above enable better coordination of these efforts.

- Pallet covers – to retain cold air and attenuate temperature and humidity changes.
- Pre-cooling – to remove residual heat from produce before preservation.
- Freezing technologies – including high-pressure freezing, dehydrofreezing, and use of antifreeze to increase the quality of frozen food, especially where combined with other processes like ultrasound, magnetic resonance, electrostatic, microwave, and radio frequency.
- Superchilling – chilling just below freezing point, maximising preservation without damaging produce
- Unit temperature reduction – lowering the temperature of refrigeration units overall can help reduce food waste with minimal product damage.
- Controlled atmosphere storage – manages the gaseous atmosphere in a store and reduces food deterioration because of negative impact on growth of microorganisms.
- Zero energy cool chambers (ZECC) – on-farm, low-cost storage cooling technology based on direct evaporative cooling. Does not require electricity or power to operate and is constructed from easily available and cheap materials such as bricks, sand, and bamboo.

2.4

Waste management

Waste management can be positioned across the supply chain. In the literature studied, waste management comes up occasionally. Waste management often addresses food loss and waste by seeking to make productive use of products that would otherwise be disposed. It is often the least efficient method of food loss and waste management, but it is extremely important in minimising negative environmental and financial impacts. Waste management technologies seem to fall into three categories: digestion, reduction, and energy generation. Each is summarised below.

2.4.1. Digestion

- Anaerobic digestion – organic waste is broken down by micro-organisms in the absence of air. Emitted gasses are captured and made usable. The methane-rich biogas produced can be burnt or stored in gasometers, or converted directly to electricity, hydrogen, heating, and vehicle fuel.
- Aerobic digestion – food waste is broken down by bacteria in the presence of oxygen, producing nutrient-neutral grey water, disposed of through the sewage system. Can be applied at the small- to medium-sized establishment level.
- Thermal hydrolysis – a two-stage process involving high-pressure boiling of waste followed by rapid decompression. The waste sludge is then digested anaerobically by bacteria, producing high yields of biogas.
- Compost – food waste is aerobically broken down by bacteria, producing a nutrient rich organic solid that can be composted to produce fertilizer. Applicable for small to medium size businesses.

2.4.2. Reduction

- Food waste pulpers and shredders – mechanical blades grind or shred waste with water to create a pulp, which is then pressed to remove water content. Volume/weight reductions are in the vicinity of 80-90%, depending on composition of feedstock.
- Food waste dehydration – heat and agitation are applied to waste to evaporate moisture. The dried pulp is then removed and disposed of via landfill, as feedstock for composting, or as an ingredient in animal feed and soil fertilisers.

2.4.3. Energy generation

- Incineration – combustion and capture of heat to generate electricity and heat via steam boilers.
- Pyrolysis – the thermo-chemical decomposition of organic material in the absence of oxygen. Produces flammable syngas, crude oils, and high carbon content ‘char’, which serves as solid fuel.
- Gasification – the conversion of organic wastes into CO, H_2, and CO_2 at high temperatures with insufficient oxygen for combustion. Generates hydrogen-rich syngas, liquid bio-oil, and biochar, a stable form of solid carbon.
- Fermentation – yeasts and bacteria convert organic molecules into acids, solvents, or alcohol-based fuels. The most common commercial systems convert the sugars

in corn to produce ethanol, which is then blended with gasoline to create fuel.
- Transesterification – acid or base-catalysed reaction of oils and an alcohol into a mono-alkyl ester, commonly known as biodiesel.
- Bioelectrochemical – systems including microbial fuel cells and microbial electrolysis cells, which use bacteria to convert organic and inorganic matter and directly produce electrical current or hydrogen.
- Hydrothermal liquefaction – uses depolymerisation under conditions of moderate temperature and high pressure to convert wet biomass into a high energy density bio-oil product.

2.5

Industry 4.0/digital transformation

The term 'Industry 4.0' represents the fourth Industrial Revolution. It refers to a set of principles widely adopted across the food supply chain. Integration of Industry 4.0 technologies into agriculture and food production allows producers to be far more efficient with resources and provides producers with more detailed insights into their processes through big data sets. Each relevant Industry 4.0 technology is described below.

2.5.1. Neural networks

This is a self-improving recognition system, able to learn and recognise data trends and produce meaningful outputs. To date, this technology has been successfully deployed to grade rice, bananas, and packaging. This technology contributes to the concept of a "self-thinking supply chain" , and links with other technologies to create a digitally-based solution for supply chain management. It improves supply chain efficiency by intelligently adapting to needs and conditions. This in turn contributes to efficiencies that assist with food loss and waste prevention, primarily through food grading, where neural networks can replace human inspection as a means of assessing food quality and predicting shelf life. Artificial intelligence is increasingly used.

2.5.2. Blockchain

A digital transaction ledger, blockchain is maintained by a network of computers that do not rely on a trusted third party, preventing fraud and tampering. Blockchain is particularly valuable for traceability within supply chain management, food security, and data integrity, because it can accurately capture output quality. This technology has been successfully deployed in a number of manufacturers, including Walmart in 2016 in collaboration with IBM . As businesses seek to adopt new Industry 4.0 technologies, Blockchain will help build trust in transactions of information by making them more visible, transparent, and trustworthy. This information could provide data to achieve more accurate date labelling as well, help consumers gain more insight into the supply chain, and help to identify hotspots of food loss and waste.

2.5.3. Internet of Things

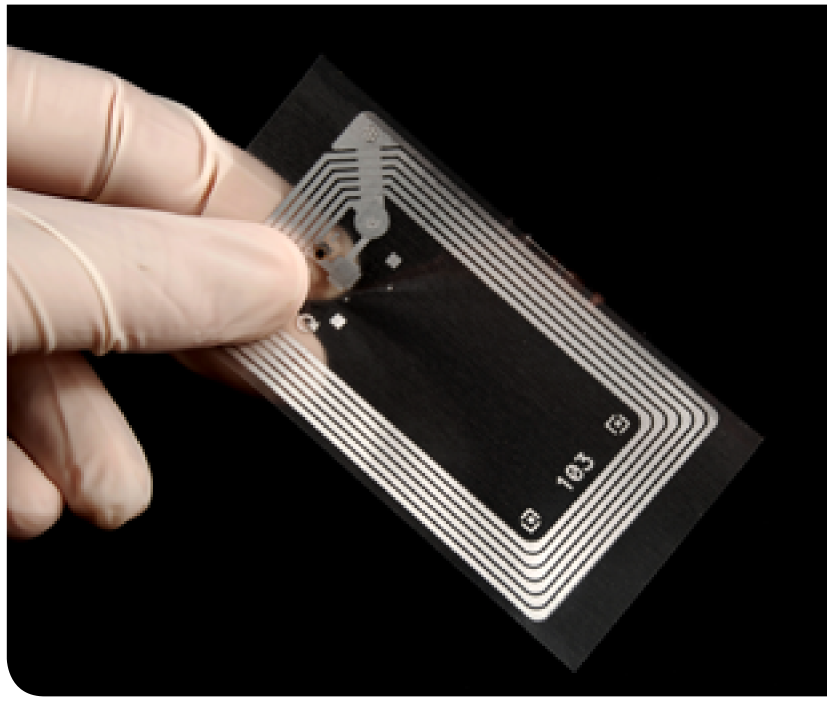
This is a term referring to a network of interconnected physical devices over the internet. To date, this technology has been successfully deployed to increase in productivity in sorting and packing potatoes. This technology can provide real time data on food waste, eliminating the need for manual data entry, automating processes, and improving efficiency and accuracy of food systems. It reduces food loss and waste by developing a trusted consumer perception on food quality, networking sensors that can detect food spoilage throughout the supply chain, and providing producers with more accurate consumer information regarding date of food spoilage, enabling them to avoid food loss and waste as produce ages. See **section 2.3.1** for further detail on sensor technology.

2.5.4. Sensors and RFID

These are physical devices that sense some physical property (chemical, temperature, humidity) of food to provide data about it's condition. RFIDs enable the connection of sensors in the agricultural supply chain, which can help traceability along the food supply chain. By providing real-time information on the condition of a food product throughout the supply chain at various points, sensors identify opportunities for improvement. This technology has been deployed with particular success in predicting perishability of tomatoes. Sensor types include humidity, light, temperature, oxygen, chemical, gas, weight, pressure, motion and vibration, ph levels, location, radiation, freshness, integrity, biosensors, and TTIs. The adoption RFID technology is currently very low within agriculture, partly due to high cost of implementation. See **section 2.3.1** for further detail on sensor technology.

2.5.5. Robotics

Robotics are used to automate processes along the food supply chain to improve efficiency and effectiveness. The literature currently focusses on the use of robots for food waste processing, and there is a gap regarding the used of robots throughout the production process. Asia and Australia are uptaking this technology the fastest, with Europe and America accelerating. Current relevant uses for robotics include nuclear magnetic resonance to detect the oil to water ratio and internal browning, near-infrared spectroscopy to detect sugars and acid content, hyperspectral imaging to detect contaminants, and computer vision to classify foods. Robots are predicted to make a positive impact on the automation of fresh produce production by replacing human labour with faster, more efficient machinery, with minimal downtime. However, automation practices using robotics in food processing has lagged behind robotics in other industries.



03

Conclusion and recommendations

The literature shows that there are clear links between the identified processing and packaging technologies and related machinery, and food waste or loss reduction. While these technologies may be effective in addressing specific problems or leveraging specific opportunities for process efficiency and food loss and waste management, the overarching theme that emerges is that a whole-of-system approach to the integration of these technologies will provide substantially greater rewards than piecemeal implementations.

Several common themes emerged during this literature review:

- The link between food waste reduction and the quantification of savings or impact was weak in the literature, and was largely inferred rather than quantified. As such, there seems to be a lack of monitoring and evaluation of implemented technologies in relation to food waste and loss, resulting in a lack of data and insights into sustainability benefits and benchmark data .

- The distribution of identified technologies is uneven throughout the food supply chain. For example, sensor technology is featured more frequently in relation to transport and distribution stages, rather than the retail or wholesale stages, whereas Industry 4.0 technologies feature predominately in the processing stage. Apart from the need to take an integrated approach on technologies, there are also opportunities to apply these technologies more widely across the supply chain, which would enable data sharing and coordination and learning.
- Several technologies were noted to have been widely adopted by other industries while the food industry lagged behind in adoption. For example, robotics and automation are not yet widely employed by the food supply chain. Or, in other words, limited attention is paid to food supply robotics, which may also relate to still lower levels of automation on farms compared to other industries. With proper analysis of the causes for this slow uptake, and adjustment for any specific needs of the industry, these technologies may provide substantial benefit. Using *'lead user'* industries that have already adopted them could provide case studies and implementation and management templates.

- Technologies that have been taken up by the food supply chain demonstrate significant connectivity. For example, early stages of the supply chain employ technologies to reduce or destroy microbial, chemical, or enzymatic spoilage activity, and are followed by food quality tracking and cold chain monitoring technologies in the transport stage: two separate mechanisms serving the same objective. Better sharing of data between these systems will potentially allow for improved coordination and learning. This also serves to illustrate how new technologies may be successfully taken up. Blockchain studies are also growing in this area, but research mostly shows the potential impacts, rather than measured impacts.
- The use of identified technologies to empower and educate the consumer (i.e. smart labelling technology) and using mobile phones to get product information are rarely discussed in the literature, despite consumer practice being a major source of food loss and waste in the supply chain. This may illustrate a gap in the supply chain that could be filled with existing technologies. The fridge in the household is often still a very basic piece of machinery.
- Given the search term procedure, limited studies appear to be situated on farm, in the pack shed, and in retail. There seems to be growing attention for robotics in retail given the growth of online grocery shopping. This does not preclude the importance of these stages of the food supply chain, but illustrates the opportunity for member-based organisations like APPMA to connect with similar organisations in these sectors. This opens up opportunities for a whole-of-supply-chain approach to reducing food waste.

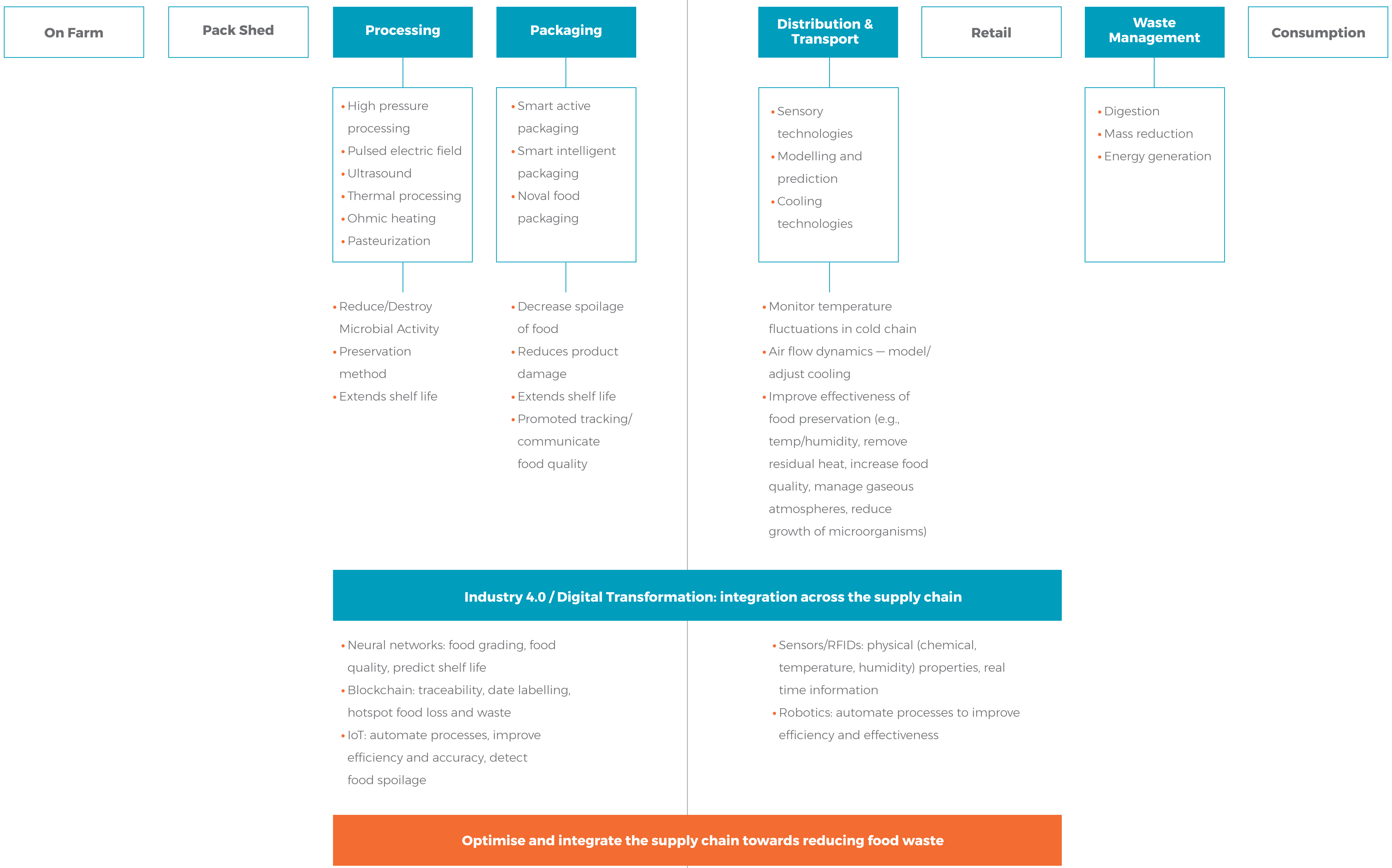
Several key insights from the review of technologies are identified from this literature review:

- A a whole-of-supply-chain approach, that places specific technologies within the broader context of their use and seeks to integrate them with other process improvements, will ensure the technology works successfully and does not conflict with other stages of the process, including factors such as incompatibility or bottle-necking.
- There is limited research that provides evidence that economic goals and sustainability goals are connected in the studies in the sample. Most literature identifies the potential for sustainability impact only.
- The implementation process regarding packaging and processing technologies is recognised as important. Proper planning and feasibility analyses of technology upgrades will enable a strategic, harmonious, and cost-efficient approach to technology implementation, in contrast to acting based on the novelty or value posed by one improvement.
- Communication between stakeholders throughout the supply chain further enhances the benefits supplied by a strategic approach, ensuring that implemented technologies are adopted and managed towards target outcomes.

These insights are presented in a summary in **Figure 2**. The summary shows that the Processing and Packaging technologies and machinery have a strength in the middle of the supply chain, which offers a range of opportunities for collaboration and expansion up- and downstream. To create a more circular system, more attention needs to be given to measure waste and loss impact.

FIGURE 2

Summary of machinery and technologies across the food supply chain and how they tackle food loss and waste



Acknowledgements

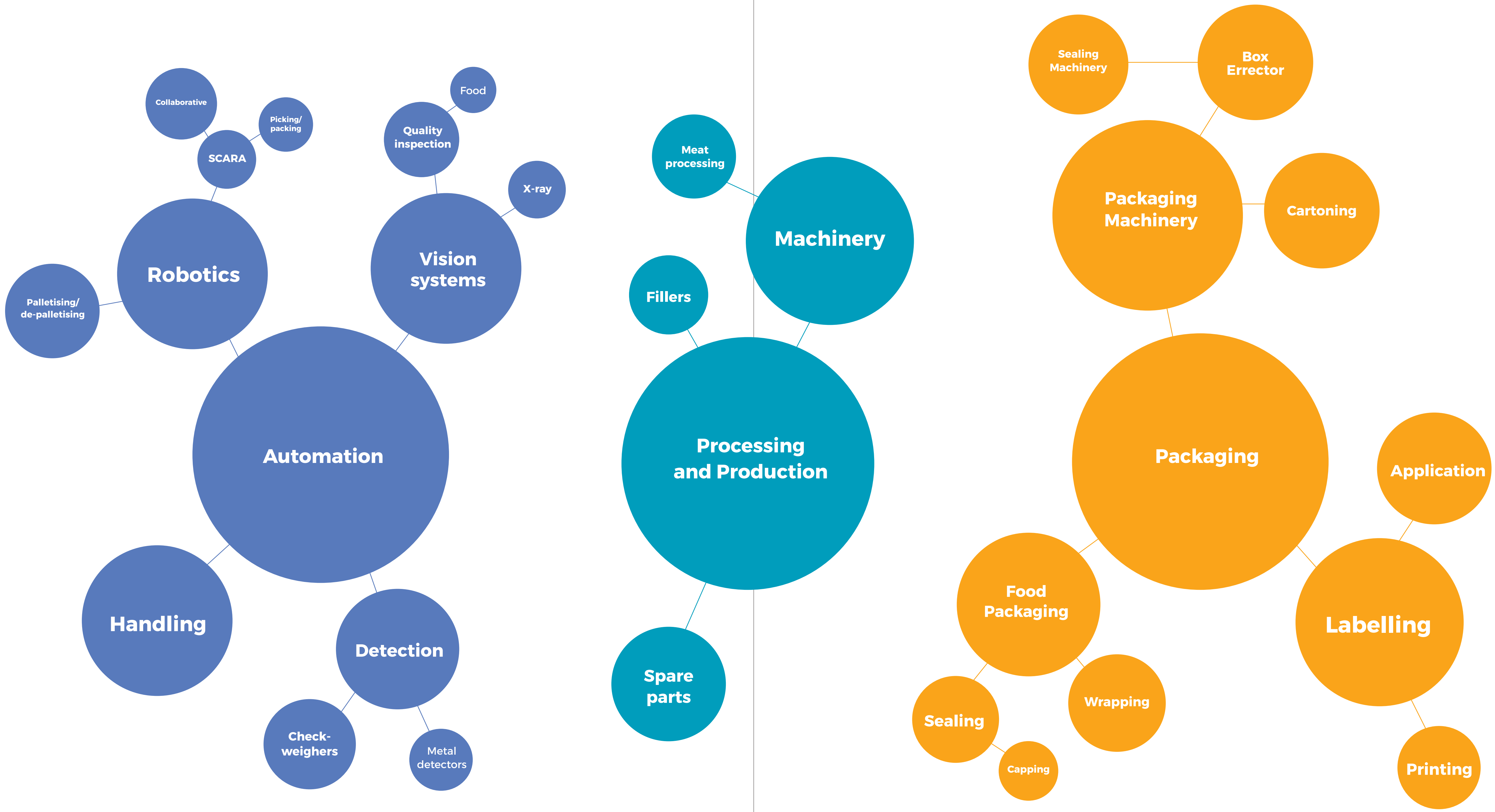
This research project is funded by the Fight Food Waste Cooperative Research Centre in partnership with the Australian Packaging and Processing Machinery Association (APPMA) and RMIT University. The project is a one-year study to further understand the opportunities for packaging and processing machinery to tackle food waste project.

The Fight Food Waste Cooperative Research Centre activities are funded by the Australian Government's Cooperative Research Centre Program. The CRC Program supports industry-led collaborations between industry, researchers and the community. Find out more about the Fight Food Waste CRC **here**.

Appendix

5.1

APPMA Members' focus of organisation map



5.2

List of search term combinations

All search term combinations listed below were used with "food loss OR food waste" as the primary search term.

Secondary - Search Terms	Tertiary - Search Terms	Further - Search Terms	
automation	checkweigher		
automation	handling	conveyors	
automation	handling	counting	
automation	handling	distribution	waste reduction
automation	handling	pick and place	
automation	handling	sorting	
automation	quality control	detection	
automation	quality control	sensors	
automation	robotics	collaborative	
automation	robotics	palleti/sing/zing	
automation	robotics	pick and place	
automation	robotics	sensors	
automation	vision system/s	inspection/s	
collaborative strategy/ies			
food processing OR food production	temperature management		
food processing OR food production	sterilisation		
food process/ing technology			
food packaging	labelling	application	waste reduction
food packaging	labelling	date/s	waste reduction
food packaging	machine/ry/s	capping	
food packaging	machine/ry/s	FFS	
food packaging	machine/ry/s	films	waste reduction
food packaging	machine/ry/s	filling	
food packaging	machinery	packing	waste reduction
food packaging	machine/ry/s	wrapping	

Secondary - Search Terms	Tertiary - Search Terms	Further - Search Terms	
food packaging	machinery	sealing	
handling machine/s/ry			
processing OR production	machine/ry/s	blending	waste reduction
processing OR production	machine/ry/s	extrusion	waste reduction
processing OR production	machine/ry/s	granulator	
processing OR production	machine/ry/s	homogenisers OR homogenizers	
processing OR production	machine/ry/s	pasteuriser OR pasteurizer	
processing OR production	machine/ry/s	pneumatics	
processing OR production	machine/ry/s	sterilisation OR sterilization	waste reduction
processing OR production	machinery	cooking	waste reduction
processing OR production	machinery	electronics	waste reduction
processing OR production	machinery	filling	waste reduction
pack/aging innovation/s			
packaging	labelling	printing	
pack/aging machine/s/ry			
packaging	machinery	box erector	
packaging	machinery	cartoning	
packaging	machinery	sealing	
process/ing innovation			
process/ing machine/s/ry			
R&D equipment			
shelf life extension	machine/s/ry		
tech/nology trade-offs			
vision system/s			

5.3

Consolidated list of literature

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