

Packaging's Role in Minimizing Food Loss and Waste Across the Supply Chain

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This paper presents the results of Australian research that explored the role of packaging in minimizing food waste in the supply chain. The economic, social and environmental costs of food waste have been well documented elsewhere. This research contributes to the debate by identifying opportunities to reduce or recover food loss and waste through improved packaging.

In the fresh produce sector, e.g. waste can be reduced through the use of packaging that improves product protection, ventilation and temperature control. Other opportunities include improved design of distribution packaging to reduce damage in transport and handling; design of primary packaging to reduce waste in the home, e.g. through appropriate portion sizes and by reducing confusion over date labels; and the use of retail-ready packaging that minimizes handling and improves stock rotation in stores. An important conclusion of the study is that packaging can have a significant impact on reducing food waste in the food supply chain; and in some cases, a focus on reducing food waste will require more rather than less packaging. Packaging developers must therefore consider the product and its packaging as a complete system to optimize sustainability. Copyright © 2015 John Wiley & Sons, Ltd.

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INTRODUCTION

The global food supply chain faces significant challenges as a result of population and environmental pressures.^{1–11} With the global population predicted to rise from 7 to 9 billion by 2050,¹² the supply of food will need to increase by an estimated 77% compared with that in 2007⁸. This challenge is compounded by the diminishing availability of both productive agricultural land and clean water, which is influenced by salinity, drought, floods, climate change and competing land uses.¹³ It is estimated that around 40% of all food intended for human consumption in developed countries end up as waste.³

Food 'loss' occurs during agricultural production, post-harvest handling or processing, whereas food 'waste' occurs at the end of the food chain (during distribution, retail sale and final consumption).¹⁴ The reasons for food loss and waste are many and complex, e.g. Quested *et al.*⁹ and Buzby and Hyman¹⁵ requiring action and cooperation by stakeholders at each stage of the food supply chain. Solutions to this problem include increased efficiency and waste reduction in the food supply chain, better planning by consumers¹⁶ and improved packaging systems.¹⁷ Product protection, which is the primary goal for packaging sustainability, sometimes requires more packaging rather than less to reduce food waste.^{18,19} This paper presents the results of Australian research that explored the opportunities to design packaging to play an even greater role in reducing food waste.

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BACKGROUND – ROLE OF PACKAGING IN FOOD PROTECTION

Packaging plays a vital role in containing and protecting food as it moves through the supply chain to the consumer. Functions of packaging include²⁰

- protection, including preventing breakage, spoilage and contamination;
- promotion, including describing product features, ingredients and branding;
- information, including product identification, product preparation and end-of-life management;
- convenience, including preparation and portioning;
- utilisation and handling, including providing for transport and retailing; and
- waste reduction, including increasing shelf-life.

With respect to food, the functions of packaging are continually evolving from simple preservation methods to include aspects such as convenience features, tamper evidence, active packaging innovations that extend product shelf life or improve safety or sensory properties while maintaining product quality and intelligent technologies that provide stakeholders with the status of the food or its surrounding environment.²¹ According to Grönman *et al.*²², the main function of packaging ‘is to protect and distribute the right product to the right end-user in a safe, cost-efficient and user-friendly way’.

In order to supply the increasing demands of consumers for fresh and processed foods all year round, a combination of different materials and packaging formats is used to contain, protect, preserve, distribute and sell each food item. Packaging can be divided into the following:²³

- Primary packaging: the retail or consumer pack that contains the sales unit (e.g. a plastic bag, glass jar or steel can, or a plastic crate for loose fresh produce).
- Secondary/tertiary packaging: additional layers to protect and contain the primary packs during distribution (e.g. a corrugated box, plastic or timber pallet, plastic crate for processed foods or stretch wrap).

Packaging designed to effectively contain and protect food, or be ‘fit-for-purpose’²⁴ across the supply chain should minimize both food and packaging waste. However, minimizing food waste is generally the priority because it accounts for a larger proportion of the life-cycle environmental impacts of the food-packaging system.^{17,19,22,25,26} As an example, on average, packaging is estimated to account for only 10% of the total energy inputs for one person’s weekly consumption of food (Figure 1). Packaging plays a critical role in ensuring that the other 90% of energy inputs to the supply chain are not wasted.

Product protection needs to be the primary goal for packaging sustainability, and sometimes, this requires trade-offs between the amount of packaging and the amount of food waste generated. It is therefore critical to recognize and investigate the potential trade-offs between packaging consumption and food waste that may be required to produce the best environmental outcome (Figure 2). For example, the shift to single-serve formats in some food categories may result in more packaging per serve, but the potential for food waste is reduced, meaning the overall environmental impact from the system of food and packaging will decrease.^{17,18}

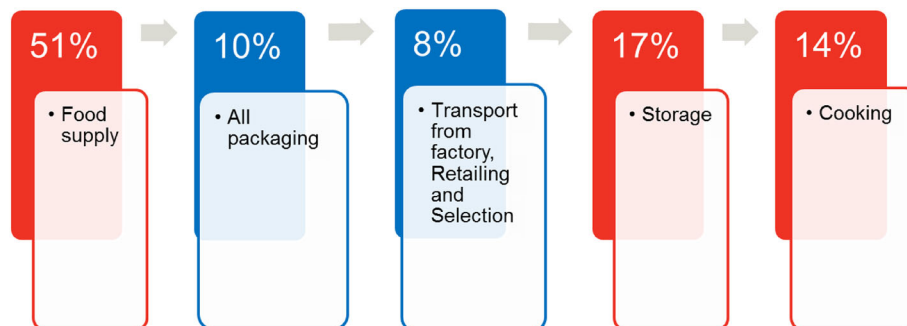


Figure 1. Energy for one person’s weekly consumption of food, MJ/person/week. Source: Adapted from INCPEN and Verghese *et al.*^{69,29}

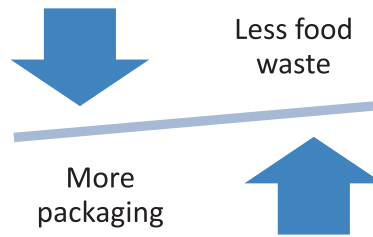


Figure 2. Trade-offs between food waste and packaging.

In addition to product protection, the decision to use a particular type of packaging is a complex one driven by demands at numerous points along the supply chain (Figure 3) including the intended market for the product/packaging.²⁷

The increasing focus on food waste adds another dimension to the decision-making process. Through a literature review and interviews with stakeholders (as described in the Section on Data and Methods), an understanding of where and why food waste occurs throughout the supply chain was assembled (Section on Where and Why Food Waste is Generated). With the insights gained from the literature review, and also from stakeholder interviews, it was then possible to identify where opportunities exist for packaging to be improved to protect food and reduce food waste (Section on Opportunities to Reduce Food Waste through Improved Packaging).

DATA AND METHODS

There has been little research on the role of packaging in protecting fresh and processed foods at every stage of the supply chain, and in reducing food waste. These important functions are often overlooked in debates about food security and waste. One reason for this is the focus on legislation to minimize packaging because of a perceived waste problem (e.g. Institution of Mechanical Engineers²⁸). The need for further research on these interactions was originally identified in the Australian Food and Grocery Council's Future of Packaging White Paper.²⁹ The research presented in this article makes a unique contribution by focusing on packaging opportunities that may help to reduce food waste along the entire supply chain.

The research presented later in the text drew upon an international literature review and interviews with representatives from 15 organizations in the Australian food and packaging supply chain. It

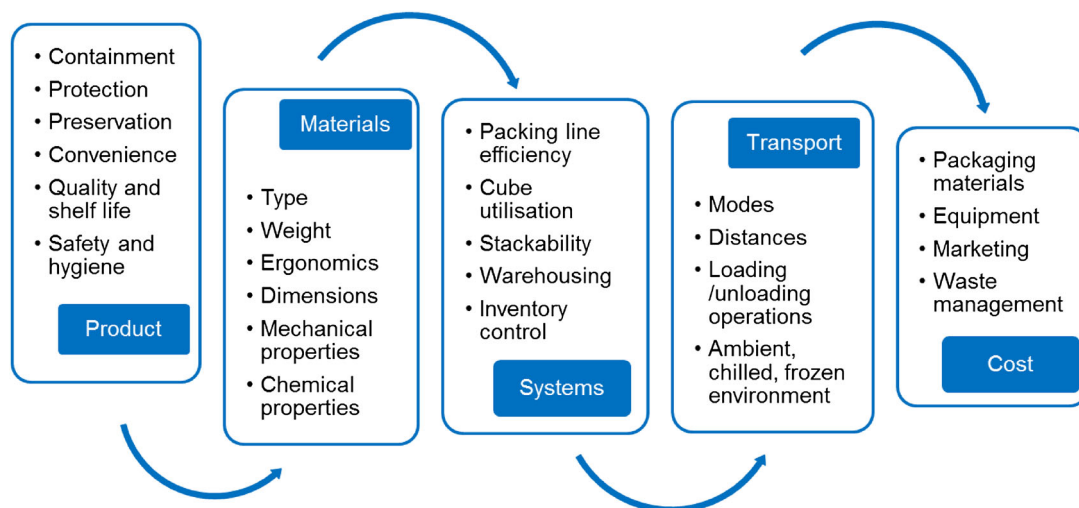


Figure 3. Examples of packaging decisions for fresh and processed foods. Source: Adapted from Olsson *et al.*; Hellstrom and Saghir; Robertson; and Azzi *et al.*⁷⁰⁻⁷³

Table 1. Summary of online database literature review.

Online database	Search result
ScienceDirect	151 articles found for: TITLE-ABSTR-KEY('food waste') and TITLE-ABSTR-KEY('food loss') AND LIMIT-TO (contenttype, "1,2","Journal") 36 articles found for: TITLE-ABSTR-KEY("food loss") AND LIMIT-TO (contenttype, "1,2","Journal")
Springer LINK	69 Result(s) for 'food AND waste AND "food loss" AND (cause OR or OR reason)' within Article
Wiley Online	There are 75 results for: food loss in Abstract AND food waste in All Fields AND packaging in All Fields

considered food waste along the entire food supply chain, but with a particular emphasis on food waste that occurs prior to consumption, i.e. during agricultural production, post-harvest handling and storage of raw materials, and in the commercial and industrial (C&I) sector (food manufacturing, wholesale trade, food retail and distribution, and food services). The role of food 'rescue' was also considered, by engaging Foodbank, Australia's leading not-for-profit food rescue organization, and documenting their operations and their packaging requirements.

The literature review

While it is acknowledged that packaging waste also occurs through supply chains, this was not the focus of the research. The literature review investigated food waste in the supply chain, including the quantities wasted and reasons for this waste in relation to packaging.

The initial literature review was undertaken in March 2013 from three databases: ScienceDirect, Springer LINK and Wiley Online (as detailed in Table 1). The abstracts in the scientific journals were studied, and those that explicitly mentioned why food is wasted and how much is wasted were selected for deeper analysis. A selection of unpublished reports was also reviewed. The analysis of the literature review is presented in the Section on Where and Why Food Waste is Generated.

Stakeholder interviews

The interviewees, who included representatives from farming, food manufacturing, packaging, wholesale, retail and food rescue organizations, were selected from the research team's industry contacts and the funding body's customers. They were initially approached via email and phone, with details of the study and reasons for stakeholder engagement, and invited to participate in an interview. The interviews were conducted by one of the research team, by phone or face-to-face, and generally took 1 h to complete. They were audio-recorded and later transcribed in a point form.

The interviews provided personal insights into the role of packaging in minimizing food waste and opportunities for improvement. These insights and quotes from interviewees were combined with the literature review to make the analysis of packaging opportunities more profound (Section on Opportunities to Reduce Food Waste through Improved Packaging).

WHERE AND WHY FOOD WASTE IS GENERATED

Efforts by government agencies, farmers, food producers, retailers and consumers to measure and understand the reasons for food waste have gained momentum in recent years. According to a report to the Food and Agriculture Organization of the United Nations, 1.3 billion ton of food produced for human consumption is lost or wasted globally each year⁵.

There is no publicly available data on the percentage of food that is grown or sold in Australia for human consumption that eventually becomes waste. However, food loss for North America and Oceania combined (including Australia) is estimated to be around 280–300 kg/capita/year,⁵ which is

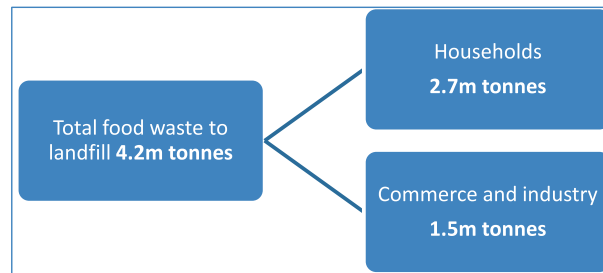


Figure 4. Sources of food waste in Australia. Source: Estimates from DEWHA⁷⁴ and Encycle Consulting and Sustainable Resource Use.³² Note: These figures exclude food that does not reach its intended market and is either donated to charity, sold at a lower market value (e.g. as stock feed) or recycled.

equivalent to around 6.5 million tonnes of food waste in Australia^a (based on population data from ABS.³⁰) The average household in New South Wales throws out \$1036 of food each year.³¹ If this figure is extrapolated to all households in Australia, the total figure is close to \$8bn.^b

Around 4.2 million tonnes of food waste are disposed to landfill in Australia each year, with an estimated 2.7 million tonnes from households and 1.5 million tonnes from C&I (Figure 4).

The largest single sources of food waste in the C&I sector are the food services, food manufacturing and food retail sectors³² (Figure 5):

- The food services sector, made up of businesses such as hotels, pubs, restaurants, cafes and commercial caterers, is the single largest contributor of food waste (generating 661 000 tonnes) with only 2% being recycled.
- The food manufacturing sector generates a significant amount of food waste (generating 312 000 tonnes), although most of this (an estimated 88%) is recycled. This is because manufacturers produce relatively consistent and uncontaminated wastes that can be used for animal feed or as feedstock for composting.
- The food retail sector is the third largest contributor of food waste (generating 179 000 tonnes), while only 5% is recycled.
- The remaining food waste is generated in manufacturing and service organizations that are largely outside the food supply chain (generating 680 000 tonnes). Most of this waste is related to employee consumption, i.e. generated in canteens and kitchens.

The main reasons that food is lost at the agricultural and post-harvest stages in less developed countries are inefficient harvesting, storage, transport and processing.⁷ This is very different to developed countries, where waste tends to move up the distribution chain to the retail and consumer levels.^{6,7} There are many reasons why food is lost and wasted across the supply chain, e.g. Gunders; Gustavsson, Cederberg and Sonesson; Queded *et al.*; Mason *et al.*; Baker, Fear and Denniss; Katajajuuri *et al.*; Mena, Adenso-Diaz and Yurt; Reidy *et al.*; Stuart; Sustainable Restaurant Association; Ventour; Viridis; and Williams *et al.*;^{4,5,9,16,33–41} and quotes from interviews reported by Verghese *et al.*⁴² They include the following:

- Agricultural production: damage from pests and disease; unpredictable weather conditions; and not meeting quality specifications
- Post-harvest handling and storage: not meeting specifications for quality and/or appearance; pest damage; and spillage and degradation
- Processing and packaging: trimmings and other food preparation waste; production line start-up; batch mistakes; and inadequate remaining shelf life

^aBased on a population of 22 893 354.

^bBased on ABS figure of 7 760 320 occupied dwellings from the 2011 census (www.censusdata.abs.gov.au/census_services/getproduct/census/2011/quickstat/0).

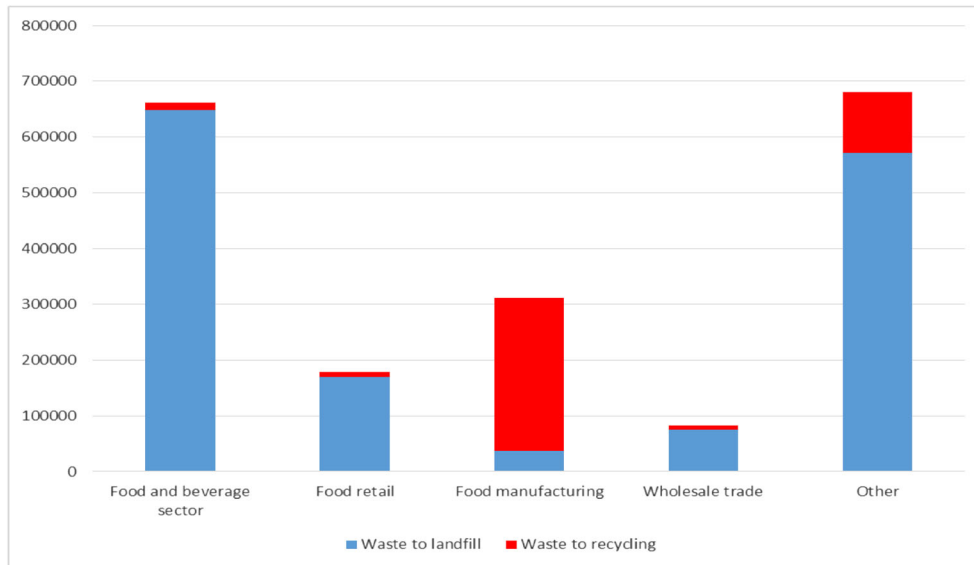


Figure 5. Food waste generated in the commercial and industrial sector in Australia and sent for recycling and landfill, 2012* (tonnes). Source: Based on unpublished data from Encycle Consulting and Sustainable Resource Use.³² *The 'other' category includes over 20 other sectors that include all other manufacturing (mainly plate waste from canteens and kitchens), other retail, accommodation, finance and other service sectors.

- Distribution (wholesale and retail): damage in transit/storage due to packaging failures; product spoilage; fresh produce not meeting specifications or damaged during handling; and inadequate remaining shelf life due to poor stock rotation or low sales
- Food service: trimmings and other food preparation waste; poor inventory management (e.g. over-ordering); improper food handling; confusion over use-by and best-before dates; and plate leftovers
- At home: trimmings and other food preparation wastes; food spoilage; preparing too much food; past use-by or best-before dates; and plate leftovers

OPPORTUNITIES TO REDUCE FOOD WASTE THROUGH IMPROVED PACKAGING

There are many opportunities to design appropriate packaging systems to deliver protection of fresh produce and processed food in transit, storage, at point of sale and prior to consumption. These are discussed in the following sections and summarized in Figure 8.

Agricultural production and post-harvest handling and storage

Improved protection, ventilation and temperature control. *We believe most of the damage to fruit occurs at the picking stage, we heavily monitor this as bananas are easily bruised in the packing areas, things like knife cuts etc. can be problems if not monitored. We used to use a two piece carton, but we believe that neck injury damage that was being sustained during transport was too high and hence moved to a stronger, higher box. Broken neck damage has almost been completely eliminated. By using the "clear bag" which was introduced to our business nearly 4 years ago, we have also increased shelf life of the product. Food waste results from poor staff training, poor quality monitoring and the use of inferior packaging products.*

Interviewee – Banana grower

There are many elements to consider around the selection of packaging to ensure fresh produce moves efficiently from farm to consumer. Primary and secondary packaging systems used to contain, protect and transport fresh produce or meat/fish from the farm or fishery through to the packing shed,

processor, wholesale or retailer include single-use corrugated containers, waxed cardboard and reusable plastic crates. In fresh produce, e.g. a good understanding of the natural characteristics and shelf life of different fruits and vegetables and meat/fish, in conjunction with considerations such as packaging materials that provide ventilation and temperature control, logistics, transport distances, storage and handling conditions, and procurement costs will lead to reducing food loss and waste. For instance, there is significant loss of bananas each year in Australia with a combination of reasons for such waste including inadequate packaging and poor staff/consumer handling. Trialling of reusable plastic crates or usage of more stable corrugated cartons in conjunction with the introduction of retailer-owned ripening rooms has seen significant savings (Figure 6).

Recover and redirect to food rescue. *Two years ago we saw the plateauing of processed food, followed by a decline in supply. We are now increasing supply from the farm gate, and our aim is to increase the proportion of fresh fruit and vegetables to around 40%.*

Interviewee – Food recovery agency

As manufacturers and retailers become more efficient in managing their stock, the amount of surplus and unsaleable processed food being provided to food rescue organizations is levelling off. Foodbank, Australia's largest food rescue organization, has in recent years been exploring opportunities to increase supply from the farm gate.^{43,44} This will require new and efficient logistics and packaging systems that can contain necessary quantities from farm or post-harvest handling all the way through to the charitable agencies warehouses and distribution centres. It is important to limit re-packing to ensure efficiency in the supply chain and also to protect the food items as additional re-packing could lead to damage and generation of unnecessary waste. These packaging systems will need to accommodate the transport of bulk quantities from farm to food recovery organizations, as well as smaller orders from distribution centres to individual charities.

Processing and packaging

Fit-for-purpose. An essential objective at any stage of the food supply chain is to ensure that packaging is 'fit-for-purpose',²⁴ which means being designed to meet market and consumer needs at minimal cost.^{22,24} This requires dialogue with suppliers and customers to ensure that functionality and efficiencies are achieved across the supply chain. For example, procurement of secondary and tertiary packaging requires an understanding of the physical demands on packaging as it travels through the supply chain:

We purchased a company last year and found a very high rate of damaged packaging. The source of the problem was inadequate packaging design in the initial selection. It was designed without knowing that pallets are stacked two high in distribution, and it was very rare for a pallet to get through the supply chain without damage. They were relying on suppliers and co-manufacturers to provide advice on packaging but they weren't receiving good technical input. There was a lack of understanding of the distribution chain and what was required. Interviewee – Food brand owner



Figure 6. Banana loss and waste, and process and packaging opportunities to improve efficiencies. Source: Quantity of loss from White *et al.*⁷⁵; column two from interview reported by Verghese *et al.*⁴²; column three from Ekman *et al.*⁷⁶ and from an interview reported by Verghese *et al.*⁴²

Pre-packed or processed foods. The popularity among consumers of ‘convenience’ foods that reduce preparation and cooking time^{45,46} must be balanced with the desire of processors and retailers for extended product shelf life. Fresh produce that is pre-packed, often with some processing (e.g. cut and washed lettuce leaves), and foods that are ready to eat (e.g. fresh soups or frozen meals) are such examples. The challenge is to ensure that product-packaging design balances convenience, packaging materials, product shelf life and product waste for each type of product by utilizing available innovations in packaging materials (e.g. Mahalik⁴⁷ and Quested *et al.*⁴⁸) and new formats that cater to changing demographics such as smaller households⁴⁹ and an ageing population.⁵⁰ For example, a fresh produce supplier interviewed for this research noted that plastic film around a bunch of fresh herbs can extend its shelf life from 2 to 5 days, and the use of plastic punnets can double this again. However, there can also be negative impacts upon shelf life. For instance, some fresh cut vegetables may have a shorter shelf life because of washing, peeling and cutting, which result in a faster physiological deterioration and microbial degradation.⁵¹

Packaging can also make it more difficult to recover food at retail if it has perished or passed its use-by date:

A big issue for us is that we’re getting more produce in packaging, for example in punnets. These need to be manually handled to remove the produce for recycling. The recycler can handle some contamination but not all in one load.

Interviewee – Produce market

These potential impacts on food waste are illustrated for a hypothetical example in Figure 7, which compares a pre-prepared packaged salad with a salad made from individual ingredients at home.

Packaging materials and technologies that extend shelf life. There are many new technologies that help maintain produce and product freshness for longer periods (Table 2). Most of the technologies are applied to primary packaging, because this is where shelf life is a critical design requirement. Secondary and tertiary packaging are generally used to facilitate the movement of the primary pack through the supply chain, rather than to extend shelf life. As one food brand owner quoted:

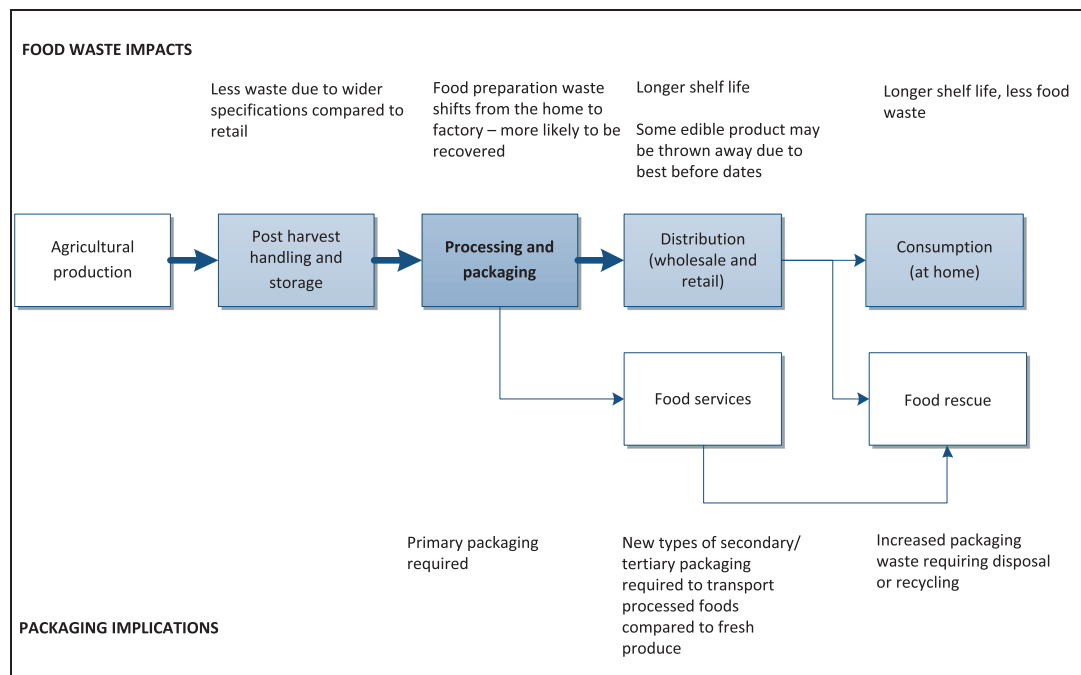


Figure 7. Buying pre-prepared foods – possible impacts on food and packaging waste.

Table 2. Examples of primary-packaging technologies to extend shelf life.

Technology	Description	Potential impact on food waste
Multi-layer barrier packaging	Packaging that contains multiple layers to provide the required barriers against moisture, gases (see MAP later in this table) and odour. Specific requirements can be met using a combination of polymers, aluminium foil and/or coatings.	Keeping out moisture and oxygen delays product degradation.
Modified atmosphere packaging (MAP)	Gases are added to packaging before it is sealed to control the atmosphere within the pack, and then maintained by a high-gas barrier film, e.g. through vacuum packaging. Carbon dioxide is added, alone or with nitrogen and sometimes oxygen, depending on the product (e.g. meat, cheese, fruit and vegetables).	Reduces respiration rates in the product and reduces growth of microorganisms.
Edible coatings	Based on a range of proteins, lipids, polysaccharides and their composites, they can be used on fruit, vegetables, meat, confectionary and other products.	Creates a barrier directly around food products (rather than external packaging).
Ethylene scavengers	A range of different technologies that involves chemical reagents added to polymer films or sachets to absorb ethylene. Used for fruit and vegetables.	Removal of ethylene delays ripening and extends the shelf life of fresh produce.
Oxygen scavengers	Substances that remove oxygen from a closed package. They are often in powder form (e.g. rust powder) in a sachet. New technologies include oxygen scavengers in the film itself. Used for sliced processed meat, ready-to-eat meals, beer and bakery products.	Oxygen accelerates degradation of food by causing off-flavour, colour change, nutrient loss and microbial attack (bacteria and fungi). Removing oxygen slows the degradation process and extends the shelf life of the food.
Moisture absorbers	Pads made from super-absorbent polymers, which absorb moisture. Used for fresh meat, poultry and fresh fish.	Maintains conditions that are less favourable for growth or microorganisms.
Aseptic packaging	Packaging that has been sterilized prior to filling with ultra-high-temperature (UHT) treated food. This gives a shelf life of over 6 months without preservatives. Formats include liquid paper board, pouches and bag-in-box.	High temperatures kill microorganisms, and tight seals on the packaging prevent the entry of microorganisms, gas or moisture that could promote degradation.

We are trying to achieve a better product shelf life, and packaging plays a major role in that. We are looking for any gains that we can get that will influence our ability to produce goods in advance of the dates they are required, but also to enable things to be on the shelf for longer, to allow the consumer to feel more confident about the products they are purchasing... this allows for a longer supply chain and will reduce food waste through spoilage.

Interviewee – Food brand owner

From a cost and food waste perspective, it is particularly important to protect food products with high environmental impact, like fish, meat and dairy products (e.g. Institute of Mechanical Engineers⁶ and Kummu *et al.*⁷). Packaging solutions such as modified atmosphere packaging (MAP) or time-temperature food quality labels may increase shelf life.⁴⁷ It is also important in the product-packaging design development to understand consumer's perceptions and acceptance of these technologies. It is all good and well to develop such technologies, but if consumers do not understand their objectives and operations, or have levels of mistrust in their design and use, then they will not be accepted. For instance, a study of consumers (via focus groups and surveys) from France, Greece, Germany and Finland, when presented with an example of a time-temperature indicator (TTI), found that one of the negative perceptions was around the design of the label – 'the removability ("sticker-like nature") of the TTI caused mistrust as it was considered possible that actors along the cold chain could manipulate the indicator. Further, the safety of the TTI was challenged (all countries except Greece)'.⁵²

Date marking. There is evidence to suggest that confusion about the meaning of date labelling such as ‘best-before date’ and ‘use-by date’,^{4,37,53–55} results in edible food being removed from supermarket shelves or thrown out by consumers. The Food Standards Code in Australia only requires a use-by or best-before date on packaged food with a shelf life of less than 2 years. Despite this, dates are increasingly being added on products with a shelf life longer than 2 years to aid with stock management and to help consumers identify how long a food has been in their pantry.⁵⁶ Newsome *et al.*⁵⁵ have also found that globally regulatory frameworks for date labelling vary considerably as they may be based upon food quality, safety, health, nutrition or a combination. They listed examples of the different date labelling terminology that included ‘sell by’, ‘use-by’, ‘best-before’, ‘best-by’, ‘best if used by’, ‘best if used before’, ‘durable life date’, ‘minimum durability’, ‘frozen on’, ‘display until’ and ‘best if purchased by’. All of which have the potential to lead to confusion and misunderstanding between manufacturers, retailers and consumers of how dates relate to food safety and quality. Manufacturers need to ensure that the clear and appropriate date labels on packaging are visible and easy to read. Missing or inadequate labelling may prompt consumers or retailers to throw food away when it is still edible.

Design for smaller households. Trends towards online shopping,⁵⁷ an ageing population,⁵⁰ smaller households⁴⁹ and the demand for more convenience and pre-prepared foods are all significant social and lifestyle changes. There are opportunities to redesign product-packaging configurations to help consumers reduce waste through a selection of packs sizes and other convenience features,^{19,58} although pricing policies need to support consumers to ensure they see value in the smaller pack sizes (and that they will not waste product) instead of being encouraged to buy larger pack sizes because of quantity discounts.⁵⁹ However, the trend towards bulk retailing to provide value for consumers may increase food waste if consumers end up buying more than they need:

Because of their focus on value [earning more money], retailers are pushing for larger format products ... This might be driving product into the pantry, but some product will degrade before it's consumed. "Two for one" and large formats are going against demographic trends, which are towards smaller households and people eating alone.

Interviewee – Food brand owner

Examples of design strategies for primary packaging to reduce food waste are described in Table 3. The same considerations apply to primary packaging whether the product is sold in-store or online.

Consumers understanding and perception of packaging technologies and packaging misconceptions. While many packaging technologies, such as MAP, active packaging and intelligent packaging including TTIs, radio-frequency identification data (RFIDs) and integrity or freshness indicators and sensors exist or are being developed, further research is needed to understand consumers understanding, perceptions and acceptance of the technologies.

In the case of TTIs, investigating consumers’ understanding and trust of such technology is important because it relates to how the technology is accepted and implemented into the market.⁵² Pennanen

Table 3. Examples of primary-packaging design to reduce food waste in the home.

Design feature	Description	Potential impact on food waste
Reclosable packs	Examples include zip-lock bags and pouches, resealable cheese and cereal bags, and ‘fridge packs’ (plastic screw-top jars) for products like baked beans.	Being able to reseal packs helps to keep food fresh for longer.
Smaller packs	Examples include half loaves of bread and single serves of yoghurt.	Allow smaller households to only buy what they need.
Subdivided packs	Packs divided into portions, e.g. sliced meat in separate compartments.	Allow consumers to use what they need and keep the remainder sealed in the packaging.
Detailed storage advice on the label	This could include where to store the food, e.g. whether or not it should be stored in the fridge, or encouraging consumers to ‘freeze before the date’.	Could improve food storage practices and extend shelf life in the home.

et al.'s⁵² recent research involving French, Greek, German and Finnish consumers has identified both positive and negative perceptions of TTIs for packaged meat/poultry and fish.⁵² Positive perceptions included TTIs inducing safety and security with respect to cold-chain management before and after purchase; an additional selection criterion when purchasing food items; and general excitement of the innovative aspects of the technology. Negative perceptions included concern related to increased food waste caused by TTIs; mistrust regarding the possibility for retailers to manipulate or remove TTIs (due to the fact they are not integrated into the packaging); consumers not using their own judgement to determine freshness and relying upon the labels to indicate freshness; reliability of the technology; confusion by the consumer in proper interpretation of the TTI message (e.g. does slight colour change mean throw product out?); or relationship with other freshness indicators (e.g. if TTI was in contradiction with best-before or expiration date label). Using TTIs as an example of intelligent packaging, challenges and opportunities therefore still exist for this technology's broader application and use.

Consumers tend to also have a poor understanding of the benefits of packaging, with a limited awareness or even negative perceptions in regard⁶⁰ to the role of packaging in keeping a product safe and fresh. As a result of this knowledge gap, some people remove food prematurely from packaging designed to keep it fresher for longer, or pierce the packaging to let food 'breathe'.⁶⁰ The benefits and challenges of packaging technologies and how they can best meet the needs of specific food supply chains and enabling the movement of product to market need must be considered alongside consumer understanding and perceptions of such technologies. Mapping stakeholder needs and expectations against these packaging and technology interactions could also provide for valuable information. Clear advice on packaging, e.g. on whether or not food can be frozen, and use-by and best-before dates, could help to improve consumer understanding and behaviour.

Distribution (wholesale and retail)

Understanding and tracking supply chain losses. *We aim to waste no more than 5% of our [produce] in the packaging plant. This is not being monitored properly at the moment so we're putting a process in place to collect better data. We already know our daily output and we're putting scales on the line to weigh product coming into the facility.*

Interviewee – Grower

There is still a low level of understanding and tracking of supply chain losses from the initial production or processing point through to the retailer. There is an opportunity for growers and manufacturers to work more closely with retailers to understand and monitor food waste in the supply chain. A large brand owner in the USA, e.g. works closely with its retail customers to audit the quantity of 'unsaleable' products.⁶¹ Week-long audits are conducted at their customers' warehouses and retail stores to identify any sources of waste and to identify opportunities to improve efficiencies. Over the past 10 years, the quantity of unsaleable products has fallen by almost 50% at this US brand owner.

Intelligent packaging and data sharing. Collaboration and information transparency will 'enable a more synchronised value chain with greater visibility and traceability'.²³ As an example, retailers are starting to share data on sales and demand forecasts with their major suppliers to improve their production planning, achieve faster stock turnover and reduce waste:

Now that we've got an integrated data management system, we can see what the customer has in stock and we can work out what we need to make and what we need to send them. This means that we can keep our inventory as low as possible. We used to get truckloads of stuff out of date – it just wasn't moving. That tends not to happen these days. We are more in control of it, so we've moved onto other things.

Interviewee – Food brand owner

Product waste is increasingly tackled by improving the systems that forecast demand and by sharing data on sales and stock levels. For example, Coles Supermarkets in Australia is now buying grocery and dairy products with a just-in-time approach through an automated sales-based system forecasting demand for a particular store.⁶² This approach can also include shared logistics between supply chain actors that traditionally had separate transport channels.

Table 4. Examples of intelligent packaging and impacts on food waste.

Technology	Description	Potential impact on food waste	Challenges
Radio-frequency identification (RFID) tag ('smart tag') in primary, secondary or tertiary packaging	Contains a microchip, normally enclosed in plastic, which stores data on the product, e.g. use-by date. Hundreds of tags can be read simultaneously from metres away.	Can be used to trace products throughout the supply chain (in transport, at the distribution centre, entering and leaving the backroom at the retail store etc.). RFID tags improve inventory control, minimizing 'out of stock' and ensuring that products are sold before they are out of date and require disposal. They can also record the temperature history of the product (see the text later in this table).	High infrastructure costs compared with bar codes. Accuracy problems in applications involving a large amount of metal or water.
Thermal sensors	A range of technologies that can indicate the time-temperature history of the product, e.g. thermochromic inks that change colour when a temperature has been exceeded or changed, or digital data loggers that can indicate the period during which a product experienced out-of-tolerance temperatures.	Can be used to ensure that products stay within their required temperature range during distribution, particularly in cold chains. Time-temperature labels on consumer packaging can also help consumers to know when a product is safe to eat.	Higher packaging costs. Exposure of thermochromic inks to ultraviolet light, high temperatures or solvents may degrade colours or functionality.

Intelligent food packaging (examples shown in Table 4) can complement collaboration and data sharing by providing real-time use-by or expiration data, product tracing and temperature indicators (either time based, activated by certain chemicals, driven by radio-frequency identification data or thermal sensors) to provide better 'on-demand' feedback to various supply chain stakeholders.⁶³ Intelligent technologies in primary, secondary or tertiary packaging can send information back to suppliers on quality, safety, shelf life and logistics efficiency,⁶⁴ which in turn can be used to reduce product time in the supply chain, extending shelf life, reducing the likelihood of product spoilage and increasing the potential to reduce food waste in the supply chain.

For food products with low environmental impact, investments in these technologies may be too high from both economic and environmental perspectives; in other words, the functional positives of the technologies may be outweighed by the costs. It is also important to monitor and manage any possible negative effects of new technologies on packaging recycling.

Retail ready packaging. Retail-ready packaging generally describes packaging that is a ready-to-sell at retail as a merchandized unit that delivers products direct from the grower or processor. This can include merchandizing units or 'shelf-ready packaging' (SRP), or directly on the shop floor (full or fractional pallets), and can include one-way or reusable options.

Shelf-ready packaging has particularly increased with new secondary-packaging formats developed with a reduced number of retail units in each secondary pack and 'easy-opening' features. Retailers have pushed this rise of SRP (generally cartons and boxes), claiming they reduce product waste because of increased sales (through better visibility and availability) driving stock rotation, and in turn increasing the speed of replenishment.⁶⁵ SRP is also designed to facilitate better product recall processes, with better stock accountability and potentially less waste in the process.⁶⁶

Generally, the benefits of SRP to retailers have been improved operational efficiencies at the store level. This is achieved by 'designing from the shelf back', with packaging configurations developed to reflect the sales volume and to maximize layout considerations.⁶⁷ There are associated benefits for food manufacturers because faster restocking helps to ensure that their product is always available on the shelf:

SRP has been introduced to improve productivity, but it may have some benefits for food waste. If there is product at the back of the shelf the customer won't see it, whereas SRP helps to keep the product front and centre.

Interviewee – Retailer

There has been anecdotal evidence, however, that SRP increases product waste in transport and storage. One of the most common formats is a perforated shipper that allows for easy opening. Perforations can also reduce box strength, leading to crushing or breaks during transport, storage and handling:

SRP is not decreasing product waste; probably the opposite [because] perforation reduces box strength. The board is strengthened to accommodate this but it's impossible to control perforation exactly at the point of production ... If there's not enough cut you can't open the board; and if there's too much it will open in transport, and we've experienced that. It's an inherent problem with perforation. There is a solution, 'tray and hood', but this requires capital investment that is difficult to justify.

Interviewee – Food brand owner

Reusable packaging systems for distributing fresh produce, packaged food and beverages, and some of these are also available in retail-ready formats such as plastic crates or pallets. There has been little research on whether such options do or do not reduce food waste. As an example, reusable shelf-ready crates are likely to reduce product damage because they are packed at the farm or packaging shed, thus eliminating the need to unpack produce in store. This reduces the amount of handling and the likelihood of product damage, particularly for soft fruits. In contrast, if the packaging is too rigid, it may damage produce more than single-use 'softer' package. Reusable display pallets can provide a 'one-touch solution' that delivers products from the point of manufacture through to the point of sale. Some supermarket chains have adopted these to reduce handling and product damage in the distribution chain with no need to unpack at distribution centre or retail store.

Key insights and discussion

The research in this paper has identified a number of key insights into packaging opportunities to reduce waste. Figure 8 presents a summary of the reasons for food loss and waste at four key stages across the food supply chain, along with packaging opportunities that can be considered and implemented by manufacturers, retailers, government agencies and food rescue organizations.

These opportunities, identified through the research, can be further explained as follows:

1. Better protection and shelf life for fresh produce with distribution packaging for farm to retailer with potential tailored solutions.
2. Recovery of surplus and unsaleable fresh produce from farms with distribution packaging that is compatible with food rescue supply chains.
3. Fit-for-purpose secondary packaging that adequately protects food products as they move through the supply chain.
4. Pre-packed and processed foods to extend the shelf life and reduce waste in distribution through to consumption (the home or food services provider), including packaging recoverability sensitivities.
5. New packaging materials and technologies to extend shelf life, i.e. modified atmosphere and oxygen scavengers.
6. Use-by and best-before date mark education of manufacturers, retailers and consumers to ensure that these are used appropriately and avoid confusion about date marking, which can result in food being thrown away when it is still edible.
7. Changing consumption patterns and smaller households driving packaging design, where single and two-person households benefit from packaging formats such as single-serve and smaller-serve products.
8. Improvements to industry's understanding of food waste where collaboration between manufacturers and retailers in the supply chain can focus more attention on where and why this occurs to reduce the costs and environmental impacts of waste.

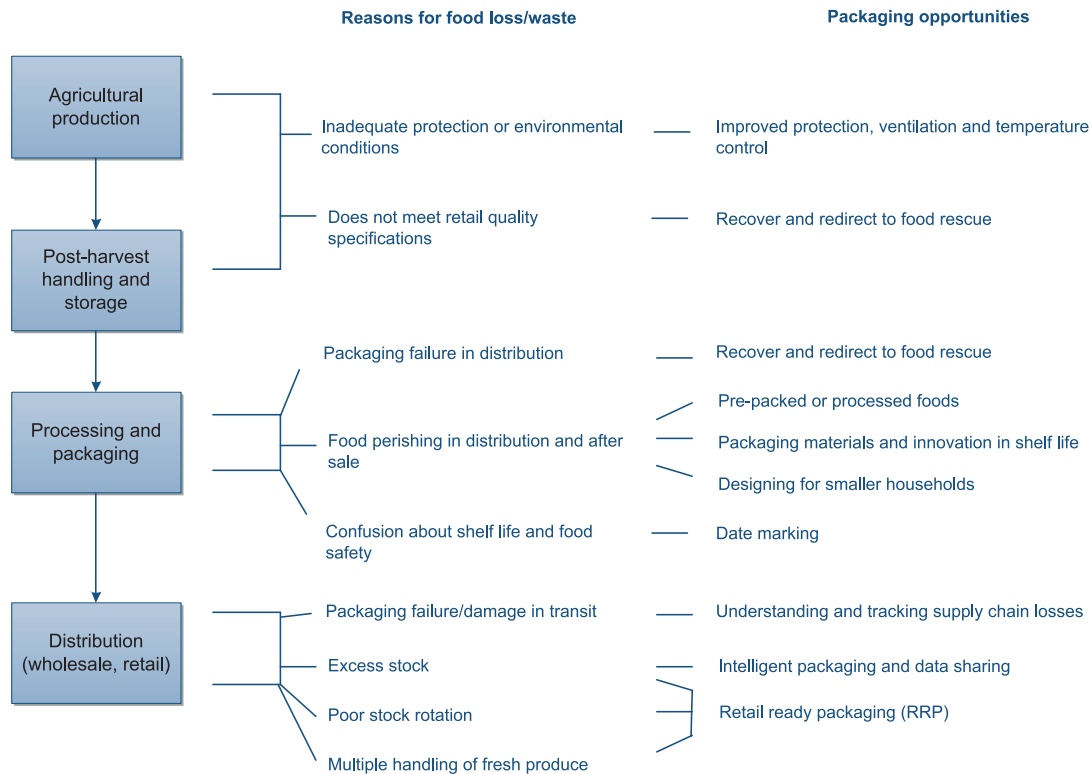


Figure 8. Packaging opportunities across the food supply chain (up to retail).

9. Intelligent packaging and data sharing to create more synchronized supply chains to reduce excess or out-of-date stock.
10. Retail-ready packaging to reduce double handling and damage and improve stock turnover, while ensuring that it is designed 'fit-for-purpose' and for recoverability (reuse or recycling) at end of life.

The implementation of the initiatives in the preceding text could be supported through further research to highlight advantages and risks associated with packaging consumption, protection of product and food waste, including the following:

- Direct observations and sampling at key aggregation points, such as post-harvest grading, sorting and packing to identify opportunities for waste reduction by analysing waste in the context of supply chain trends.
- Food supply chain specific research on the potential for packaging systems to reduce waste. This could be driven by industry associations, individual companies, government departments, scientific organizations and universities; and food items could be selected based on their contribution to the economy, unit sales value, environmental impact or waste volumes in the supply chain.
- Causality research for waste in food services premises to identify packaging innovation and waste improvement opportunities, including better systems to capture waste for appropriate end-of-life waste management treatment, i.e. composting.
- Life-cycle assessment of primary-packaging formats (e.g. MAP) that extend shelf life to better understand the trade-offs between packaging use and food waste and the interplay between primary, secondary and tertiary packaging.
- Life-cycle assessment of packaging formats (e.g. single serves and bulk packaging) and ambient, chilled and frozen products to understand the entire life-cycle impacts on product protection and food waste.

Through this further research, it is envisioned that researchers may enable industry and consumers alike to engage in processes and practices that help to reduce food waste, and in turn reduce the associated environmental impacts.

CONCLUSIONS

Packaging improvements and technical innovations represent significant opportunities to reduce food waste in the supply chain. Food loss and waste, from damage on the farm to food preparation scraps in the home, occurs for many reasons. While some waste is unavoidable, much of it is due to supply chain inefficiencies and damage in transport and handling.

In order to reduce such food waste, more work needs to be performed to raise awareness and educate food and packaging supply chain stakeholders on the types of opportunities presented here. Existing educational initiatives run by government, industry and professional organizations could assist by targeting food waste and packaging. Programmes such as the British Waste & Resources Action Programme initiative (Love Food Hate Waste) could include information on the role of packaging in extending shelf life, and opportunities to use it more effectively. This could include case studies of the best practice from industry showcasing where and how packaging innovations and supply chain improvements led to food waste reductions.

The supply chain also needs to understand and address consumer food waste, which is influenced by trends to smaller households, demand for more convenience foods and consumer confusion about date markings and the role of packaging.

This research represents the beginning of a process to try to understand and reduce food waste in the food supply chain in Australia. It has identified a series of opportunities that could be used to help manage the complex interactions between packaging and food waste to achieve optimal environmental and commercial outcomes. These insights can also be used as a basis to explore food supply chains in other geographical regions.

The Australian National Food Plan⁶⁸ highlights many of the challenges and opportunities facing the Australian food industry, including strong growth in demand from Asian economies and the sustainability of agricultural production and manufacturing. A critical sustainability goal within the plan is to reduce Australia's per capita level of food waste. Designing fit-for-purpose food product-packaging systems that maximize efficiency and reduce waste at all stages of the supply chain will be a prime concern in the context of an increasingly resource constrained world.

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APPENDIX 1: INTERVIEW SCHEDULE

The following questions were used in the stakeholder interviews.

- a) Please describe how your supply chain operates – who are the players and how do products move from farm and processing through to retail?
- b) Where is food waste generated in your supply chains, and why do you think this happens?
- c) Where do you see the most waste generated in your supply chain?
- d) What types of packaging materials (all levels) are currently used in the supply chain?
- e) Are you able to provide an indication of product waste allowances (shrinkage rates)?

- f) Have supply chains for your sector changed in recent years? How and why?
- g) What do you think supply chains of the future will look like?
- h) Are there any trends that you think will increase or decrease food waste in the future?
- i) How can packaging help to reduce the length of the supply chain?
- j) How can packaging be improved to reduce food waste in the supply chain (primary, secondary, tertiary and labelling)?
- k) Do you think that reusable secondary and tertiary packaging can help to reduce food waste, and if so, how?

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