REPORT —

The role of packaging for Australian fresh produce

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Abstract

Globally, it is estimated that over US$1.2 trillion of food is lost or wasted across the food supply chain, equivalent to 1.6 billion tons of food per annum.

"In Australia, it is estimated that $20 billion worth of food is lost or wasted per annum, ..."

an estimated 7.3 million tonnes across the entire Australian supply and consumption chain.

Fresh produce is a vital component of human health. Yet many Australian adults fail to meet national guidelines on fresh produce consumption, risking adverse health effects. Therefore, it is imperative for strategies to be deployed which ensure access for consumers to fresh, nutritious food, rather than allowing it to be wasted.

Packaging plays an important role in the integrity and protection of food as it travels through supply chains from farm, through retail, to plate.

"The trade-off between food waste and packaging is a delicate balance; more packaging can result in less food waste and therefore less impacts."

The impact of this extra packaging must also be considered to develop the optimal packaging-to-food ratio.

In light of these issues, the Australian Fresh Produce Alliance (AFPA), made up of 14 of Australia's key fresh produce growers and suppliers, sought to provide key stakeholders with an objective and evidence-based understanding of the value that packaging provides within the life cycle of fresh produce. AFPA engaged Empauer and RMIT University to examine the role of packaging in minimising food waste whilst ensuring quality produce reaches consumers.

RMIT University is one of Australia's largest Universities and is considered a leader in technology, design, global business, communication, global communities, health solutions and urban sustainable futures. Empauer is a leading sustainability consultancy focussed on providing organisations with information to make better decisions, convert those decisions to actions, and deliver the business outcomes they desire.

The project was specifically concerned with the following:

- Mapping the life cycle of 10 fresh produce items, both with and without packaging. Specifically, this included describing the food supply chains, and projecting/estimating the shelf life of produce which is extended with packaging, compared to the shelf life without packaging i.e. sold loose.
- Describing product diverted from waste because of packaging, and product going to waste because of no packaging.

Data for the research was collected from literature, stakeholder interviews, company documents, correspondence and laboratory testing. The data was analysed through a combination of qualitative and quantitative methods. The resultant research was peer reviewed by Dr. Lilly Da Gama from the University of Portsmouth. The

"... results reveal a consensus that packaging is designed to protect products from farm to retail."

Packaging is aimed at limiting food waste particularly from packing to the retail shelf. It is primarily designed to provide; mechanical protection in handling and transport; respiration management; gas management i.e. for ethylene; food safety aspects; and limiting access to stop people touching produce to reduce bruising or damage. As such, produce is generally delivered to consumers intact. According to producers, such measures provide more chance for the food to: get to market in an acceptable condition; be purchased; and be consumed, rather than be discarded at some stage in the supply chain.

Cold chains were identified as integral to preserving fresh produce during supply. The interaction bewteen packaging and the cold chain was also seen as critical to extend shelf life and minimise waste in many instances.

It was clear that new packaging formats assisted in the establishment of new markets for previously out of specification produce, such as oddly shaped or smaller produce. Packaging played a role in getting this product to market and aligning that product with target audiences to further reduce food waste.

Retail planning and forecasting was a big factor in how much cultivated product is used, so that optimising and aligning production to retail ordering is essential.

There was a tension between packaging aimed at extending shelf life and consumer demand for perceived environmentally conscious packaging materials i.e. post-consumer recycling content, high recycling rates, or bio based/ compostability. Dealing with such tensions is challenging for producers.

It was evident that consumer and industry education, about the balance between packaging that reduces the environmental impacts of food waste, compared to reducing packaging environmental impacts, is both lacking and overdue. Interviewees also revealed that very little is known about the role that packaging plays, in extending the life of food, when stored by consumers at home. This may be an opportunity for producers and retailers to engage more deeply with their customers about such issues.

Sensory changes varied across 10 categories of produce observed in laboratory conditions. Sensory aspects relate to dimensions that consumers 'sense', such as when they touch, see or smell a food. Some categories maintained sensory quality in packaging, whilst others showed little difference in quality regardless of packaging or not.

Abstract continued

Recommendations that developed from the research results are as follows:

- **Increased measurement of food waste is urgently needed:** Currently there is little food waste data recorded, which should be rectified. Data and metrics collected could be shared across the supply chain to ensure transparency and effective responses to concerns. This would help highlight where food waste spikes and facilitate flexibility on actions needed to address it.
- **Continuous optimisation of cold chain management:** Continuing to optimise cold supply chains should be a focus, and the role packaging plays. This could be an opportunity of mutual benefit for stakeholders.
- **Leveraging good relationships for packaging optimisation:** Constructive planning and ordering that occurs between supply chain partners, could be leveraged to include more work on the role of packaging in reducing food waste across the supply chain. This could result in further extended shelf life, good product protection, and consumer benefits within the home.
- **Education of consumers on the role of packaging:** There is a gap between what consumers perceive and why packaging is specified. Education is needed here.
- **The circular economy is an opportunity:**

Circular economy approaches to packaging may be beneficial to reduce the stigma that packaging currently holds with consumers. This may require partnerships between producers, retailers, government, researchers and waste/ logistics organisations. It would also require education of, or engagement with, consumers.

- **Consumer waste levels need more clarity:**

There is little known about consumer food waste in the home, in particular, the role packaging plays in reducing/avoiding waste. Research should examine if packaging features, designed to reduce waste, are misunderstood.

- **Packaging to maintain food safety needs further research:** For 'ready to eat' produce, packaging assists in food safety. Further research is required to clarify the value of packaging for safety, including any food waste reduction attributes.
- **Packaging can maintain sensory aspects:** From observational data collected, packaging is vital to maintain sensory properties and quality for some produce categories.
- Sensory issues need more research: Whether packaging extends the shelf life from a sensory perspective requires further investigation. Further work would require testing with a sample of consumers representing statistical significance i.e. across the Australian population.

Future investigations are warranted to further clarify the role of packaging in the Australian fresh produce environment. Such research could determine whether further packaging innovations should be considered to reduce waste and improve quality.

1.0 Introduction

1.0 Introduction

Packaging plays an important role in the integrity and protection of food as it travels through supply chains from farm to plate (Verghese et al., 2015). These benefits are not widely known to the general public. There is a need to research the link between food, packaging and waste specifically, to clarify these relationships.

The Australian Fresh Produce Alliance (AFPA), made up of 14 of Australia's key fresh produce growers and suppliers are seeking to provide stakeholders, namely, retailers, government and consumers, with an objective and evidence-based understanding of the value that packaging provides within the life cycle of fresh fruit and vegetables. To this end, the AFPA commissioned Empauer and RMIT University to conduct relevant research, focused on participating producers' products and their respective supply chains.

The research aimed to examine and understand the role that packaging fulfils in minimising food waste, and maximising quality control. The project was specifically concerned with the following:

- Mapping the life cycle of 10 fresh produce items, both with and without packaging. Specifically, this included describing the food supply chains, and projecting/estimating the shelf life of produce which is extended with packaging, compared to the shelf life without packaging i.e. sold loose.
- Describing product diverted from waste because of packaging, and product going to waste because of no packaging.

By using these foci the role retail and logistical packaging formats provide for the protection and longevity of nominated fresh produce was investigated. This report details that research.

A novel approach to this research was chosen, by combining supply chain participant insights with laboratory testing of fresh produce. For clarity, the contexts across which research was conducted were farm through to retail environments. Consumer aspects were only covered through perspectives provided by some food supply chain participants (rather than direct consumer data). Such data and contexts assisted in demonstrating the role of packaging in managing fresh produce shelf life and food waste.

The discussion section in particular articulates the role of packaging within broader fresh produce supply chain contexts. This includes how packaging relates to cold chains, temperature management, and supply chain collaboration in providing protection and longevity for fresh produce. We conclude by recommending how the report should be used, and any actions that may be pertinent as a result of the research.

1.1 Food Loss and Waste

Food loss and waste represent a misuse of resources that are used in producing food, with the financial and food waste volume impact being significant. Globally, it is estimated that over US$1.2 trillion of food is lost or wasted across the food supply chain per annum, equivalent to 1.6 billion tons of food (Hegnsholt et al., 2018). In Australia, it is estimated that $20 billion worth of food is lost/wasted per annum (Lapidge, 2015). New figures recently released estimate that 7.3 million tonnes annually of food were lost and wasted across the entire Australian supply and consumption chain (298 kilograms per capita) (ARCARDIS et al., 2019).

Food loss and waste occurs at all stages of the supply chain and are caused by different driving forces (Flanagan et al., 2018, Gustavsson et al., 2011, Hegnsholt et al., 2018, DoEE, 2017). The Food and Agriculture Organisation (FAO) of the United Nations (UN) defines food loss as any food that is lost in the supply chain between the producer and market. This may be due to weather, customer specifications, inventory management and ordering changes, damage during transport, breaks in cold chain management or improper storage.

Food waste concerns the discard or non-food usage of food that is safe and nutritious for human consumption due to confusion about various factors including date labelling, over purchasing, incorrect storage, and preparing more food than is required for consumption (Gustavsson et al., 2011, Flanagan et al., 2018). The United Nations Sustainable Development Goal (SDG) Target 12.3 aims to 'by 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses' (Flanagan et al., 2018, UN, 2019, Wikström et al., 2018).

Approximately 56% of total food loss and waste occurs in the developed world—North America, Oceania, Europe, and the industrialized Asian nations of China, Japan, and South Korea (Lipinski et al., 2013). Within this region more than 40% of the food loss and waste occur at retail and consumer levels (Gustavsson et al., 2011, Lipinski et al., 2013). For fruits and vegetables in particular, 15-30% is wasted as it is discarded by the consumer (Gustavsson et al., 2011).

> "Studies have shown that fresh fruit and vegetables are the most perishable food items. Fresh fruit and vegetables also account for the highest share of food losses globally ..."

and are usually among the most wasted items, followed by bakery goods, dairy products, meat and fish (Manalili et al., 2014).

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There is significant activity in Australia around addressing food loss and waste across industry, government, not for profits and consumers. In November 2017, the federal government launched the National Food Waste Strategy which is aligned to the UN SDG 12.3 (DoEE, 2017) and sets a path forward toward 2030. In 2018, the Fight Food Waste Cooperative Research Centre commenced bringing together industry, research and the community to capitalise on Australia's food waste opportunities (Fight Food Waste CRC, 2019). Collaboration within countries and around the world has also identified many opportunities to reduce this loss and waste. These include policy support, business improvements, financing, market development, education and behaviour change (DoEE, 2017, ReFED, 2016). As a result, food waste reduction has become a growing field, in Australia and on a global scale.

1.2 The value of providing access to fresh produce

Good nutrition is something that benefits all people, which can be provided through fresh produce. The World Health Organisation (WHO) has recommended adults consume 400g of fruits and vegetables daily (WHO, 2003). In the Australian context, the Australian Guide to Healthy Eating recommends that Australian adults (aged 19 years and over) eat a minimum of 2 serves of fruit a day and 5-6 serves of vegetables a day (National Health and Medical Research Council, 2013). A standard serve of fruit weighs approximately 150g and can encompass a fruit of "medium" size (for example, apple, banana, orange or pear) or 2 "small" fruits (for example, apricots, kiwi fruits or plums) (National Health and Medical Research Council, 2013). A standard serve for vegetables weighs approximately 75g and can encompass ½ cup cooked green or orange vegetables (for example, broccoli, spinach, carrots or pumpkin) or 1 cup green leafy or raw salad vegetables (National Health and Medical Research Council, 2013). The Australian Guide to Healthy Eating also recommends that individuals "try to choose different types and colours of vegetables to make sure they have enough of all necessary micronutrients" (National Health and Medical Research Council, 2013). This fresh produce plays a crucial role in health and well-being.

Fruits and vegetables have historically held a place in dietary guidelines because of their concentrations of essential vitamins and minerals, which humans are unable to synthesize themselves (Slavin and Lloyd, 2012). Essential vitamins include (but are not limited to) A, C, E and B group vitamins. These play a variety of important roles in the human body, including maintaining healthy eyes and skin, acting as antioxidants to protect cells from damage, and contributing to healthy reproduction and growth (Ryan-Harshman and Aldoori, 2005b). Essential minerals include (but are not limited to) potassium, magnesium, calcium, phosphorus and selenium. These also play important roles, such as maintaining blood pressure and bone health, and contributing to normal muscle and nerve functioning (Ryan-Harshman and Aldoori, 2005a).

High nutrient foods such as fresh fruit and vegetables are also beneficial to human health in playing a role in preventing oxidation and inflammation, lowering lipid effects, and providing beneficial effects on blood pressure (Slavin and Lloyd, 2012, Barrett and Lloyd, 2012). Studies also suggest that regular consumption of fruits and vegetables may play an important role in preventing chronic disease, including cardiovascular disease (Crowe et al., 2011), type II diabetes (Carter et al., 2010), dementia (Hughes et al. 2010), and some cancers (Barrett and Lloyd, 2012, Nutrition Australia, 2018, Key et al., 2004). However, many humans are not getting the right nutrition or the necessary amount so are unable to benefit (FAO, 2018c); this is the case in Australia where 96% of the population eat less than half of the WHO recommended daily intake (Nutrition Australia, 2018).

Despite the benefits, consumers do not take in sufficient quantities of fruit and vegetables. The latest National Health Survey found that just over half (51.3%) of Australian adults met the guidelines for the recommended minimum 2 daily serves of fruit (Australian Bureau of Statistics, 2019). However 50 grams of dried fruit was considered acceptable as 1 serve of 'fruit', despite 30 grams of which being recommended to eat "only occasionally" according to The Australian Guide to Healthy Eating (National Health and Medical Research Council, 2013).

The National Health Survey also found that 1 in 13 Australian adults (7.5%) met the guidelines for serves of vegetables (Australian Bureau of Statistics, 2019), whilst only 1 in 20 (5.4%) met both the fruit and the vegetable recommendations (Australian Bureau of Statistics, 2019).

These rates have remained fairly consistent over time (Australian Bureau of Statistics, 2019). Thus, there appears to be a local deficiency in people consuming the fresh produce they need to stay healthy.

An inadequate intake of fruits and vegetables, with a concomitant increase in consumption of processed foods can subsequently lead to an insufficient intake of essential vitamins and minerals. This may increase the risk of adverse health effects associated with micronutrient deficiencies. As an example, over recent decades the rates of chronic disease, including type 2 diabetes, have been increasing both in adults and children (Obesity Policy Coalition, 2018). It is predicted that, by 2023, health expenditure for type 2 diabetes will have risen \$1.4 billion to \$7 billion per year, due mostly to increasing weight gain (National Health and Medical Research Council, 2013). Also, if current Australian trends continue, an estimated 83% of men and 75% of women aged over 20 years will be overweight or obese by 2025 (National Health and Medical Research Council, 2013). Therefore,

1.0 Introduction continued

"...it is important to utilise strategies which ensure access to food that is nutritious, both for the individual and in addressing broader public health issues."

A primary objective of food production is to ensure a safe and acceptable product to be delivered to market. Packaging may serve to transport nutritious produce, such as fruit and vegetables, safely to consumers all over Australia with minimal waste. If people are to consume more fruit and vegetables and in turn reduce their risk of contracting chronic diseases, it is therefore important to provide consumers with a product which is of a high quality and maximises its shelf life. This pursuit is diminished if there is food waste. An underutilised solution in addressing food loss and waste is packaging (Fisher, 2018, Flanagan et al., 2018, Heller, 2017, ReFED, 2016, Wikström et al., 2018, Verghese et al., 2015). The effect of packaging on fresh produce waste and loss will be explored through literature in the following sections.

1.3 What is packaging, and the role it plays in reducing food waste?

Packaging is an integral part of the fresh produce supply chain; the way packaging is designed has implications through the food supply chain from product protection, logistical, retail, food safety, use and ultimately end of life waste management perspectives. Packaging design requires a collaborative process that involves finding a solution that fits parties across the supply chain (Verghese et al., 2015). Critical to this is for all stakeholders in the food supply chain, from producers, manufacturers, retailers, packaging, government and consumers to engage in discussions and a better understanding of the role that packaging plays in the food supply chain.

To determine the suitability of packaging for fresh produce, it is necessary to first understand where packaging is used in the supply chain, and primary functions packaging serves (Table 1).

Table 1: Types of packaging and their functions

Type	Area of supply chain	Functions	Examples
Primary Packaging	Sales, consumer and retail	Protection, promotion, convenience, information, handling, safety	Sales units at the point of purchase in the form of "shelf-ready" packaging, such as strawberries in punnets or apples in bags.
Secondary Packaging	Display merchandising	Protection, promotion, convenience, information, handling, safety	Packaging used at the point of purchase to contain or present several sales units; it can be removed from the product without affecting its characteristics. This includes a display stand containing individually packaged items.
Tertiary Packaging	Distribution and trading	Protection, information, handling, safety	Used to facilitate handling and transport of several sales units or grouped packages in order to prevent physical handling and transport damage; does not include road, rail, ship and airfreight containers.
Industrial Packaging	Business to business setting	Protection, information, handling, safety	Used for transport and distribution of products for industrial use.

Source: adapted from (Verghese et al., 2012, p 8).

Product protection is the primary goal of packaging (Verghese et al., 2012, Dominic et al., 2015). Packaging should enable the safe and efficient supply of produce, therefore minimising the environmental impacts of producing, transporting, using and disposing of those products (Verghese et al., 2012).

The packaging material and packaging format should work synergistically to create a situation that is conducive to product protection and good product shelf life as it travels through the supply chain. To ensure good product protection, an optimal amount of packaging material needs to be used (Dominic et al., 2015, Verghese et al., 2015). Insufficient material can lead to product damage, but extra material can contribute to unnecessary impacts. There has also been a recent increase in instances of malicious tampering with fresh produce, for example in 2018 with the Australian strawberry needle case being the most prominent. There is a demand to mitigate safety threats through packaging. For instance, the use of punnets

1.0 Introduction continued

and plastic film makes it easier to identify if a product has been tampered with. Packaging can also be used to reduce microbiological contamination. Following sanitation processes, packaging can also ensure that contamination does not occur in the supply chain and cause harm to the consumer, which can be particularly important for fresh cut or 'ready to eat' produce (Farber et al., 1998, Luo et al., 2010).

In summary, according to the literature, packaging performs specific functions of which there are key features (Lindh et al., 2016). These are to:

- **protect** the content of a package: features include mechanical, barrier and sealing properties;
- **facilitate handling:** features include openability, resealability; and
- **provide communication:** product information and instructions.

1.3.1 Packaging impacts versus food impacts: The case for product protection

Sustainability concerns about packaging generally relate to the direct environmental impacts of production and the end-of-life treatment options (Lindh et al., 2016). The concerns over these direct packaging impacts may be addressed through initiatives to reduce use of excess packaging, designing packaging to be recyclable or compostable, and developing the appropriate systems to support such packaging end-of-life waste management treatment options (Verghese et al., 2012).

While such measures are initiated with well-meaning intentions, it should be noted that a reduction in packaging to decrease direct environmental impact may actually result in an increase in the indirect environmental impacts, resulting in no net benefit (Wikström et al., 2016).

The trade-off between food waste and packaging is a delicate balance; more packaging can result in less food waste and therefore less impacts, but the impact of this extra packaging must also be taken into account to develop the most sustainable packaging-to-food ratio (Verghese et al., 2015). This concept is shown in Figure 1.

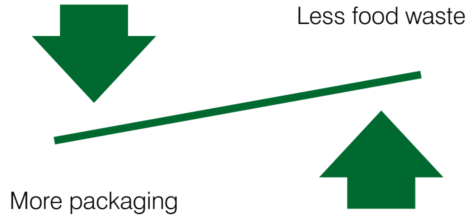


Figure 1: Trade-offs between food waste and packaging: (Verghese et al., 2015, p 605)

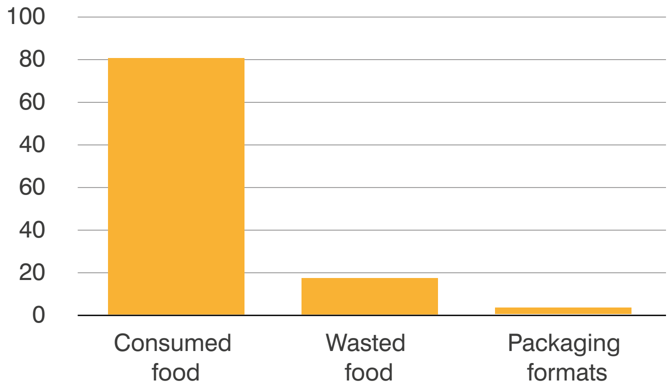
The packaging impacts cannot be separated from those of the product, so the product-packaging system as a whole must be optimised to minimise negative environmental impacts (Verghese et al., 2012, Wikström et al., 2018).

For example, if packaging material fails to protect food, then there will be greater impact associated with the resources that went into producing that food being wasted and not consumed (Dilkes-Hoffman et al., 2018, Verghese et al., 2012). A more appropriate material type would also offer protection benefits to fresh produce, resulting in extended shelf life, less food waste, and reduced overall carbon impact. The emission effect of food-to-packaging ratios should also be considered, and they vary widely depending on the type of food, packaging material, method of production and transportation for both packaging and food (Wikström et al., 2018, Dilkes-Hoffman et al., 2018, Fisher, 2018, Heller, 2017, Wever et al., 2007). This is where life cycle assessment (LCA) tools can assist.

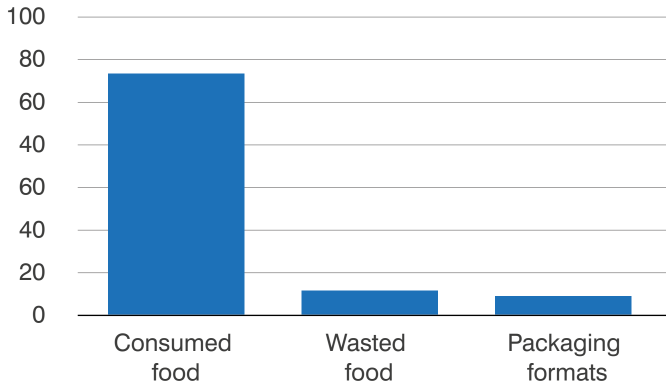
Life cycle management and associated tools for an LCA are used to generate product environmental life cycle maps and identify improvement strategies. LCA is a useful way to calculate the environmental burden of a product-packaging system (Verghese et al., 2012, Wikström et al., 2018, Wever et al., 2007) and then work towards the optimisation of the 'system' as a whole. Yet LCA needs to be considered on a case by case basis, owing to the difference between product and packaging impacts respectively from one food system to another (Williams and Wikström, 2011). Actions as a result of LCA requires productive supply chain partnerships to achieve better and long term environmental benefits that avoid creating new impacts or 'burden-shifting' (Verghese et al., 2012). For instance, when considering the greenhouse gas emissions of growing and producing food, with packaging material production and food waste, packaging when designed appropriately can reduce the likelihood of food being wasted (Wikström et al., 2018). See Figure 2 for more on this.

1.0 Introduction continued

Meat, fish & eggs



Dairy



Fruits, vegetables & nuts

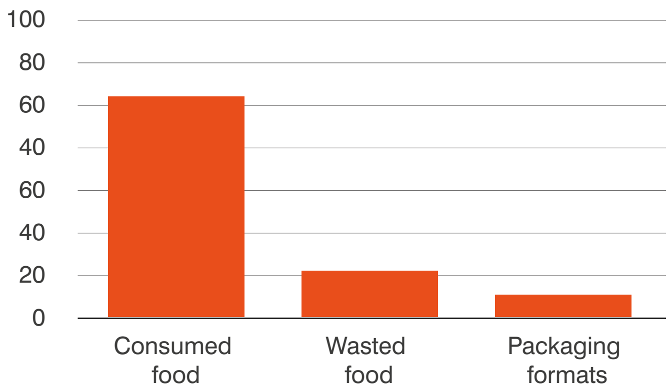


Figure 2: Greenhouse gas distribution between food consumed, food wasted and packaging materials for meat, fish and eggs, dairy and fruits and vegetables for a 4-person household over 1 week. Source: (Wikström et al., 2018, p 4)

This concept is explored in a study, by Wikström et al. (2016), on the influence of packaging attributes on recycling and food waste behaviour through an environmental comparison of 2 packaging alternatives. The authors advised that, apart from direct environmental effects, indirect environmental effects and behaviour should also be considered in environmental assessments of packaging, to obtain meaningful results. Suitable packaging will consider manufacturing impacts, consumer recycling rates, promote less food waste via ease of emptying and most importantly, promote less food waste through design for optimised product protection (Wikström et al., 2016).

> Product protection should be the primary goal of packaging, as food waste generally accounts for a larger proportion of the life-cycle environmental impacts of the food-packaging system (Verghese et al., 2012).

It has been estimated that, on average, packaging accounts for only 10% of the total energy inputs for a person's weekly consumption of food (INCPEN, 2009). The other 90% of energy inputs is in food supply, transport, storage and cooking. This highlights the important role packaging plays in product protection, making sure this energy input is not wasted.

Sometimes more packaging is required to achieve the goal of product protection, as in the case of single serve food portions. While the packaging impacts will be increased, the potential for food waste is reduced; meaning the overall environmental impact from the system of food and packaging will decrease (Verghese et al., 2015). While packaging and the products contained within will both have environmental impacts, the most sustainable product-to-packaging ratio often results where product protection is favoured over reduced packaging that puts a product at risk of damage.

1.0 Introduction continued

1.3.2 End of life waste management of packaging

In Australia, a Senate Inquiry has pushed to phase out single use plastics nationwide by 2023 (Noyes, 2018). This would include plastic bags, takeaway containers, plastic lined coffee cups and chip packets, among other single use food packaging formats. This is supported by the Australian National Waste Policy projected to 2030, which seeks to provide a framework for collective action by businesses, governments, communities and individuals (Commonwealth of Australia, 2018).

The National Waste policy identifies 5 overarching principles underpinning waste management in moving toward a new, circular economy (Commonwealth of Australia, 2018):

- Avoiding waste
- Improving resource recovery
- Increasing use of recycled material and building demand and markets for recycled products
- Better management of material flows to benefit human health, the environment and the economy
- Improving information to support innovation, guide investment and enable informed consumer decisions.

The policy has also set the ambitious target of diverting 80% of waste from landfill by 2030. National packaging targets have also been launched. With 70% of plastic packaging set to be recycled or composted by 2025, and all packaging to have an average recycled content of 30% by 2025 (Commonwealth of Australia, 2018, Topsfield, 2018).

Industry moves toward sustainable packaging and Government initiatives to reduce plastic waste represent an opportunity for further research and innovation in the sustainable packaging field.

However, the potential knock on effects of reducing or eliminating packaging need to be considered holistically in relation to product protection and reducing food waste across the supply chain. Recyclable packaging should be supported by the development and maintenance of efficient recycling systems, otherwise accumulated waste can result in negative environmental impacts that reach far beyond the waste origin country.

Packaging must also be designed with end-of-life management in mind (Verghese et al., 2012, World Economic Forum et al., 2016). The benefits can only be realised when materials are properly disposed of. It requires both appropriate packaging material selection and design to ensure compatibility with waste management systems and relies on consumers to understand the associated terminology and assumes a willingness to cooperate with proper disposal. Recyclables put into general waste represent a resource loss and are a negative waste impact (World Economic Forum et al., 2016). The study by Wikström et al. (2016) noted that the influence of packaging attributes on user behaviour with regard to food losses, recycling and cleaning are more important for the environmental outcome than the direct impact of the packages.

Each material type used in a packaging system should be clearly labelled to enable suitable disposal to reduce the waste impact of improperly disposed packaging due to confusion. It has been over 40 years since the launch of the first universal recycling symbol on packaging (World Economic Forum et al., 2016) and progress has been made since. In 2018 the Australasian Recycling Label (ARL) (Figure 3) was launched by Planet Ark and the Australian Packaging Covenant Organisation (APCO) in a bid to provide clearer packaging disposal guidelines to Australian and New Zealand consumers (Planet Ark, 2018, APCO, 2018). The standardised labels are aimed at providing easy to understand information for each piece of packaging thereby removing confusion, increasing recycling, and reducing waste. The ARL has been used on packaged food items including dairy and bakery products, with plans to expand to all packaged food categories (Planet Ark, 2018).

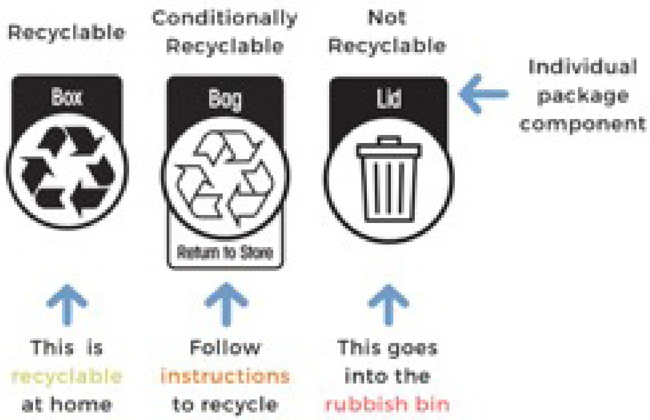


Figure 3 Australasian Recycling Label, an explainer (Planet Ark, 2018)

The use, disposal and recovery of materials from packaging generate environmental impacts by consuming materials, energy and water. It is therefore essential to understand the total environmental burden of the packaging system by considering the trade-offs between product protection, packaging environmental footprint, packaging recycling, and FLW (food loss and waste) to make informed decisions about packaging for sustainable development (Wikström et al., 2018).

1.3.3 Role of plastic packaging for fresh produce

Two relevant reports addressing the role of packaging for fresh fruit and vegetables include *The Value of Flexible Packaging in Extending Shelf Life and Reducing Food Waste* (McEwen, 2014) and *Evidence Review: Plastic Packaging and Fresh Produce* (White and Stanmore, 2018). Both of these reports review currently available evidence of the effects of plastic packaging on reducing the amount of fresh fruits and vegetables disposed of domestically and provide an array of produce-specific examples where packaging is either beneficial or detrimental (See Table 2). The logical premise is, that if packaging provides consumers with more time to purchase and store fresh produce there is more chance food is consumed accordingly.

1.0 Introduction continued

Table 2: Effect of packaging on various fruits and vegetables

Fresh produce	Packaging focus	Shelf life effect vs. no packaging	Study details – methodology	Literature Sources
Apples	Paper mould trays and corrugated fibreboard	Both packaging interventions limited spoilage to 6%, but apples are robust and fridge storage alone is beneficial.	(Wijewardane and Guleria, 2013) observed quality changes in Royal Delicious apples over a period of 45 days in both cool and ambient conditions. Sample size was not mentioned in the original paper	Literature review by (White and Stanmore, 2018) referencing (Wijewardane and Guleria, 2013)
Apples	3 types of polymeric heat-shrink film wrap: HDPE, polyolefin and "Cryovac"	The film wraps can extend shelf-life by 2 weeks, with reduced weight loss from 10.7% to 2.3% during storage at ambient temperatures	(Sharma et al., 2013) observed quality changes over 7 days in wrapped and unwrapped Royal Delicious apples at 22-28 °C. Sample size was not mentioned but the experiment was repeated 5 times	Literature review by (White and Stanmore, 2018) referencing (Sharma et al., 2013)
Bananas	Polyethylene plastic bag from supermarket at room temperature	Bananas in bags at room temperature retained moisture and visual quality for < 3 days extra. Fridge storage not recommended as it caused blackening	Original study conducted by WRAP over a 3 week period for wrapped and unwrapped produce in both cool and ambient conditions.* Sample size: 24 bananas in bags of 6	WRAP documents: (White and Stanmore, 2018, Johnson et al., 2008)
Bananas	18kg shelf ready boxes	Shelf-ready boxes of loose bananas reduced damage from repeated handling	Original interview-based study conducted by WRAP in 2009, each interview lasting an hour each.** Retailers observed damage from repeated handling of bananas by customers, and transfer of fruit by staff from storage boxes to retail shelf	WRAP documents: (White and Stanmore, 2018, Terry et al., 2011)
Bananas	Perforated HDPE and LDPE	Shelf life extended to 36 days with high density polyethylene and low-density polyethylene; unpackaged lasted 15 days (McEwen 2014)	(Hailu et al., 2014) evaluated the effect of 4 packaging materials on the shelf life and qualities of Poyo, Giant Cavendish and Williams I banana cultivars. The experiment lasted 36 days. 5 fingers were used for analysis on each sampling date.	Literature review by (McEwen, 2014) referencing (Hailu et al., 2014)
Cucumber	Shrink wrapped, stored at 12°C	Storage at 10°C-12°C best. Wrapped kept shelf life for 9 days vs. unwrapped at 2 days	(Dhall et al., 2012) studied the effect of shrink wrap storage for maintaining quality in immature green cucumbers. The individually wrapped cucumbers were observed over a period of 15 days. Sample size not mentioned but damaged fruits were not used. Cryovac brand D955 film was used	Literature review by (White and Stanmore, 2018) referencing (Dhall et al., 2012)
Lettuce (whole)	Sealed polyethylene plastic bag from supermarket plastic, kept in fridge	Lettuce was still edible after 28 days – a 4.5 shelf life difference vs. loose storage	A copy of the original report by (Goodman-Smith, 2017) was not available to review online, and the literature review by (White and Stanmore, 2018) provides no details of methodology. Lettuce variety not specified	Literature review by (White and Stanmore, 2018) referencing (Goodman-Smith, 2017)

1.0 Introduction continued

Fresh produce	Packaging focus	Shelf life effect vs. no packaging	Study details – methodology	Literature Sources
Mushrooms (whole)	Polyethylene plastic bag from supermarket, kept in fridge	Reduced browning for extra >2 days, but ideally use a paper bag	Original study conducted by WRAP over a 3 week period for wrapped and unwrapped produce in both cool and ambient conditions. * Sample size: 6 x 0.5kg	WRAP documents: (White and Stanmore, 2018, Johnson et al., 2008)
Pears	Polyethylene plastic bag from supermarket, kept in fridge	Retained freshness & quality for >14 days extra	Original study conducted by WRAP over a 3 week period for wrapped and unwrapped produce in both cool and ambient conditions. * Sample size: 6x 1kg	WRAP documents: (White and Stanmore, 2018, Johnson et al., 2008)
Pears	Modified atmosphere packaging: Non-perforated polypropylene (PP) in ambient conditions performed the best out of all tested packaging materials.	Of all the tested packaging materials, PP non-perforated was the most for extending the shelf-life for <15 days at the end of the storage period the fruits remained closest to their initial quality at the start of the storage period. The PP packaging retained maximum firmness in the fruits at 5.16 kgf and the least amount of ascorbic acid / vitamin c loss at 49.97%.	(Nath et al., 2012) studied if different packaging materials could be used to extend the shelf life of pears. The fruits were divided into 450-500g groups, with each pear weighing 85-110g. The control was kept unwrapped. Tested packaging formats included low density polyethylene polypropylene (PP, 0.025 mm), linear low-density polyethylene (LLDPE, 0.0125 mm) and high-density polyethylene (HDPE, 0.025 mm) with or without perforation. The packages were stored at ambient condition (25±2 °C and 65.0±5% RH), with observations every 3 days to a total of 15 days.	Literature review by (White and Stanmore, 2018) referencing (Nath et al., 2012)
Strawberries	Modified Atmosphere Packaging (MAP)	Inhibits mould and rot if temperatures are constant, otherwise MAP can have negative impact (unspecified) on fruit.	Original interview-based study conducted by WRAP in 2009, each interview lasting an hour each.**	WRAP documents: (White and Stanmore, 2018, Terry et al., 2011)
	Polyethylene plastic bag from supermarket, kept in fridge	Retained freshness & quality for >10 days extra and reduced weight loss from dehydration	Original study conducted by WRAP over a 3-week period for wrapped and unwrapped produce in both cool and ambient conditions. *Sample size: 8 x 0.5kg	WRAP documents: (White and Stanmore, 2018, Johnson et al., 2008)

Sources: Literature reviews by (White and Stanmore, 2018, McEwen, 2014), with details of research methodology obtained from the referenced original studies where available.

Additional Notes: * WRAP tested ways to extend the storage-life of 17 different fruits and vegetables: lemons, melons, peppers, tomatoes, potatoes, oranges, apples, strawberry, grapes, kiwifruit, pears, broccoli, carrots, mushrooms, onions, bananas, pineapples. The produce was stored wrapped and unwrapped in both refrigerated and ambient conditions to observe changes over a 3-week period. Refrigeration was found to be vital in extending the freshness and storage-life for 13 out of 17 produce types. A conclusion was made that storing loose products in perforated polyethylene (PE) bags – of the type available in supermarket fresh produce aisles – was beneficial in conserving water and maintaining freshness in most of the products tested. For more details see Johnson et al. (2008).

** WRAP interviewed over 45 UK fresh produce suppliers, wholesalers and retailers. They were asked for their views on the causes, level and destination of waste for the 11 products studied in the research project: strawberries, raspberries, tomatoes, lettuce, apples, onions, potatoes, brassicas, citrus, avocados and bananas. In addition to the interviews, secondary data on waste was collected by tracking specific fresh produce consignments through the supply chain, providing a valuable sense-check on the data provided during the interviews. Both data sets were used to inform the final report: see Terry et al. (2011) for more details.

1.0 Introduction continued

In 2018 AMERIPEN released *Quantifying the Value of Packaging as a Strategy to Prevent Food Waste in America*, highlighting opportunities to implement and design improved packaging strategies at the consumer level (Fisher, 2018). These three reports show that packaging tailored specifically to the produce within, fare better than generic one-form-fits-all packaging. Additionally, the ReFED (2016) roadmap for reducing food waste was released in the USA. Of the 27 solutions identified, there were several packaging related prevention strategies, being: standardised date labelling; packaging adjustments such as optimising food packaging size and design to ensure complete consumption and avoid residual container waste; and spoilage prevention packaging such as the use of active intelligent packaging to prolong product freshness and slow spoilage of perishable foods.

The following section explores literature on packaging interventions related to fresh produce waste such as the ability of technological innovations such as Modified Atmosphere Packaging (MAP), Active Packaging (AP), and thermal indicators that extend the shelf life of fresh fruits and vegetables.

1.3.4 Plastic packaging can extend shelf life with effective cold chain management

Plastic packaging can be beneficial to shelf life when combined with cold storage. WRAP UK reports that cold storage of fresh produce in a polyethylene (PE) bag can help to retain moisture and freshness, with a significant improvement of more than 3 days for lemons and peppers/capsicum when comparing packaged vs. unpackaged. The report also suggests that re-usable airtight containers could offer similar benefits to single-use polymeric/plastic packaging and extend shelf life benefits for consumers within the home (White and Stanmore 2018). The benefits of cold storage are also supported by the report *Reducing Food Loss and Food Waste* (Lipinski et al., 2013).

While plastic packaging can assist in protecting food, there is a flip side. Poor cold chain management of produce packaged in non-permeable plastic film can promote accelerated ripening and degradation due to trapped respiration gasses and moisture, resulting in higher spoilage rates (FAO, 2018a, FAO, 2018b). This is demonstrated by packaging case studies found in the literature:

- Shelf life issues were observed in tomatoes packed in sealed polyethylene bags. The tomatoes were not stored at a suitably low temperature, leading to build-up of respiratory heat and gases (FAO, 2018a, FAO, 2018b).
- Shelf life issues were observed in tomatoes packed on polystyrene foam trays sealed with stretch wrap. The tomatoes were displayed under refrigerated conditions, but condensation often occurred due to temperature fluctuations, leading to pathological problems in the produce (FAO, 2018a, FAO, 2018b).
- Shelf life issues were observed in mushrooms packed in polyethylene bags stored at 22°C. After 4 days the mushrooms were discarded. Trapped condensation had resulted in rot lesions. Packaged mushrooms stored in the refrigerator had an extra 4 days of shelf life (White and Stanmore, 2018).

Maintaining storage at an appropriately low temperature is therefore key for maintaining freshness of fresh produce packaged in plastic. This is further supported by (White and Stanmore 2018), with an average of 7-14 days of extra shelf life reported for produce stored at <5° compared to 22°C.

1.3.5 MAP can be beneficial for food quality

Modified Atmosphere Packaging (MAP) has been recommended by various organisations such as the Food and Agricultural Organisation of the United Nations and US Flexible Packaging Association as a way to minimize physiological disorders in fresh fruits, thereby minimising fresh produce loss and waste (FAO, 2018a, FAO, 2018b, McEwen, 2014). The use of modified atmosphere packaging has been documented since the late 1970s as a way to improve the shelf life of fresh fruits and vegetables by regulating humidity and concentrations of certain gasses (McEwen, 2014, Zagory and Kader, 1988). MAP systems are commonly constructed from permeable polymeric films, where optimised gas permeability leads to increased shelf life.

MAP systems can also benefit fruit and vegetable shelf-life by tailoring optimal gas concentrations of oxygen (O_2), nitrogen (N_2) and carbon dioxide (CO_2) levels. MA packaging that reduces $O2_2$ levels and increases CO_2 levels can assist in delaying fruit ripening, reduce respiration and ethylene production rate, and also slow down various compositional changes associated with ripening, such as softening (McEwen, 2014, Zagory and Kader, 1988). Beneficial effects were achieved with a gas atmosphere of 0.5% O_2 with 10% CO_2 for fresh cut carrots, 3% O_2 with 10% CO_2 for fresh-cut "Iceberg" lettuce, and 1–3.8% O_2 with 3-6% CO_2 for fresh-cut "Savoy" lettuce (Francis et al., 2012). Cut 'Bartlett' pears held at –1°C in an atmosphere of 2% O_2 with 98% N_2 had a longer shelf-life than those obtained from fruit held in open air (Ansah et al., 2018).

Conversely certain fruits benefit from higher oxygen levels. High O_2 atmospheres improved sensory shelf-life of raspberries and strawberries by inhibiting the development of mould (Francis et al., 2012). Storage of Rocha pears stored at super atmospheric oxygen conditions of 100% O_2 at 5°C for 30 days was effective in delaying pericarp browning and sensorial losses of fresh-cut fruit, with further benefits of a 7-day shelf-life extension (Ansah et al., 2018)

Other examples of the effects of MAP systems have on specific produce types may be found in Table 2 (on page 13).

1.3.6 MAHP and AP for moisture control

Another benefit of MA packaging is its ability to regulate humidity levels to prevent dehydration of produce (McEwen, 2014, Zagory and Kader, 1988). Water loss in produce is caused by high transpiration rates where the effects are cumulative down the supply chain from the point of harvest, pre-cooling, storage and transport to the point of use (Ansah et al., 2018). Water loss is a main cause of commercial and physiological deterioration of fresh produce in the form of wilting, shrivelling, and decrease of stiffness, turgidity and succulence (Rodov et al., 2019, Ansah et al., 2018). These are all factors that can result in food waste and loss.

Papaya fruit stored in high-density polyethylene (HDPE) MA bags experienced less weight loss from water reduction. It also found that the use of polyethylene MA bags retarded the consumption of respiratory substrates such as sugars. The positive quality maintenance effects of the packaging systems were amplified when combined with evaporative cooled storage as opposed to ambient conditions (Azene et al., 2014). The benefits of MA packaging combined with low storage temperatures has also been documented for fresh cut cauliflower (Madonna et al., 2018).

Permeability ratios of MA film packaging must also be calculated so that appropriate humidity is maintained for the specific produce stored within (Jalali et al., 2019, Jalali et al., 2017). For example, a film perforation surface ratio of between 5%-15% helps prevent moisture condensation in lettuce packaging without the excessive produce weight loss (Volpe et al., 2018).

While water loss is a factor in wasted fresh produce, excessive humidity can also be detrimental (Jalali et al., 2019, Jalali et al., 2017). Trapped condensation inside packaging can accelerate spoilage and considerably shorten shelf life of fresh produce. Modified Atmosphere and Humidity Packaging (MAHP) and Active Packaging (AP) systems can assist by regulating humidity. MAHP systems rely on permeable polymeric films to regulate moisture (Jalali et al., 2019, Jalali et al., 2017). On the other hand, AP systems rely on the addition of active substances that regulate moisture, for example moisture absorbers (Gaona-Forero et al., 2018).

Easily perishable fruits, such as berries, have benefited from the use of MAHP packaging. Studies by Jalali et al. (2019) and Jalali et al. (2017) demonstrate that 400g punnet of strawberries lost less than 0.3% in fruit mass when stored in a MAHP film packaging with 0.8 diameter perforations under 15°C ambient temperatures. Other studies confirm the benefits of MAHP and MAP in maintaining the shelf quality of strawberries (Bovi et al., 2018, White and Stanmore, 2018).

In some cases, the MAHP and AP systems may be combined with favourable results. Mushrooms are especially prone to high transpiration rates, resulting in rapid weight loss and the risk of water condensation inside the package, resulting in accelerated deterioration and decay (Rux et al., 2015, White and Stanmore, 2018). Mushrooms stored unpackaged in the fridge became desiccated after 11 days but were still considered edible.

Conversely mushrooms packed in impermeable polypropylene bags retained moisture at the expense of developing rot and off-odours (White and Stanmore, 2018). Use of MAHP trays are beneficial to retaining mushroom quality over non-permeable packaging or no packaging at all, and the addition of the active substance sodium chloride can greatly enhance the benefits of MAHP. Sodium chloride laminated within a multi-layer, perforated polymeric film helped prevent moisture loss in mushrooms without excess condensation (Rux et al., 2015). It was also found that the use of ethylene absorbing, gas permeable packaging film increased mango shelf life from 20 days to 40 days (McEwen, 2014).

The benefits of appropriately designed MAP, MAHP and AP systems in maintaining the quality of fresh produce are documented in the literature. Packaging that helps produce a favourable storage environment is a way to help prevent fresh produce waste and loss.

1.3.7 Consumer behaviour determining food waste: packaging can play a role

While packaging can have its benefits in reducing food waste, the impact of packaging combined with consumer behaviour cannot be dismissed. Consumer choice to eat or waste food is affected by packaging's ability to retain freshness, packaging size, accessibility to food within packaging, and visual communication cues found on packaging such as traditional date labels and colour changing freshness indicators.

Fit-for-purpose packaging that protects produce can only be beneficial if it is kept intact.

> Studies have found that many consumers do not recognize that packaging protects food in the home, which in turn leads many consumers to adopt strategies that potentially decrease the longevity of products, leading to unnecessary waste.

This includes taking products out of their packaging or piercing the packaging (McEwen, 2014, Plumb et al., 2013), or consumers perceptions that unpackaged food is fresher than packaged products (Fisher, 2018).

Being unable or unwilling to consume the entire food contents inside packaging is another issue that leads to waste. For food that is unable to be finished, portion sizes and the ability to effectively remove food from packaging play a role. Consumers may purchase larger packages as part of a bulk-buy cost saving effort but be unable to finish the contents before the food spoils or reaches the food safety date label. Packaging interventions that may assist include packaging food into smaller individual portions, and easily accessible packaging that is resealable (Wikström et al., 2018, Hebrok and Heidenstrøm, 2019, Verghese et al., 2015, Fisher, 2018).

For fresh produce that consumers are unwilling to finish, packaging's role in retaining freshness plays a part. A case study of bread in Norway showed that consumers were least likely to eat bread that they perceived as un-fresh. Therefore, packaging that prevented bread from going stale for longer facilitated the consumption of the entire loaf, thereby minimising food waste (Svanes et al., 2018). Similarly, use of packaging to divide food into smaller portions can increase food's utilisation better than larger packs of food items, because these smaller portions will keep the food aesthetically appealing and fresh (Hebrok and Heidenstrøm, 2019).

Date labelling can also affect perceived freshness. "Best Before" and "Use By" dates are the standard industry approach for packaged foods. Food that has passed the "Use By" date for guaranteed food safety is acceptable to throw out, but some consumers hesitate to consume food that has passed its "Best Before" date – an indicator for food quality but not safety. It should also be noted that dates are often conservative to minimise risks from consuming spoiled food, leading to reduced effective shelf life and increased consumer disposal of food. The issues surrounding date labelling and its effect on food waste is well documented in the literature (Blomfield, 2019, Poyatos-Racionero et al., 2018, Verghese et al., 2015, Lipinski et al., 2013, Pink, 2016).

Visual information is often relied upon for determining the quality and perceived freshness of fresh produce, influencing the decision as to whether it should be eaten or thrown out. Intelligent packaging systems could reduce the amount of food being thrown out due to uncertain judgment and assessment of produce quality. Intelligent packaging systems monitor and communicate the quality of produce in real-time, making it easy to quickly and effectively judge if food is fit for consumption, for example if food is contaminated by pathogenic microbes (Francis et al., 2012). Systems include RFID tags, time-temperature indicators, integrity indicators, and colour-changing freshness indicators (Poyatos-Racionero et al., 2018, Dirpan et al., 2018, Sachdev et al., 2016, Kuswandi et al., 2013). Intelligent packaging systems are common for protein products, but recent literature shows that use of such systems is expanding to fresh fruits and vegetables. Colour changing freshness indicator stickers have been used for guavas (Kuswandi et al., 2013), mangos (Dirpan et al., 2018) and onions (Sachdev et al., 2016) to detect postharvest spoilage. The stickers are attached to the packaging to detect the build-up of certain respiratory gasses.

Intelligent packaging systems can provide reliable, real-time visual cues to indicate if produce is fresh or spoiled, therefore reducing unnecessary wastage of food (Poyatos-Racionero et al., 2018, Kuswandi et al., 2013). While packaging systems can reduce food waste, it is important that consumer behaviour also be considered.

1.3.8 It's a wrap: Packaging effects summary for fresh produce waste and loss

The beneficial effects of packaging on fresh produce waste and loss cannot be ignored. Packaging can extend the shelf life of produce if it is tailored to the needs of the fresh produce type.

Packaging that encourages unfavourable storage environments leads to spoilage of fresh produce. It should also be noted that, apart from suitable packaging, maintaining an appropriate storage temperature is key where cold environments are favourable to longer shelf life.

Packaging can also communicate to consumers if food is fit to eat, thereby preventing good food from being thrown out.

The proportion of packaging compared to food product, and potential waste with no packaging, should also be considered regarding respective environmental impacts. Other consumer related behaviour should also be considered – such as the detrimental effect of protective packaging being removed, importance of perceived freshness and clear communication on edibility. The literature supports the principle that appropriately designed packaging plays a role in preventing fresh produce waste and loss. Additional research is needed to fill knowledge gaps on the food waste effects of packaging versus no packaging.

2.0
Project scope

2.0 Project scope

Table 3 presents the 10 fresh produce categories, related packaging sizes, and associated packaging formats/materials that were selected for investigation in this project. These categories were identified and selected by members of the Australian Fresh Produce Alliance (AFPA).

Table 3 Fresh produce categories investigated in the study

Produce	Packaging size	Packaging format/ material reviewed
Tomatoes (small snack pack)	200 grams	Punnet – PET
Mushrooms (cup & sliced)	200 grams	Punnet – PET
Raspberries	125 grams	Punnet – PET
Blueberries	125 grams	Punnet – PET
Leafy Salad	Various	Various
Cucumbers (small pack)	250 grams	Punnet with BOPP flow wrap – PET
Cos Lettuce (twin pack)	Twin pack	Pre-pack flow wrap – BOPP
Banana (kids pack)	750 grams	LLDPE flow wrap
Apples	Various	Various
Pears	Various	Various

Note: Materials: PET – Polyethylene terephthalate; BOPP – Biaxially orientated polypropylene; LLDPE – Linear low-density polyethylene;

3.0 Project methodology

3.0 Project methodology

To understand the role that packaging fulfils in minimising food waste, and maximising quality for fresh produce, this project was divided into 2 main stages:

- Life cycle mapping (including food waste), and
- Laboratory observations of fresh produce sensory aspects.

Table 4 presents the different types of data that were collected and used for each produce category. The following sub-sections provide details of these methods that were undertaken at each stage of this project, along with how data were used.

Table 4: Research data used in the study

Fresh Produce	Life cycle mapping			
	Email/ phone data	Company documents	Interviews conducted	Lab sensory observations
Tomatoes (small snack pack)	Yes	Yes	3	Yes
Mushrooms (cup & sliced)	Yes	Yes	3	Yes
Raspberries	Yes	Yes	3	Yes
Blueberries	Yes	Yes	3	Yes
Leafy Salad	Yes	Yes	3	No
Cucumbers (small pack)	Yes	No	3	Yes
Cos Lettuce (twin pack)	Yes	Yes	3	Yes
Banana (kids pack)	Yes	No	4	Yes
Apples	Yes	Yes	3	No
Pears	Yes	No	3	No

3.1 Life cycle mapping

To map each fresh produce category life cycle, we analysed and compared various related data (Tracy, 2010). Combining the different data sources (summarized in Table 4) we developed descriptive analyses of each life cycle, as well as a diagram capturing packaging, storage, and food waste dimensions of each stage of the supply chain.

The descriptive analysis was firstly developed using secondary data from each supply chain, such as internal company documents, correspondence with stakeholders, and literature (Coghlan and Shani, 2014, MacInnis, 2011). For example, supply chain diagrams, sensory testing reports and emails supplied by producers were compared to try and explain what happened for each produce life cycle. Following Coghlan and Shani (2014) we connected data to develop a written reflection of what packaging was used; what were typical produce shelf lives; as well as what the impact of packaging was on food waste.

Our explanations remained incomplete by only looking at these secondary data. Hence, semi-structured interviews were carried out by the research team (Brinkmann, 2018). For instance reports and internal testing were lacking specific causes of food waste in the supply chain, which interviews helped to clarify more specifically. Ethics is relevant as to how a researcher relates to people participating in research. Ethics for qualitative research acknowledges the relative aspects between humans, their interactions within, and understandings about the world (Christians, 2018). How a researcher interacts with research participants and relevant data is then framed by that ethical view. Research ethics approval was sought from RMIT University on that basis and approved. A plain language statement was developed to provide a clear explanation of the research to potential external interview participants. The statement explained what the research was about, how their data would be used, and measures to protect data. It also described their rights as a participant during and after the research was conducted. Procedures from the ethics application regarding participant rights and data were applied.

A total of 29 semi-structured interviews (with 31 interviewees) were conducted, and this was judged as providing sufficient data to explain each of the life cycles under study. Interviews were conducted on the phone averaging 45 minutes, between December 2018 and February 2019. Interviewees were selected to represent the range of stakeholder knowledge and perspectives within the respective fresh produce supply chains (see Table 3). They included farm personnel, packing shed managers, logistics managers, packaging technologists, brand managers, and retailers. Interviews were mostly recorded (for those who granted permission), then transcribed via, the online transcription service, Rev. Hand notes were also taken, and a summary report prepared for each interview. When an interviewee did not want to be recorded, hand notes were used to capture the data from the interview. These data were then used with other secondary data to further develop our descriptive and visual life cycle maps for each fresh produce category.

3.0 Project methodology continued

Quotes captured from interviewees were included in our descriptive analysis, complementing secondary data used throughout the life cycle mapping. A multi-vocal quality then developed in our account as described by Taylor and Lindlof (2002). The accounts were therefore 'narrated' by multiple people within the selected fresh produce supply chains, documenting what they experienced occurring. Individual perspectives provided richness to our account of life cycles that would have been difficult with only secondary data.

As a range of both interviewee and researcher views were present through the research, reflexivity was required. As Tracy (2010) suggested, self-reflexivity is applied to make sense of what is occurring, including the role the researcher plays. For all interviews, reflexivity was key to separate what the researcher said or asked, what the researcher sensed, what interviewees said, and then what that all meant. Thus, as we developed our descriptions of the life cycles, we had multiple people from the research team work through the separate interview data to determine whether what we had documented collectively made sense. Thus we applied a measure that ensured what had been heard, recorded and sensed aligned between researchers and interviewees (Taylor and Lindlof, 2002).

Finally, we applied a key method throughout the qualitative research to verify results. We drew on member reflections to check what data we had collected and then synthesised. Member checking is applied by "taking findings back to the field and determining whether the participants recognise them as true or accurate" (Taylor and Lindlof, 2002 p. 242). We sought reviews of our work by providing draft reports to participating research partners and between researchers.

A member checking measure verified that what had been synthesised aligned with research participant recollections. This avoided conflict, as participants made suggestions on where understanding may have differed from theirs.

As directed by the producers, the scope of the life cycle stages that were included in the project were from farming, harvesting, packing, transport, through to retail sale of the fresh produce.

3.2 Laboratory testing of fresh produce

To complement qualitative insights provided by the interviewees, 7 out of the 10 fresh produce products were provided for sensory observations made under laboratory conditions. There was interest from producers to observe the laboratory samples for sensory aspects, as it can relate to shelf life. Sensory aspects relate to dimensions that consumers 'sense', such as when they touch, see or smell a food, that may affect their decision to purchase fresh produce, or not.

All fresh produce products were harvested by their respective producer and packed according to the pack size and packaging type indicated in Table 5. Representatives from each producer organised for at least 3kg of each product to be transported to the RMIT University Chemical Engineering Laboratory (Melbourne, Australia) on a day representative of when each product would typically arrive at Melbourne Distribution Centres (DCs) for items harvested interstate or leave the farm for items harvested in Melbourne.

Table 5: Typical packaging conditions for each fresh produce item studied for sensory observations

Produce	Pack Size	Packaging Type
Tomatoes (small snack pack)	200 g	Punnet – PET
Mushrooms	200 g	Punnet – PET
Blueberries	125 g	Punnet – PET
Raspberries	125 g	Punnet – PET
Cucumber (small pack)	250 g	Punnet with BOPP flow wrap – PET
Cos Lettuce (twin pack)	Twin pack	Pre-pack flow wrap – BOPP
Banana (kids pack)	750 g	LLDPE flow wrap

Note: Materials: PET – Polyethylene terephthalate; BOPP – Biaxially orientated polypropylene; LLDPE – Linear low-density polyethylene

3.0 Project methodology continued

Upon arrival at RMIT University, 1kg of each product was segregated for immediate observations. Thus, this time point was indicative of each product's sensory profile at 'baseline' (Day 0).

Representatives from each fresh producer advised on the storage conditions (temperature in degrees Celsius and length in days) that each product would typically be exposed to between leaving the Distribution Centre (DC) or farm and being available for purchase by consumers at a retailer (Table 6). These storage conditions were then simulated at RMIT University for the remaining 2kg of each product.

Throughout storage, 1kg of each product was left in the packaging provided by the producer and referred to as the 'package' condition, and 1kg was removed from the packaging and referred to as the 'no package' condition. Produce with no package were placed in bulk aluminium trays throughout storage, with the exception being mushrooms which were stored in bulk in a cardboard box (at request of the producer's Representative), as this is the producer's current non-plastic packaging alternative.

Table 6: Produce storage conditions as advised by producer representatives

Produce	Storage Length	Storage Temperature (°Celsius)
Tomatoes (small snack pack)	3 days	12°C
Mushrooms	4 days	2 days 1-4°C, 2 days 6-8°C
Blueberries	3 days	1-4°C
Raspberries	3 days	1-4°C
Cucumber (small pack)	4 days	12-14°C
Cos Lettuce (twin pack)	3 days	1-4°C
Banana (kids pack)	3 days	12-14°C

Note: Storage length representative of time between produce leaving DCs or farms and "point of purchase" for consumers at the retailer.

Produce was delivered to the laboratory and sorted into storage conditions described in Table 5 and Table 6. Fruit and vegetables were evaluated by an individual researcher on 2 separate days, once when they first arrived from the distributor (baseline), and then 3 or 4 days later (day of purchase as per Table 6). Each product was rated on its appearance and aroma, with specific attributes being selected for each product (Table 7). Photographs were also taken of the fresh produce under each storage condition and at baseline and day of purchase, using a digital camera (Nikon Coolpix L840).

At baseline and day of purchase, the assessor observed and evaluated the fruit and vegetables in packaged storage and no package storage. The assessor rated each product by making a mark on a 150mm Visual Analogue Scale ranging from 'not very…' to 'very…' (depending on the specific attributes of each product as outlined in Table 7). To determine the rated value of each product, the marking was measured from zero to where the mark had been made by the assessor; the scores ranged from 0 = 'not very…' to 15 = 'very…'. The assessor also provided open-ended general comments about the look, feel and aroma of each of the products.

3.0 Project methodology continued

Table 7: Sensory attributes used to evaluate products at baseline and day of purchase

Produce	Sensory attributes	Scale anchors
Blueberries	Plumpness	Not very plump to very plump
	Bloom	No bloom to lots of bloom
	Wrinkle (of skin)	Not very wrinkly to very wrinkly
	Bruising	No bruising to lots of bruising
	Aroma	No off aroma to off aroma
Lettuce	Crispness	Not very crisp to very crisp
	Limpness	Not very limp to very limp
	Sliminess	Not very slimy to very slimy
	Colour	Manky green to fresh green
	Aroma	No off aroma to off aroma
Mushrooms	Firmness	Not very firm to very firm
	Blemishes	No blemishes to lots of blemishes
	Sliminess	Not very slimy to very slimy
	White colour	Dull white to bright white
	Aroma	No off aroma to off aroma
Raspberries	Red colour	Dark/dull red to bright red
	Firmness	Not very firm to very firm
	Collapsibility	Collapses easily to hold its shape
	Aroma	No off aroma to off aroma
Tomatoes	Evenness of colour	Patchy colour to full colour
	Firmness	Not very firm to very firm
	Wrinkle (of skin)	Not very wrinkly to very wrinkly
	Aroma	No off aroma to off aroma
Cucumbers	Crispness	Not very crisp to very crisp
	Firmness	Not very firm to very firm
	Wrinkle (of skin)	Not very wrinkly to very wrinkly
	Green colour	Uneven green colour to even green colour
	Aroma	No off aroma to off aroma
Bananas	Yellowness	Green/yellow to dark brown/yellow
	Firmness	Not very firm to very firm
	Blemishes	No blemishes to lots of blemishes
	Splitting	No splits to split
	Ripe aroma	Not very ripe to overripe

3.3 Peer review

A peer review was undertaken by Dr Lilly DaGama, and expert in food waste and supply chains from Portsmouth Business School at University of Portsmouth. Lilly's suggestions are included in Appendix A, along with the responses from the research team and changes that were subsequently implemented.

4.0
Results

4.0 Results

In this section the life cycle mapping of the fresh produce categories are presented. Data gathered during the stakeholder interviews and secondary data collection are presented to summarise the life cycle mapping of each fresh produce category, and the role of packaging on food waste. Data gathered from the interviews on the role of packaging of fresh produce are also presented. Anecdotal laboratory observations of sensory aspects of the fresh produce tested is also provided.

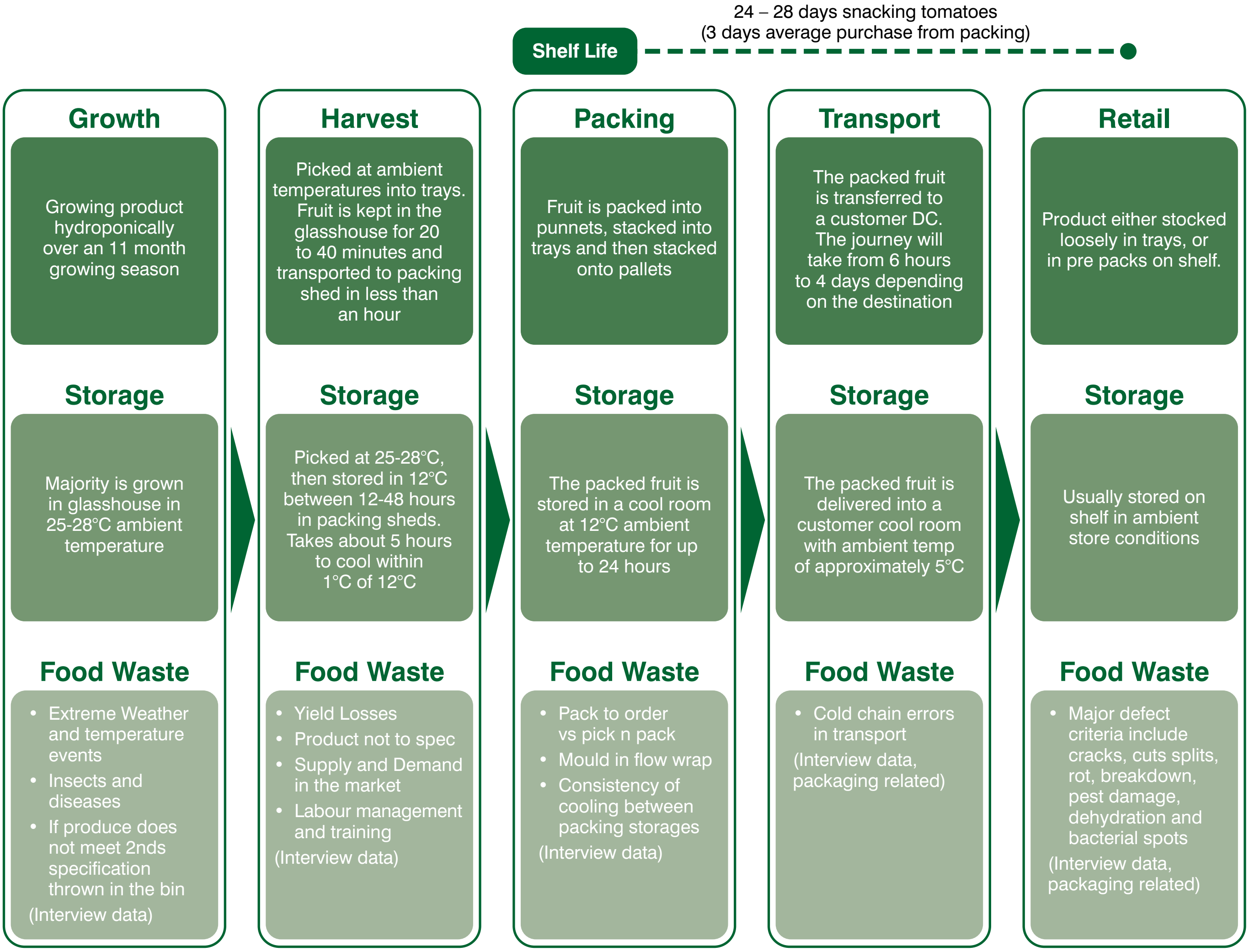
4.1 Tomatoes (Small snack pack)

There are a wide variety of tomato products and species that are grown in Australia. After harvesting, some are packaged as loose or on the vine, into cardboard boxes ready for transportation to market. While the remaining varieties of tomatoes are packed into a variety of primary plastic or cardboard pre-packs (retail packaging). Truss tomatoes can be flow wrapped (with 5 tomatoes onto a plastic tray) as well as in larger cardboard cartons; snacking tomatoes into plastic clamshell punnets as per Figure 4, and cocktail tomatoes in heat-sealed punnets with a plastic base.

Figure 4: Packaged tomatoes (Small snack pack)

4.1.1 Life cycle mapping

The assembled tomato product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 5.



Data from documents and interviews

Figure 5: Tomatoes life cycle map

4.0 Results continued

Growers work closely with retailers and other buyers to select preferred varieties and forecast market demand. Tomatoes are grown in indoor hydroponic glasshouse facilities, at 28° as an ideal temperature with a fruiting period of 11 months. The plants are pollinated by hand as well as raised and lowered by workers as the plant grows up to 35km over its life. Over the optimum growth period, around 9 months of the fruiting period, picking is performed twice a week.

After picking (harvesting) the tomatoes are sent to a grading table and then on to trolleys to be transported to the packing shed. There they are graded again to further remove misshaped or out of specification fruit. From there the tomatoes are packed into their specific packaging which changes between varieties. Some varieties are packed into PET clamshell punnets, or flow wrapped with a PET tray, while some are packed loose into varnished cardboard boxes.

In the tomato supply chain, there is a significant focus on cold chain management post-harvest, meaning it is highly engineered and closely monitored by producers and retailers. Tomatoes are picked during the day off the vine at around 25° and need to be cooled down to a range of between 10-16° as soon as possible and kept that way. In modern facilities this process is streamlined, and the exposure of tomatoes to ambient temperatures is minimised.

From the cool room the tomatoes are packed into a refrigerated truck and sent to retail DCs. Distribution is governed by demand which can fluctuate from week to week.

4.1.2 Shelf life expectancy with and without packaging

It is important to get tomatoes packed, cooled and shipped as quickly as possible to maximise shelf life. The optimal temperature is 12°, but the supply chain allows for and works within a range of 10-16°. Cooling reduces the amount of ethylene released and therefore the ripening process, where too much cooling can stop the ripening process. The tomatoes are picked, packed and shipped with an optimal ripening time in mind – and can suffer from chill damage when warming up.

"You always want to cool your product as quickly as you possibly can to the ideal temperature. The longer it stays hot for, the more gas it can release. And the more the product will degrade and start to break down. That's just part of the ripening process. Temperature control is a really important factor. So, essentially, we need to get the product as cool as possible, and pack it and distribute it as quickly as we possibly can."

Tomatoes Interviewee 1

The standard shelf-life varies – the smaller the tomato the longer the shelf life. On average a large truss tomato will last 14 days (can often be in a cardboard tray when sold in bulk). The smaller snacking tomatoes may last up to twice as long, (i.e. up to 28 days).

Tomato producers have been actively refining their packaging materials to maximize shelf life for some time. Plastics have become the preferred packaging material as they have demonstrated better shelf life outcomes from farm to plate compared to cardboard packaging materials. Cardboard materials absorb moisture from the tomatoes, dehydrating them and reducing their quality over their shelf life. Some producers are moving toward bio-degradable plastic packaging, with this also being promoted by supermarkets based on customer demand for more sustainable packaging.

The model suggested by the tomato producer as the normal time of purchase was 3 days from distribution to the retailer, with the produce kept at 12°C.

4.0 Results continued

4.1.3 Food waste, and impact of packaging on food waste

Our expert interviewees all agreed that packaging reduces food waste in the tomato supply chain. Packaging is important from when the fruit is picked, graded and packed on the farm up until when the customer purchases them off the shelf.

Producers are financially incentivized to maximize high grade produce and therefore are focused on mitigating rejections for fruit that is out of specification. Packaging is used to preserve the quality standard for high grade produce required by supermarket specifications.

Producers are obligated to manage the fruit from the farm to the retailer DC, meaning their packaging and cold chain systems are highly optimized to meet this goal. Without this in place, it can lead to a high level of wastage on the farm from crops not meeting quality standards. There can be issues with growing conditions due to the weather, agronomic problems, blossoming rot, size (too big or small), look and colour (too green or red). Produce that can't be downgraded and sold to the secondary market is either disposed of as waste to landfill or donated to food charities, such as Foodbank.

This wastage during harvest can be compounded by market demand which can fluctuate on a weekly basis. Changes to orders can on occasion mean that;

> "…the fruit doesn't get packed, it will then age. When it ages, it reduces shelf life, and then it degrades to waste."

Tomatoes Interviewee 2

Fruit that stays longer in the producer's cool room is aging and deteriorating – thus producers have to remove already ripe fruit before shipping to retail DCs and can lose some of this produce as waste as a result.

Produce can be rejected by supermarkets due to cold chain errors in transport. There is an opportunity to donate rejected fruit to food rescue organisations, and absorb the extra transports costs, rather than repacking and de-branding it to sell to secondary markets. Some producers already do this.

From the retail perspective, packaging is optimized around consumer desirability, convenience and choice. With these goals in mind, retailers have promoted pre-packed tomato products to the consumer. Plastic packaging has been very successful in improving shelf life for producers, including limiting consumer access to touch/handle the produce which can cause bruising and other blemishes. Packaging is also effective at keeping foreign objects out, whereas product packed loosely in a tray, or without wrapping or in containers, tend to deteriorate faster. While these products have enjoyed market success, some consumers have said they either don't want plastics or they want to see a reduction in plastic in the fresh produce aisle. This response has resulted in packaging specialists from producers and retailers experimenting with bio-degradable packaging with the intention to utilise such packaging in the future as the technology matures.

The biggest challenge with packaging tomatoes is managing respiration and ethylene levels over the shelf life of the pack. As the tomatoes ripen they respire, and release ethylene gas. Packaging design must account for this by having enough holes in it to allow the fruit to breathe. Incorrect packaging has resulted in rejections in the past.

4.1.4 Impact of packaging on sensory aspects

There were no differences between the packaged and no package tomatoes at baseline for any of the attributes including colour, firmness, wrinkle (of skin) and aroma (Table 8 and Figure 6). There was also no difference in aroma at day of purchase between the packaged and no package tomatoes and only a very small decline in this attribute from baseline to day of purchase. The amount of wrinkle of the skin did increase slightly compared to baseline for the packaged and no package tomatoes, with the no package increasing slightly more. Even though this did increase, it was still rated low at day of purchase. The firmness of the packaged and no package tomatoes both declined from baseline to day of purchase, with the no package variety becoming less firm compared to the packaged tomatoes at day of purchase. The patchiness of the colour also changed from baseline to day of purchase, with the packaged tomatoes becoming patchier in colour, whilst the no package tomatoes were rated as less patchy and fuller in colour compared to baseline and the packaged tomatoes (Table 8).

Table 8: Assessor's ratings of the packaged and no package tomatoes at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	**No package**	**Packaged**	**No package**
Colour (patchy)	4.9	4.9	3.0	6.7
Firmness	12.5	12.5	9.5	8.8
Wrinkle	1.5	1.5	3.0	4.6
Off aromas	1.5	1.5	1.1	1.1

4.0 Results continued

From the descriptive data, the packaged and no package tomatoes were both rated the same at baseline, which included being very firm, and somewhat uneven in colour with no wrinkles or cracks. At day of purchase, the no package tomatoes were described as being fuller in colour compared to the packaged tomatoes which were still uneven in colour (Figure 7). The no package tomatoes were softer to touch compared to the packaged tomatoes and had more bruising or dents present compared to the packaged tomatoes. When cut, the no package tomatoes seemed riper compared to the packaged tomatoes which were paler inside.

Figure 6: Packaged and no package tomatoes (respectively) at baseline

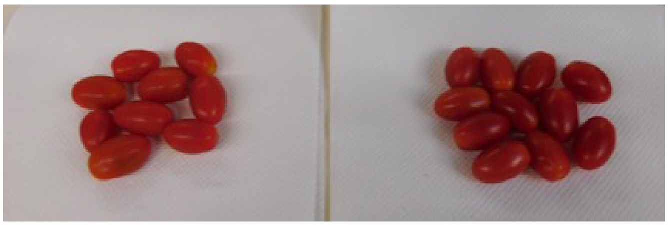


Figure 7: Packaged and no package tomatoes (respectively) at day of purchase

4.2 Mushrooms (Cup)

The mushrooms under study were common, white-cup (agaricus bisporus) mushrooms. They can be sold whole or sliced and packaged in PET punnets with a plastic wrap as per Figure 8. Whole mushrooms are also sold loose and packaged in corrugated cartons.

Figure 8: Packaged mushrooms

4.2.1 Life cycle mapping

The assembled mushroom product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 9.

4.0 Results continued

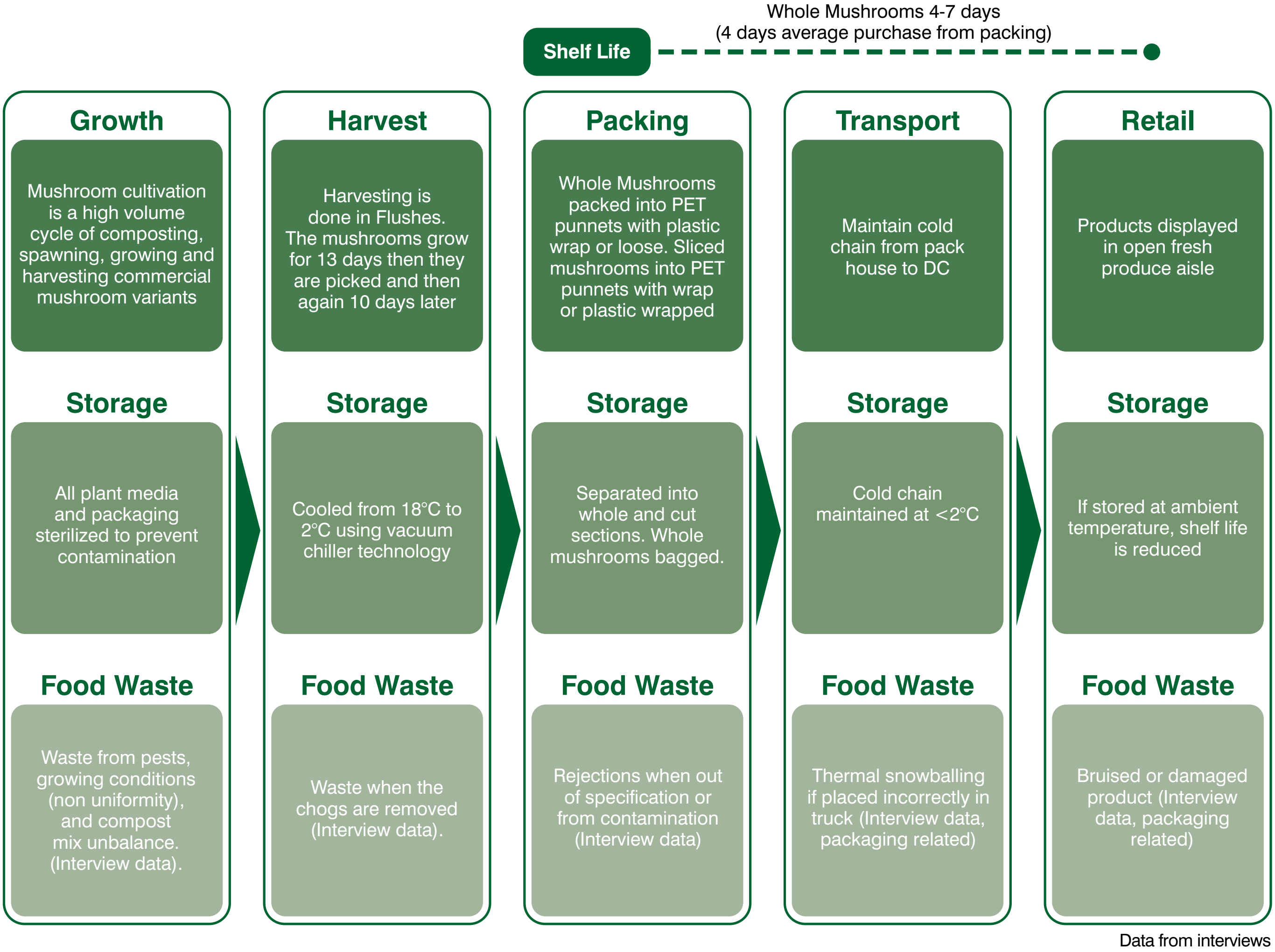


Figure 9: Mushrooms life cycle map

Mushrooms are grown indoors with the most common production method involving the use of vertical shelves or large wooden growing trays. Their growth phase is rapid, doubling in size every 24 hours, with a single stand-alone facility producing millions of individual mushrooms every week of the year.

Mushroom production involves a constant cycle of compost preparation, spawn, growth and harvest. Cycles can last between 30 – 150 days (involving what are called several ‘flushes’), depending on the species and growing techniques.

Harvesting is performed in flushes, and over the first 10 – 12 days the mushrooms are not visible. Over the 12 – 15 days period they grow rapidly in size and are picked. They then regrow and are picked around 10 days later in the second flush.

From the harvesting area, mushrooms are either placed in PET punnets (with a plastic overwrap with perforations) or loose in recyclable corrugated cardboard boxes before the produce is sent to the pre-packaging area. Some mushrooms go through a slicing process for the pre-cut product to be packaged in plastic punnets and film.

The mushrooms are tested and catalogued during all stages to make sure there is no risk of microbiological contamination.

The cold chain is highly optimized due to a short shelf life. Australia needs sophisticated cold chain technology because of the long geographical distances produce must travel. The mushrooms are kept at a low temperature from harvest to delivery to DCs. They are picked at 18°C and cooled to 2°C within 60 minutes of harvest.

Reducing the respiration rate to slow the rate of degradation of mushrooms is also key. If mushrooms get warmer than 8°C they decline in quality and shelf life rapidly. Growers use ‘vacuum chiller’ technology to cool mushrooms to 2°C. Vacuum chilling is ideal for mushrooms as they are 92 – 93% water with no skin. They lose 2-3% water when chilled.

4.2.2 Shelf life expectancy with and without packaging

Food waste can be generated when consumers reject an item of produce perceived to be of low quality. Therefore, extending the shelf life and protecting the produce is paramount in the growing, distribution and selling of mushrooms.

> "…It promotes healthy eating. So, we're preserving the product. (With packaging) we're getting better quality when it sits on the shelf. And, we're trying to drive Australians to eat healthy. "

Mushroom Interviewee 2

Passive modified atmosphere packaging has been developed, specifically to match the respiration rates of different types of mushrooms. This involves a perforated PET punnet with holes sized to maximize shelf life.

> "So, if we're preserving the shelf life of the product and maintaining the quality for longer, then, really, in essence, we're maintaining or preserving the nutrition value of that product."

Mushroom Interviewee 2

Producers are actively prototyping what are perceived as environmentally friendly packaging alternatives but have found that their PET punnets are still performing better.

In past tests, an interviewed producer developed a clam shell packaging with large holes in it for their mushroom product. This was developed because it protected the mushrooms by reducing bruising, while stacking them on top of each other. This packaging failed because it didn't deal with the respiration rate of the mushrooms. The clamshells worked well mechanically, but they reduced the shelf life to 5 days due to the respiration issues. The product was removed from further sale due to underperformance on shelf life.

4.2.3 Food waste, and impact of packaging on food waste

Packaging has played an important role for mushrooms in preserving the moisture content and preventing bruising from farm to the shelf. Growers and retailers have been very focused on reducing the wastage of their 1st grade product so their processes are highly streamlined.

Retail specifications require the chog (the mushroom stem) be no longer than 1/3 the length of the cap requiring its removal.

In the past, a big challenge in the mushroom supply chain was transportation from the grower to the retail DCs. Inconsistent cooling leads to an unacceptable level of rejections at the DCs. Producers engaged with transport companies to monitor and improve their operations, with the positioning of the packaged mushrooms in the refrigerated vehicle identified as a critical issue. If the mushrooms are placed too high they might freeze and if they are placed in the middle they can heat up and create a thermal snowball, a phenomenon that causes the mushrooms to continue to heat up over time. Sliced mushrooms are particularly susceptible because they heat up when sliced in the packaging stage as well as the increased surface area compared to whole cap mushrooms.

4.2.4 Impact of packaging on sensory aspects (whole mushrooms)

There were no differences at baseline between the packaged and no package mushrooms (whole variety) for firmness, blemishes, colour or aroma (Table 9 and Figure 10). There was a slight difference in the sliminess rating, with the packaged mushrooms being rated slightly slimier than the no package mushrooms, however this was minimal. Both firmness and white colour declined from baseline to day of purchase.
In addition, there was no difference in the firmness of the packaged and no package mushrooms at day of purchase. However, there was a slight difference in the white colour at the day of purchase of the mushrooms, with the packaged mushrooms being slightly whiter than the no package. The off aroma of the mushrooms increased very slightly from baseline to day of purchase, however this was minimal and there were no differences between packaged and no package mushrooms at day of purchase. The sliminess and blemishes ratings did increase from baseline to day of purchase for both packaged and no package mushrooms. In both cases, the no package mushrooms were rated higher, having more blemishes, and sliminess (Table 9).

Table 9: Assessor's ratings of the packaged and no package mushrooms at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	No package	Packaged	No package
Firmness	12.7	12.7	10.0	10.0
Blemishes	3.2	3.2	4.4	8.1
Sliminess	2.1	1.5	4.6	6.5
White colour	12.4	12.4	9.6	8.1
Off aromas	1.4	1.4	2.0	2.0

Figure 10: Packaged and no package mushrooms (respectively) at baseline

When observing the mushrooms, it was noted that there was moisture present at the bottom of the packaged mushrooms and there was some slight browning on the bottom, compared to no moisture on the no package mushrooms. The amount of moisture increased in the packaged mushrooms at day of purchase, and some mushrooms had water droplets on them. At day of purchase, the no package mushrooms had turned browner in colour compared to the packaged mushrooms and had a greater number of blemishes (Figure 11). There were no observable differences between the packaged and no package mushrooms when they were cut, both were reported to be firm to cut.

Figure 11: Packaged and no package mushrooms (respectively) at day of purchase

4.3 Raspberries and blueberries

The primary type of packaging for berries is a PET clamshell punnet – with sufficient ventilation for the product. A normal punnet size, is 125g for blueberries and raspberries and was the packaging format reviewed in this study as per Figure 12. There are 12 punnets that are packed onto a cardboard tray and then, in turn palletised for shipping.

Figure 12: Packaged blueberries and raspberries

4.3.1 Life cycle mapping

The assembled berry product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 13.

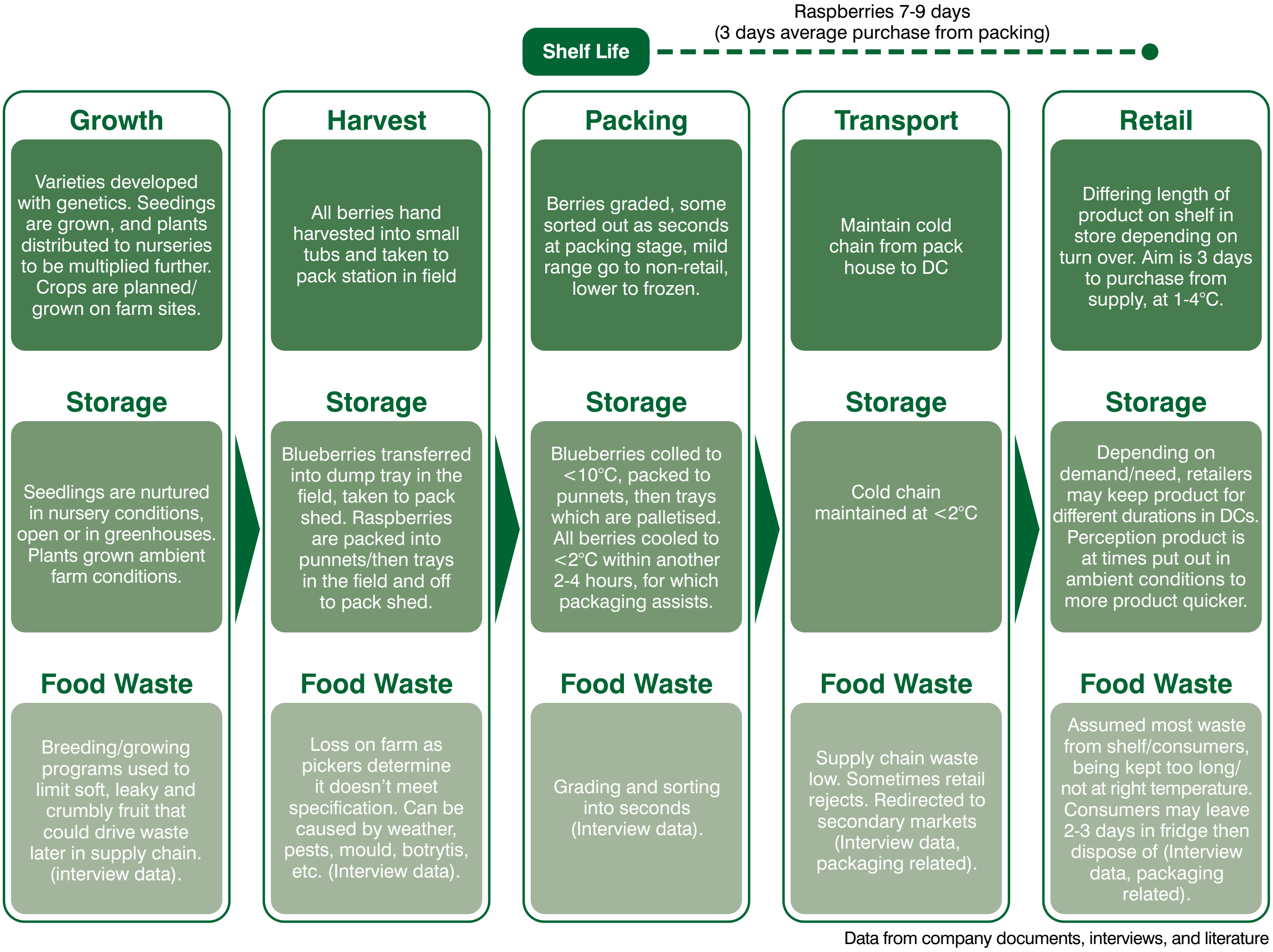


Figure 13: Berries life cycle map

Product development of both public and protected berry varieties occurs with the input of Australian and international expertise. Product is developed with advanced genetic techniques and initially grown into seedlings. A variety is then multiplied with plants distributed to nurseries to be multiplied further. They are then grown and transferred to substrate pots or planted in soil on farm. Growing specifications are determined by cropping cycles, weather, land management and water/ nutrient management.

Growers harvest the produce by hand picking. Once picked, temperature and time are key to maintaining product quality and integrity, meaning the faster the produce is transferred into a controlled environment the better the chance the fruit survives and retains its quality. This is because berries can change temperature quickly principally due to their size, and their susceptibility to mould, especially if temperature is not ideal/maintained.

Blueberries are transferred into a collection tray in the field then taken to the packing shed and cooled to < 10°C. They are then packed in punnets via a machine, with any remainder sorted into secondary trays. Raspberries are packed directly into punnets and then trays in the field before being transferred to the packing shed. The berries are graded, and those of lower quality are generally sorted as seconds at the packing stage. Mid-range grades go to non-retail outlets, while lower grades where possible will be sold as frozen product.

Trays are palletised and then cooled to < 2°C, where they are then consolidated on a refrigerated truck within another 2-4 hours. The absence of a cooled packing shed, can impact negatively on product longevity. Modified atmosphere can be used for blueberries to achieve extended cold room storage for anywhere between 6 to 8 weeks to allow some product to be sold at a later date, for example after a season has concluded.

Product is then sent to a central DC (often retailer operated), from which it is then dispatched to retailers and wholesalers. The cold chain is maintained at <2°C before and during shipping.

4.0 Results continued

4.3.2 Shelf life expectancy with and without packaging

Raspberries have a total shelf life from the farm of 7-9 days if kept in optimum condition. Blueberries are more resilient, lasting up to 17 days. Interviewees factored in shelf-life considerations when planning for optimal picking times – indicating a very high level of quality control. Factors such as variety types, sugar acidity, firmness, colour, and growing region are also considered.

The model suggested as the normal time of purchase was 3 days from distribution, kept at 1-4°C. An interviewee noted that they collected samples from retail outlets daily to aid monitoring/ testing product shelf-life quality.

4.2.3 Food waste, and impact of packaging on food waste

The first stage of any berry waste occurs on farm. This is when picked product does not meet minimum standards, such as size, colour and blemishes. There are several variables that can impact this, including issues such as effective on-farm management of crops, agronomy, pests, disease, weather, mould, and botrytis. Breeding and growing programs are also used to limit soft, leaky and crumbly fruit that could drive waste later in the supply chain. Interviewees noted farm wastage likely went to landfill and food rescue/charities. There was also no capacity for this wasted product going to lower grade fruit as it is not currently economical.

Grading techniques sort out packing shed waste. Some sites have optic sorting/grading technology which takes images of each piece of fruit at high speed, in high resolution, accurately sorting fruit by defect into grades. As an interviewee stated:

> "So it's all visible. Our pack lines give you a report and a breakdown…Red fruit, green fruit or soft berries that isn't good enough for the fresh market. It's a fairly visible and automated system."

Berries Interviewee 2

Before optic technology, organisations only had visibility of what was manually graded out. The optic grading provides higher consistency and more granular understanding of defects, with an aim to get 100% of berries into fresh grades. Only 2- 10% of fresh produce is generally downgraded into frozen product under current standard practice. The rest is packaged and sent fresh to market. Digital systems such as SAP are used to feed waste data into organisational reporting and management.

It was generally accepted, by interviewees, that packaging is essential for limiting berry waste within the packing, transport and retail stage as berries are:

- One of the most perishable horticultural products in the industry
- Soft and fragile (though blueberries are hardier/more forgiving)
- Susceptible to damage from compression and vibration – so need to be well protected for storage and transport and not have berries packed too tightly / on top of each other.

Interviewees noted that it is important at harvest to quickly transfer berries from buckets, to collection trays, and then into smaller punnets. This is to take the weight off the product and reduce compression, damage and moisture loss. Packaging also assists in cooling the product quicker by letting out the heat. It also facilitates distribution across the country rather than to local markets – so packaging also helps with scalability/ economies of scale.

With respect to transportation, humidity, temperature, logistical shocks (i.e. vibration and compression), and lighting are all factors in getting fruit to market in good condition. An interviewee noted packaging had currently been optimised through extensive testing to cater for many of the factors noted above:

> "The product that we produce is perishable, it's very delicate and any type of physical damage, compression, vibration, will have a significant impact on their ability to last. So, if the product is not protected, it will not last at all and we wouldn't be able to take it to all the different markets where it needs to get. It would be impossible. Without proper packaging, it would be impossible to have raspberries, strawberries, blackberries, even blueberries."

Berries Interviewee 1

If the produce does not meet retail quality assurance when inspected by the retailers at the DC, it will be returned. Stock is sometimes returned by retailers if a punnet is underweight but can be reassigned to frozen on return. It may then move onto the wholesale market (as soon as possible – to prevent further deterioration).

Retailers may keep the product in their DCs for different durations depending on consumer demand / need. Product may also not be kept at the ideal temperature in-store, for example product may be displayed at ambient temperature in order to sell the available volume and avoid wastage at the retail store level.

Absent of any quantitative data, interviewees had the perception that most wastage in the berry supply chains occurs at the consumer level. Issues such as produce being left out for too long or not being kept at the right temperature are the most common causes cited. From the consumer perspective, some complaints have been made that product only lasts '2-3 days' in the fridge before needing to be disposed of. Product damage and additional moisture can lead to mould and rot post purchase. Key information for consumers with respect to ensuring shelf life is to keep the berries refrigerated and to only wash them before eating. Soaker pads can be used for moisture absorption, though they are not required for blueberries.

New packaging options are currently being considered, including a top-seal over existing hard plastic punnets to minimise tampering and maximise seal (currently used in tomatoes but not berries); and modified atmosphere packaging to limit oxidisation (like that reported by for the salads sector). These are currently works in progress for the organisations interviewed.

In summary, packaging is seen as essential to managing temperature and product shelf life of berries. Packaging also provides product protection for the berries, which is important in avoiding waste through the handling, vibration and compression of the product. It also plays a role in dealing with the moisture aspects of the berries. Many factors are at play in defining the role of packaging, an interviewee observed:

"Look I think we've pretty much optimised the level of packaging as best as we could to balance out a lot of things...However, integrity of the product, consumer perception, customer requirements, commercial impact of the packaging and environmental impact of the packaging, are the basic requirements from post-harvest point of view. All of those factors, and obviously waste, are critical considerations."

Berries Interviewee 3

4.3.4 Impact of packaging on sensory aspects

In the laboratory there was no observed difference between the packaged and no package blueberries at baseline for any of the attributes; plumpness, bloom, wrinkle, bruising, off aromas (Table 10 and Figure 14). Bruising and off aromas increased very slightly compared to baseline for both the packaged and no package blueberries. The amount of wrinkle also increased from baseline to day of purchase for both, with the no package increasing slightly more than the packaged blueberries.
The amount of bloom decreased a similar amount for both packaged and no package blueberries. Both the packaged and no package blueberries decreased a large amount with respect to plumpness, with the no package blueberries rating slightly lower than packaged blueberries, meaning they were less plump (Table 10).

Table 10: Assessor's ratings of the packaged and no package blueberries at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	No package	Packaged	No package
Plumpness	12.5	12.5	8.5	6.8
Bloom	12.5	12.5	8.9	8.0
Wrinkle	1.3	1.3	3.3	4.9
Bruising	1.2	1.2	2.0	2.0
Off aromas	1.3	1.3	2.0	2.0

4.0 Results continued

Figure 14: Packaged and no package blueberries (respectively) at baseline

The assessor noted the plumpness had deteriorated in both the packaged and no package blueberries, however the plumpness had declined more in the no package blueberries. This was also similar in the fact that the no package blueberries showed some small signs of aging and wrinkle compared to the packaged blueberries (Figure 15). When cut in half, the packaged blueberries were more purple inside compared to the no package blueberries.

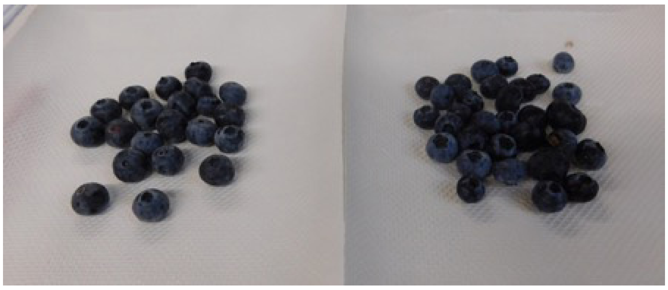


Figure 15: Packaged and no package blueberries (respectively) at day of purchase

There were no differences at baseline between the no package and packaged raspberries for firmness, collapsibility or aroma (Table 11 and Figure 16). There was a very minimal difference in the red colour, but this was negligible. From baseline to day of purchase, the intensity of the red colour increased in both the packaged and no package raspberries, with the packaged raspberries having a larger increase in rating of red colour. Off aromas also increased, but this was a minor increase and still a low rating for this attribute for both the packaged and no package raspberries. The packaged raspberries remained very similar regarding firmness and collapsibility on day of purchase, however the no package raspberries declined quite significantly, with the rating of firmness and collapsibility for the no package raspberries halving, therefore making them soft and easily crushed (Table 11).

Table 11: Assessor's ratings of the packaged and no package raspberries at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	**No package**	**Packaged**	**No package**
Red colour	9.3	9.6	11.0	10.1
Firmness	9.5	9.5	9.3	4.7
Collapsibility	6.9	6.9	6.3	3.3
Off aromas	1.4	1.4	2.6	3.7

Figure 16: Packaged and no package raspberries (respectively) at baseline

From the observations, the no package and packaged raspberries were described the same in that they were mostly of good colour, and firm. On day of purchase, the no package and packaged raspberries were both brighter and deeper in red colour compared to baseline. It was noted that the packaged raspberries were firmer and much less likely to collapse compared to the no package raspberries at day of purchase (Figure 17). There was also juice present on the bottom of the tray for the no package raspberries compared to no juice in the packaged raspberries. The packaged raspberries held their shape when cut, whereas the no package raspberries collapsed very easily when pressure was applied.

Figure 17: Packaged and no package raspberries (respectively) at day of purchase

4.4 Leafy salads ('Ready to eat' loose salad mix)

Interviews covered salads in general rather than just leafy salad mixes, therefore they are discussed in general. The leafy salads are sorted via various foreign body hurdles and sanitised before being packed, depending on the product, in plastic bags, kits or a solid plastic bowl/ tub sealed with BOPP film over the top. Figure 18 shows two examples of lettuce used in salad mixes.

Figure 18: Packaged leafy salad mixes

4.4.1 Life cycle mapping

The assembled leafy salad product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 19.

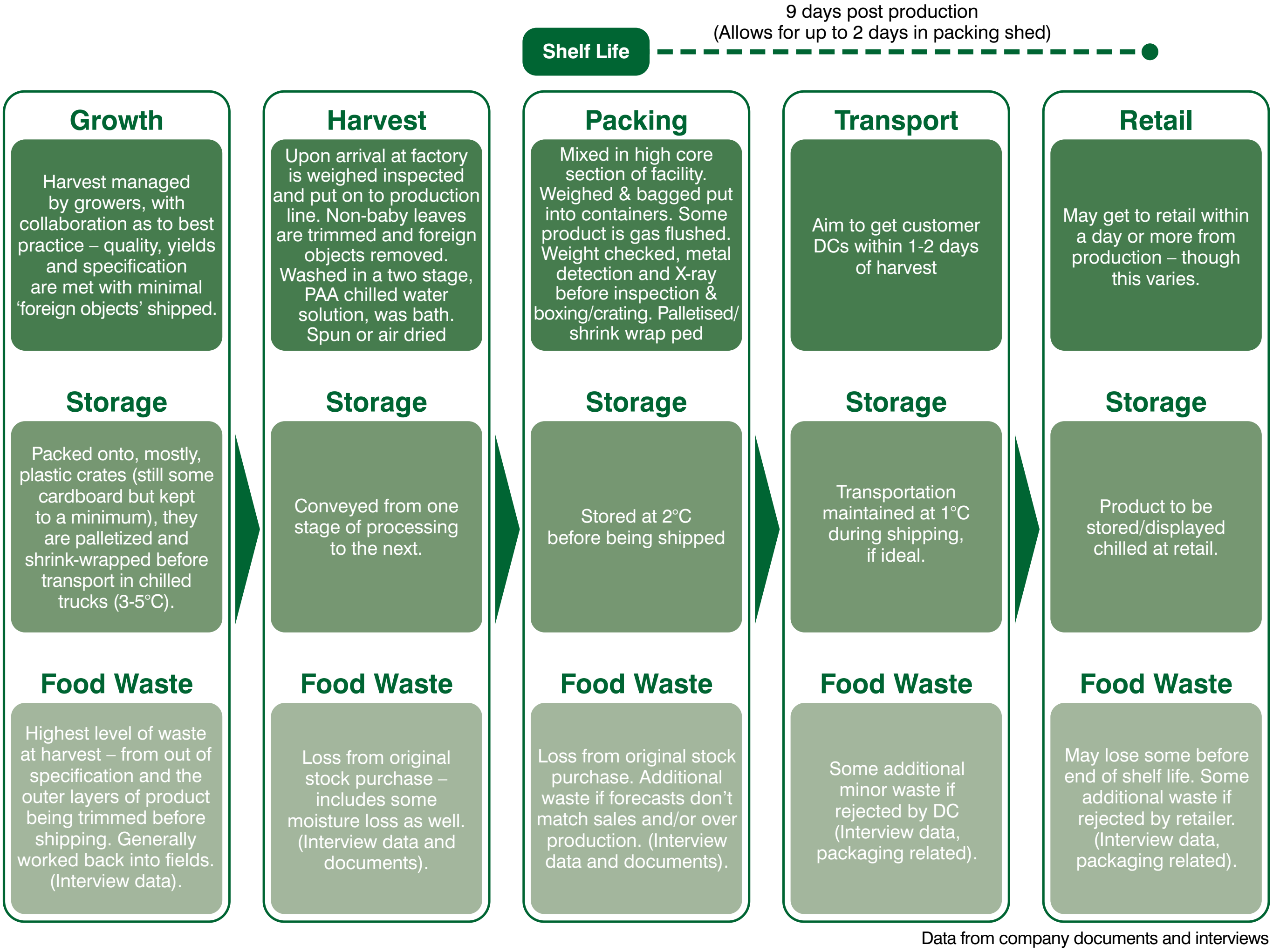


Figure 19: Leafy salads life cycle map

Production of salad mixes occurs across several states, with produce sourced from farms located in regional and peri-urban areas. None of the interviews covered on farm production in detail, therefore the life cycle process tracked from harvest, via packing and shipping to the factories / production facilities, concluding with the product being dispatched to retailers. It is worth noting that there is a high level of collaboration between the end producer and their third-party growers/suppliers to ensure quality, yields and specification are met with a focus on minimising wastage once the product is received. This includes removing the outer leaves of lettuce, where relevant.

The main leafy fresh produce being procured and processed includes 'baby leaf' (spinach, rocket, coral etc) lettuce (cos and iceberg) and kale. These are grown at a central farm location, being the principal ingredients in packaged salad product (with baby leaf estimated at over 50% of supply into the producer's facilities). Large quantities of hard vegetables including cabbage, carrot, potatoes and beetroot are also used. Other produce such as red capsicum, broccoli and onions are used to a lesser extent.

After harvesting, raw materials are packed into plastic crates, palletised and shrink wrapped, on farm and then transported in refrigerated trucks (at around 3-5°C) to processing sites. On arrival, the produce is weighed and inspected for quality and yield. If raw material deliveries pass intake inspection, it is placed onto a production line, where non-baby leaf items are trimmed and a series of 'foreign object' hurdles are utilised to remove stones, sticks, weeds, insects, small fauna etc before being sanitised in a dual stage, chilled sanitisation solution for microbiological reduction e.g. Listeria monocytogenes, Salmonella, etc.

Product is next either spun or put through an air dryer system and then mixed in a high care facility. After being weighed and bagged, some of the product may be gas flushed (in particular Cos lettuce) to stop oxidation and tinting. Further steps in the process include weight checking, metal detection, X-ray inspection before palletisation and shrink wrapping occurs. The product is then loaded and despatched to the DCs. This activity involves a mix of manual and automated/machine aided processes.

4.0 Results continued

The finished product is stored at 2°C, then transported to the DC at 1°C. This means there is a fine line between the product being kept fresh and freezing. Temperature control is required for respiration rates, reducing microbial growth and ensuring stated shelf life of products are achieved organoleptically.

Transport temperatures are monitored, and data is transmitted live/in real time to team members, so they can monitor any fluctuations and assess performance. Where necessary, adjustments to temperature can be made. Product transportation time can range from 15 minutes to 3 days, depending on the end destination.

Transport is contracted to third party haulers; however, the producer has substantive control over this process. Managing temperature in the outbound process is considered critical to operations.

> "Temperature is the biggest Achilles heel in our product and obviously we transport stuff all around Australia….if you lose temperature, or it's too warm, or it's come outside the specification, the DC will actually reject it and therefore it will never make it to the consumer."

Leafy Salad Interviewee 2

One interviewee spoke about how they trialled shipping product in uniform reusable plastic crates, instead of disposable cardboard cartons. However, this was discontinued as there were issues with managing stock loads and customer demand (the crates fit 26 versus 10 bags in the cartons) and while crates are better for air movement and can help in keeping the product cold, it can also mean if things go wrong, it can heat up quicker than is desirable.

It is worth making mention that another interviewee spoke about getting industry together to share information on specifications, including more flexible interpretations and norms, as well as best practise production, packaging and shipping to get the best outcomes for both the industry and consumers. As stated:

> "I'd get a group together … (to work out how) do we do this together. At the end of the day, we're not really in direct competition. It's about getting our product to our customer, with better shelf life, fresher, all those things. Let's work out what the best solution is."

Leafy Salad Interviewee 2

4.4.2 Shelf life expectancy with and without packaging

The shelf life of pre-processed salad products would not last for more than a few days without packaging. According to an interviewee, the standard aim is for the product to last 9 days from time of production (into a salad mix) in a packaged form.

4.4.3 Food waste, and impact of packaging on food waste

Learning and technical advances shared between growers can ensure they achieve a more 'usable crop' including in terms of minimising waste. As an interviewee noted:

> "We don't have a high quantity of waste, so a lot of it we try and use, or we try and work with our growers to ensure that …. There's not a lot of waste that we're actually generating from it."

Leafy Salad Interviewee 3

In processing and packing of lettuce there is some wastage. Management of this starts with the weight of produce (crated up) as it leaves the farm, versus what is eventually packaged up, entered and measured precisely by financial stock control systems allowing ongoing measurements and analysis of losses. Negligible volumes of produce are left behind in the reusable crates that salad leaves are delivered in. More wasted product is sorted out as foreign objects, and some weight is also lost via moisture loss.

Wastage also results from trimming parts of the produce due to quality concerns. An interviewee suggested that they could also consider re-purposing options, such as turning poor quality spinach into frozen cubes. During packing there are also negligible losses of food that is spilled on the ground.

On rare occasions (rejection rate on raw material deliveries is 0.6%) there are issues with whole loads of products delivered from farm for packing, such as spinach, being discarded as they may not be up to specification. As an interviewee noted in regard to these waste incidents when they are due to pest damage or too much stem rot;

> "… It's again, not a food safety issue but a quality issue and we reject it … It's obviously something that we try and avoid."

Leafy Salad Interviewee 1

Such wastage is diverted to the local livestock industry, such as to local pig farmers where relevant, who use the waste as feed for their animals.

In retail, there can also be wastage from packaged product that is not sold due to oversupply or rejected by the DC/retailers for non-food safety parameters. This product may be on sold to staff and/or, given to food charities. Short ordering confirmation times can create issues of oversupply despite forecasting.

Pre-processed salad products would not last for more than a few days without packaging, as opposed to 9 days from time of packing. It is also important that additional processes such as gas flushing/splashing (to displace oxygen) are implemented, as some produce such as lettuce will oxidise and turn pink/discolour rapidly after being cut – within 24 hours. Gas flush consists of an inert gas injected and frequently removed multiple times to eliminate oxygen from a package. Gas flushing can delay this process for several days; maintain the quality and visual aesthetics for a lot longer (e.g. 8 days versus 1). Furthermore packaging, when done correctly, reduces moisture loss:

> "Obviously, when they're in the packaging that helps reduce the moisture loss within the products, and therefore prevents them from shrivelling and becoming a limp product, and therefore gives them a significant benefit to their shelf life."

Leafy Salad Interviewee 3

It is worth exploring how adjustments to packaging can impact food wastage, in particular the balance with perforation and the respiration rates of the product:

> "So baby leaf respires at a fairly high rate, so we have to look at the perforations we use for that and the interaction with ingredients we have in, say, a coleslaw or a stir fry… Sometimes we've got items that are high respirators and sometimes they're low respirators, so it's about coming up with the balance around our perforations and about what works there."

Leafy Salad Interviewee 3

Thus, the balancing of sanitation, packaging, refrigeration and gas flushing are essential to reducing wastage in pre-processed salad products.

4.4.4 Impact of packaging on sensory aspects

No laboratory testing was possible for leafy salad, due to unavailability of sample produce.

4.5 Cucumbers (Small pack)

The primary type of packaging for cucumbers are rigid PET punnets, but it is also now common for trays to be made of PET plastic with a PET flow wrap as per Figure 20. The packs are then boxed and palletised for shipping.

Figure 20: Packaged cucumbers

4.5.1 Life cycle mapping

The assembled cucumber product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 21.

4.0 Results continued

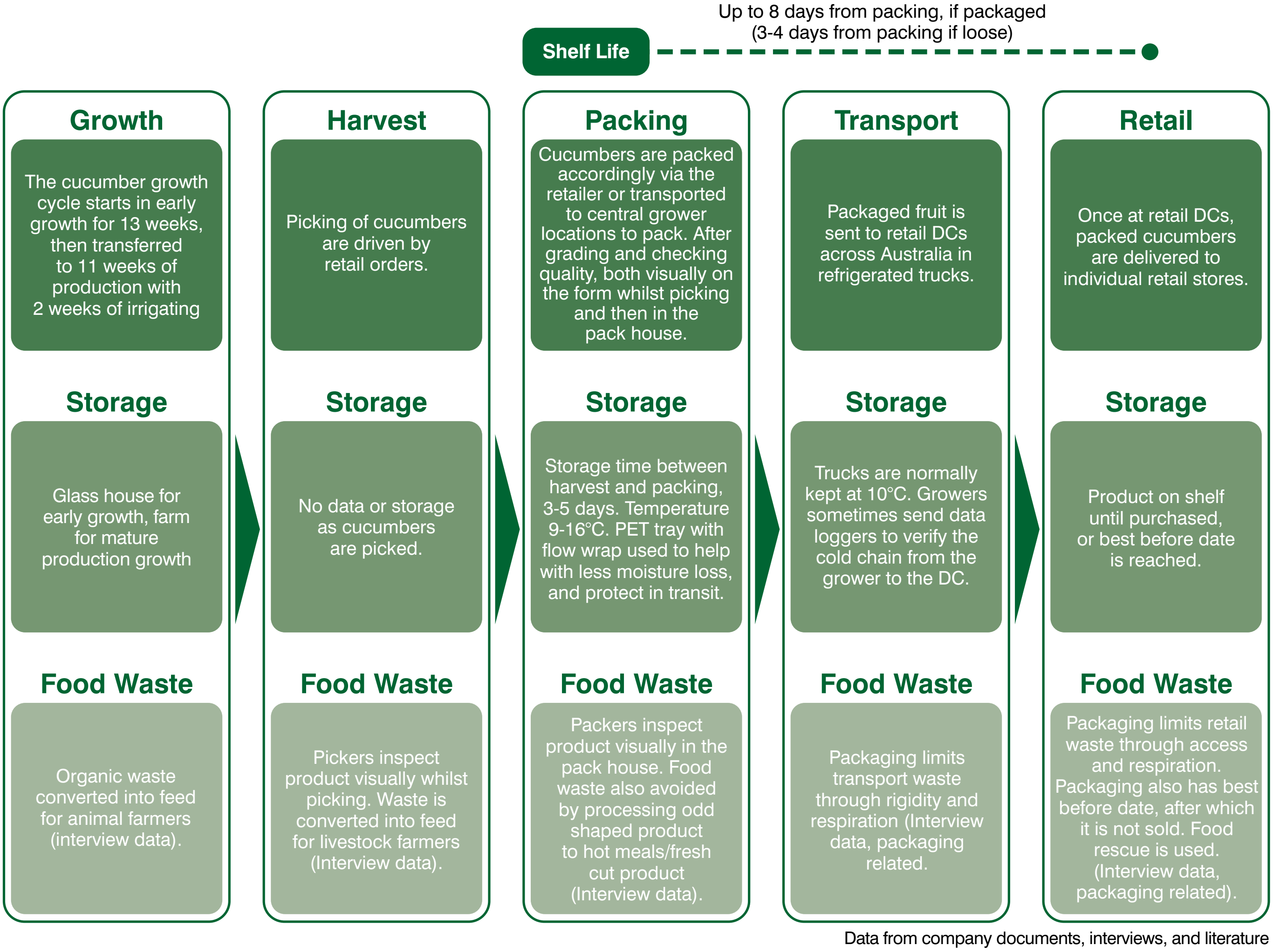


Figure 21: Cucumbers life cycle map

Small (baby) cucumbers are grown in glasshouses over a 13-week growing cycle. The timing of picking/harvesting is driven by retail orders. The cucumbers are graded and checked for quality before being packed and dispatched. Minimising storage time between harvest and packing is prioritised, which is normally limited to between 3-5 days. The packaging of small cucumbers occurs in a PET tray with flow wrap which is designed to minimise moisture loss and protect the product in transit.

It is important to maintain the cold chain from the farm to the customer. Growers keep track of temperature of the packed product in their cool rooms, utilising alarm systems to indicate if the temperature is too high or too low. Growers record the temperature during storage and immediately prior to loading the product for transport into refrigerated trucks. The ideal temperature range is 9-16°C for cucumbers.

The product is transported to the DC by third parties, however growers on occasion send data loggers to verify the cold chain from the growers' premises to the DC. The data loggers allow growers to download data, with the GPS tracking enabling them to see exactly where, and if there are, any spikes in temperature. This could be due to a truck break down or a dock transfer. Trucks are normally kept at 10°C and, the cucumber packs are dispatched from the DC to retail stores.

4.5.2 Shelf life expectancy with and without packaging

Through internal validation, bulk cucumbers will only last 3-4 days loose once they have been picked. By packing cucumbers in plastic, this reduces the rate of water loss from the product and extends the shelf life up to 8 days. This increases the amount of time that the product can be displayed on shelves, as well as its availability to consumers. As an interviewee commented:

> "(Packaging) increases the likelihood of that product being purchased versus having only a 3 or 4-day window."

Cucumber Interviewee 1

Based on the product being packaged and labelled with a best before date, the extension of shelf life from the packaging is considered vital. The model suggested as the normal time of purchase was 4 days from distribution, stored at 12-14°C.

4.5.3 Food waste, and impact of packaging on food waste

On the farm and in the packing shed, a grower noted organic waste is converted into feed for animals. This is derived from both inspecting visually on the farm whilst picking and then in the packing shed. Food waste to landfill is also avoided by processing oddly shaped vegetables into hot meals and freshly cut product. This enables the grower to sell more product and avoids food waste when there is a surplus.

Interviewees acknowledged packaging as a major part of reducing waste in transport and retail, by way of controlling and protecting food through access, rigidity and respiration, compared to loose product. As an interviewee put it:

> "Waste on the loose market compared to the pre-pack is higher…from perspective of, if they're left on shelf for longer, people turning it over, touching it."

Cucumber Interviewee 3

However, large supply chain routes in Australia can make moving food to key markets difficult. An interviewee noted that complex trucking systems and large-scale operations leads to food waste, as opposed to having shorter supply chains. To this interviewee, the problem is more of a 'whole food system' issue and reducing transport waste could be better addressed for instance by having fast rail or decentralised trucking to move food around from localised farms.

Packaging innovation to reduce waste was front of mind for interviewees. For example, a product called Breathe Away, which contains special membrane to help preserve the food it is applied to, has shown some positive results. However, its use and application must become more economical before it is used in any commercial sense. A company called Stent Cast has a product call 'Extend Berry', with interviewees looking at how this can be used to optimise respiration rates by matching packs to the ideal respiration conditions for cucumbers. This project is ongoing.

The supermarkets have a significant role to play in packaging specifications, which affects how products can perform in a food waste context. Historically there has been more of a focus on packaging materials than the attributes of packaging in minimising food waste. For example, a grower mentioned a shift toward more cardboard products and reducing their reliance on plastic. However, interviewees noted market influences can also influence how packaging may or may not be redesigned. Growers also perceive that many consumers would prefer to buy pre-packed food as opposed to picking loose items themselves. As an interviewee remarked:

> "People still want convenience. So, whilst they say they want to reduce packaging a lot, they don't particularly go in and pick up loose products on shelf and so on and so forth… So, there's got to be a definite balance at the moment between what's best case scenario to reduce all packaging out of product to what is going to sell still, at the end of the day."

Cucumber Interviewee 3

Cosmetic and food packaging standards for retail are perceived by growers as being linked to consumers' demands. However, growers also mentioned the retailers understandably require packaging to be cost effective, so they can provide affordable product to their customers, which can discount the use of certain packaging innovations that are too expensive.

4.5.4 Impact of packaging on sensory aspects

One interviewee noted that with packaging for cucumbers, PET trays and flow wrap help with less moisture loss. The fact that the cucumbers retain water to the end of shelf life the product looks fresher with less wrinkled skin and blisters.

In the laboratory, there were no differences at baseline between the packaged and no package cucumbers for crispiness, firmness, wrinkle, green colour or aroma (Table 12 and Figure 22). There was also no difference between baseline and day of purchase for aromas, nor were there differences between the packaged and no package cucumbers. Crispiness and firmness both declined from baseline to day of purchase, with the no package cucumbers declining further for both attributes, compared to the packaged cucumbers. The amount of wrinkle and green colour both increased from baseline to day of purchase, with the no package cucumbers increasing more than the packaged cucumbers (Table 12).

Table 12: Assessor's ratings of the packaged and no package cucumbers at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	No package	Packaged	No package
Crispness	12.9	12.9	8.4	6.1
Firmness	12.9	12.9	8.4	5.9
Wrinkle	1.7	1.7	6.6	7.6
Green colour	4.3	4.3	6.3	6.7
Off aromas	1.7	1.7	1.7	1.7

From observation of the cucumbers at baseline, it was noted that the no package cucumbers were slightly darker at the top compared to the tail. It was also noted that there was some condensation in the packet of the packaged cucumbers. There was more wrinkle of the skin in both the packaged and no package cucumbers on the day of purchase compared to baseline (Figure 23). The green colour of the packaged cucumbers evened out by day of purchase and they were crisp to cut. There was some water on the bottom of the packaged cucumbers and some were slightly wet, compared to the no package cucumbers where there was no water present. However, some of the no package cucumbers were limp and rubbery by day of purchase compared to the packaged cucumbers which were still crisp.

Figure 22: Packaged and no package cucumbers (respectively) at baseline

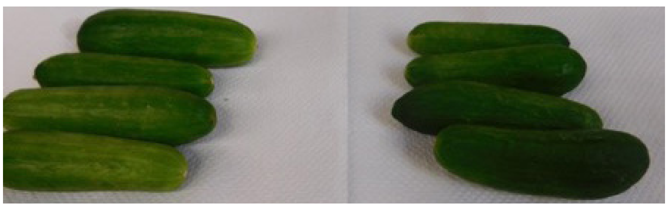


Figure 23: Packaged and no package cucumbers (respectively) at day of purchase

4.6 Cos Lettuces (Twin pack)

Lettuce is packaged depending on the variety and the supplier. For example, Iceberg lettuce is generally sold whole (with the outer leaves on) in either waxed cardboard cartons or plastic crates. Decorative lettuce such as green oak, red oak, and cos, can be packaged in an opened ended plastic/polyethylene sleeve. Gem cos and baby cos lettuce can be placed into a sealed BOPP flow wrap, with this being amongst the most popular forms of packaging as per Figure 24.

Figure 24 – Packaged baby cos Lettuce twin pack

4.6.1 Life cycle mapping

The assembled lettuce product life cycles, including cos, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 25.

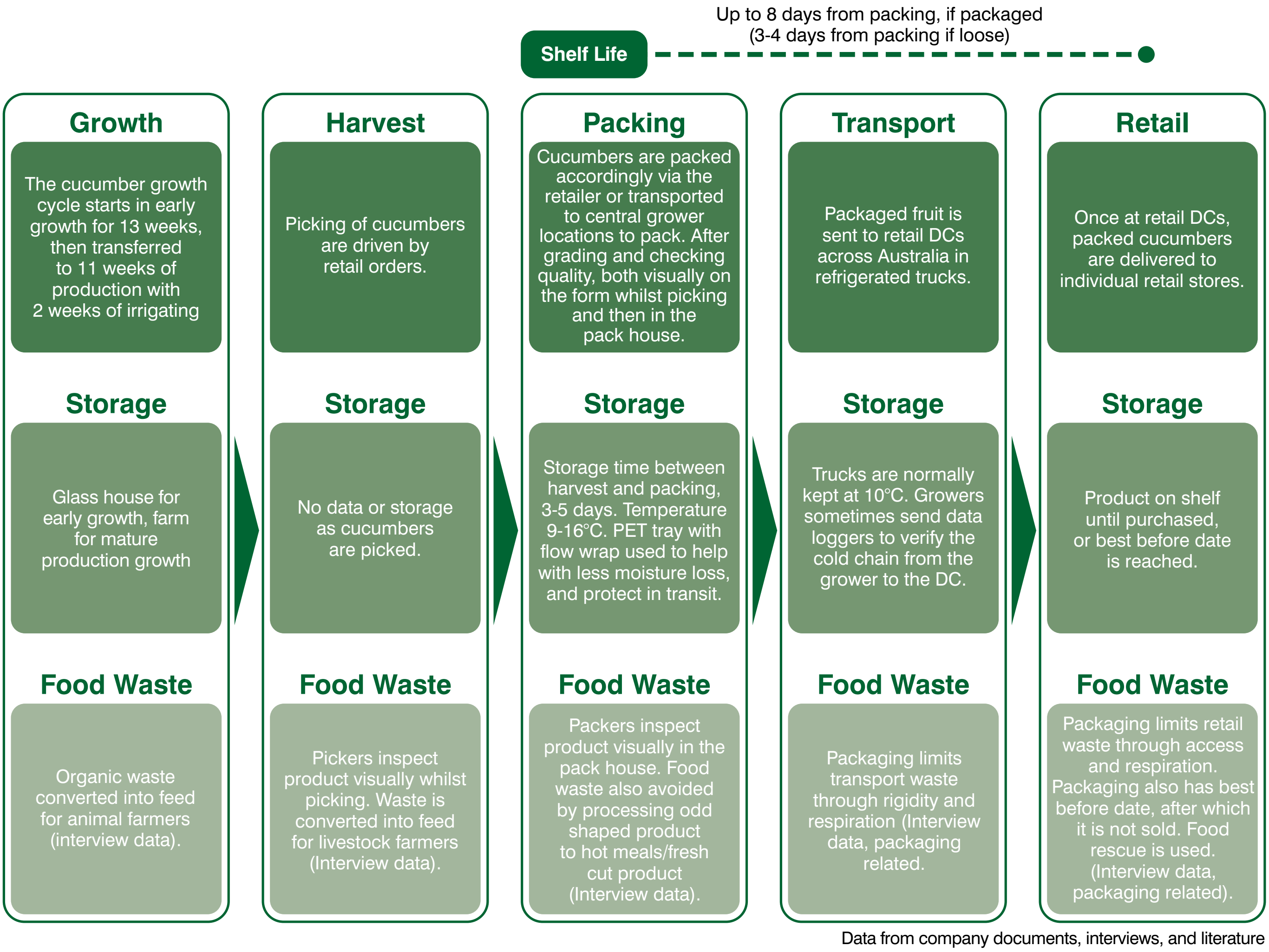


Figure 25: Lettuce life cycle map

4.0 Results continued

Lettuce varieties are commonly developed over a 2 or 3 (sometimes five) year period with the genetics developed through a limited number of international seed suppliers and trials. The remainder of the development is undertaken in-house by 2 or 3 producers interviewed. For those that undertake trials, they then test to see if the variety can meet retail specifications and minimise agronomic and plant health issues, while also delivering sufficient shelf life. They also determine the suitability for the variety to be grown in different climatic conditions around Australia. A supplier said they ultimately wanted to ensure 90 - 95% of their crop would be harvestable before proceeding to product realization.

Crops are generally planted to match forecasts and the seasons. There can be an over/undersupply, and this will obviously affect the price as with most fresh produce categories. Seeds are planted, and seedlings nurtured in nursery conditions (about 4 weeks) before planting in open fields. Planting can happen up to twice a week, 52 weeks a year. Seed to harvest can be anything from 2 to 3 months depending on season and variety.

There are 4 to 5 different sub-varieties, per lettuce variety, that are grown to suit variable seasons and weather conditions (as well as ultimately the supermarket and consumer requirements). For example, there can be summer and winter varieties of cos lettuce, as well as in-between. Trade-offs exist between breeding attributes such as weight, colour or disease resistance versus a susceptibility to weather variation. Growing outdoors without cover from the elements does make lettuce crops susceptible to insect and weather events, as well as imbalanced nutrient uptake (driven by water/rain levels). Attention to and investment in crop agronomy (soil, nutrition, irrigation-including scheduling) can also have a significant impact on improving crop yields.

At harvest time, there are different maturation rates within a crop, due to variable nutrient up take. For example, a crop may be harvested at a rate of only 50% in the first instance with a second run occurring a few days later to harvest the remainder. This means workers and machinery will be coming through the crop more than once which can result in some damage. Crops that are out of specification are left in the field and ploughed into the soil, allowing nutrients in the plant to return to the ground.

The quality and estimated volume of a crop is scouted about a week before scheduled harvest. It should be noted that a supplier (a smaller operator) indicated that they did not necessarily grow to specification and they appeared to have more flexibility and better options with getting product into secondary markets via market agents. Another supplier had a relationship with food rescue companies who regularly came by to pick up unsold, left behind and/or rejected stock. Lastly an interviewee noted that, even with specifications, there can be mismatches between how they are interpreted so they recommended better training and standardized understandings across the supply chain.

Once the lettuce is picked, temperature and time is an important factor, with the produce needing to be cooled as quickly as possible, with the target being within 1 hour of harvest. There is a higher imperative for adhering to this in summer, whereas in winter the lettuce can maintain its integrity for up to 3 hours versus as little as half an hour in summer.

Once in the cool room, hydro and/or vacuum coolers are used to lower the core temperature down 2 – 4°C as quickly as possible – within 30 minutes versus 4 to 5 hours for conventional cooling. Investment in cooling technology and the overall cool technology is paramount to this process:

> "Your cool chain is clearly very critical in certainly all the soft vegetables that we handle. Your ability to take the field heat out and get it to a temperature that retains all the qualities in the plant is critical and the technology and industry in general has improved. They have invested a lot of money into new technology, cold rooms, cold trucks, cool chain development, warehousing and distribution."

Lettuce Interviewee 5

Some products such as decorative lettuce (green and red oak lettuce) may be packed into sleeve packaging in the field. Mid-range cos; loose products, such as Iceberg, will be packed directly in the field and shipped; while others (once rapidly chilled) may be left in the crates they were placed in after picking and stored overnight before being packaged these crates may also have a plastic sheet applied over them to allow the crates to be held for more than a day. Not all varieties are washed, while some are washed more than others.

One supplier noted that their aim was to get the product to customers (i.e. DCs) within 1 to 2 days from harvest while maintaining the cold chain at 4-6°C.

4.6.2 Shelf life expectancy with and without packaging

Shelf life relationship with packaging is dependent on the product. For example, Iceberg lettuce is not generally packaged in plastic; rather it is just loose inside a corrugated carton or plastic crates and can last up to 10 days with the outer leaves on. A supplier said that, for cos lettuce, their testing indicates that packaging doubles the shelf life from approximately 5 days to 10 days.

> "We do a lot of shelf life testing. We will test packaging against un-packaged. The packaging that we use... will at least double the shelf life of the cos lettuce that we package. If we were to sell that product loose on shelf we would get about a 5-day shelf life. If we package the product, we get about a 10-day shelf life."

Lettuce Interviewee 5

4.6.3 Food waste, and impact of packaging on food waste

Specifications are key to determining what produce is supplied to retail. However, if there are significant issues with a crop, waste is minimised as it can be repurposed and sent to a secondary market such as wholesale. There is room for variation to specification, which requires supply chain collaboration. An example was that hot spells lead to a loss of hydration. In such circumstances a product of less weight may be acceptable – such as a 130-140g weight instead of the usual 150g.

A small amount of product is wasted during the packing and sorting process, with some damage from handling and non-spec products making it through from harvest. Any losses during transport, such as rare occasions where poor cold chain management occurs, the cost implications are significant. Also, any waste post packing has cost implications, significantly more than the wastage in field as there have been various investments in labour, packaging, energy, and transportation, so a focus on minimising waste at these stages is paramount.

Finally, retailers and wholesalers sometimes repack produce in store/ market. In such instances some wastage can result from trimming outer leaves off produce to make it look fresh for purchase.

In terms of the packaging role for food waste, there is a trade-off between washing a product, air flow and shelf life. An example of how packaging was recently redesigned in relation to competing demands is illustrated below.

Pre-packed lettuce was previously packed in sealed bags with no perforations. The produce was spoiling and getting wasted due to several factors:

1. The produce was unable to breathe, resulting in rapid deterioration from the trapping of carbon-dioxide and ethylene released from the produce. This results in product oxidisation and dehydration in the bag.
2. As pre-packed lettuce is prepared as a ready-to-eat product, it is also pre-washed. Water was collecting at the bottom of the bag and causing the product to rot, depending on the amount of water.

Initially modifications were made to the bags by the addition of 6 small holes at the bottom of the bag to allow the product to breathe, however this proved insufficient for all the water to properly drain. Subsequently a switch to micro-perforated bags (with pin-sized holes covering the front and back) has achieved the right balance of air circulation and water drainage.

4.6.4 Impact of packaging on sensory aspects

In the laboratory there were no differences observed between the packaged and no package lettuce at baseline for any of the attributes; crispness, limpness, sliminess, green colour and off aromas (Figure 26). There were no observed changes in aroma from baseline to day of purchase or between the packaged and no package lettuce. The green colour declined slightly from baseline to day of purchase; however, there was no difference in green colour between the packaged and no package lettuce on the day of purchase. However, for crispness, limpness and sliminess there were inconsistencies with what was observed in the laboratory for cos lettuce, compared to what the producer had tested in house. This may have been a result of inconsistent product provided for testing.

Figure 26: Packaged and no package cos lettuce (respectively) at baseline

Figure 27: Packaged and no package lettuce (respectively in each photograph) at day of purchase

4.7 Bananas (Kids pack)

The primary type of packaging for bananas is a 15kg cardboard carton containing clusters of bananas (loose); LLDPE pre-packs are also used for certain lines of bananas (the packaging format under study as per Figure 28). The pre-packs are then boxed and palletised for shipping.

Figure 28: Packaged bananas

4.7.1 Life cycle mapping

The assembled banana product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 29.

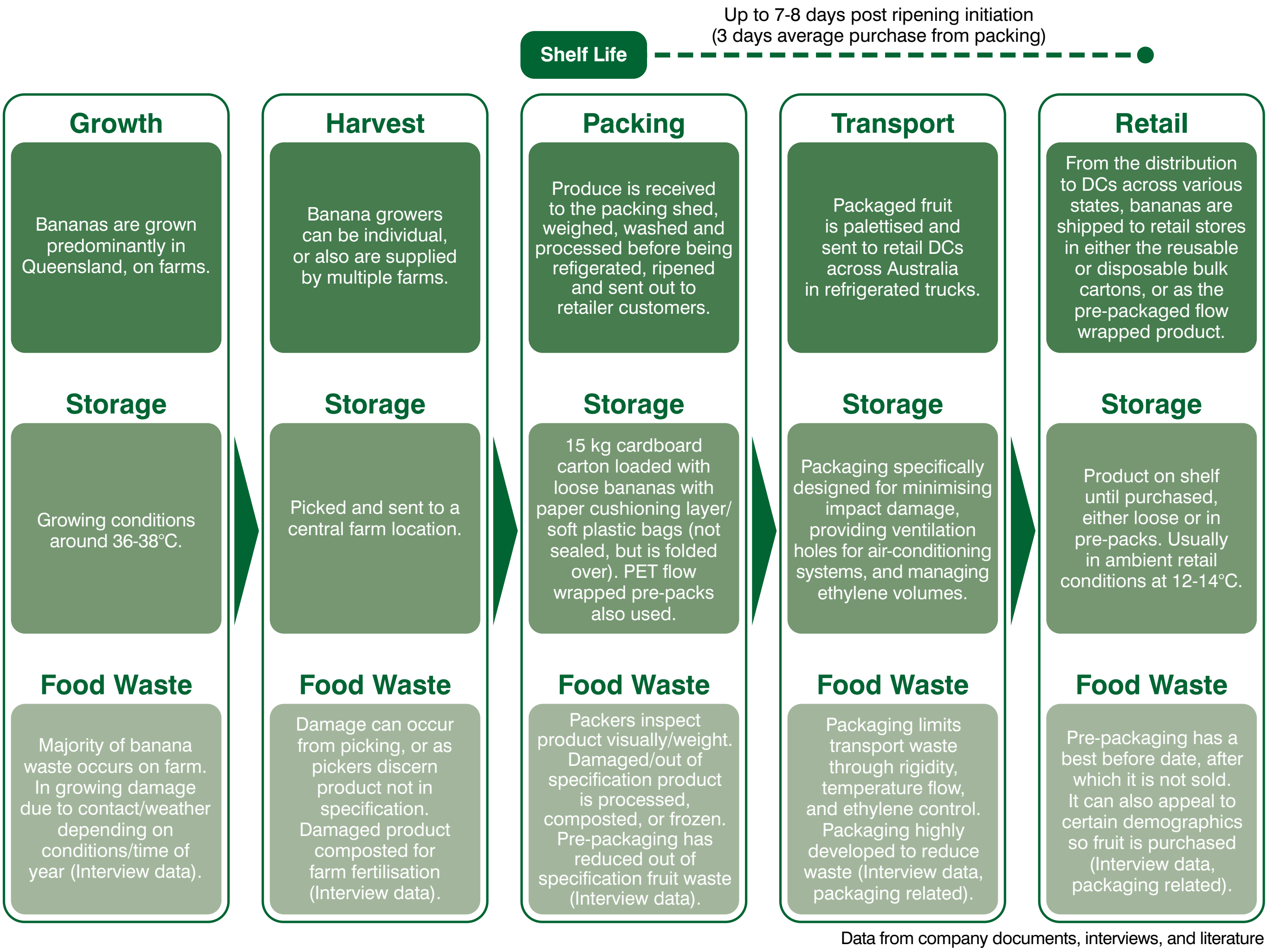


Figure 29: Bananas life cycle map

Bananas are grown predominantly in Far North Queensland and picked in 36-38°C conditions. This means they are warm when picked. Once picked, the bananas are transferred to a packing shed where they are weighed, washed and processed before being refrigerated, ripened and dispatched to retail customers.

Packaging is a key component of transportation. The prime package is a 15kg cardboard carton containing clusters of bananas (loose). Cartons include a paper cushioning layer in the base, and a soft plastic bag surrounding the product – this bag is not sealed but is folded over to close it before the carton is sealed. This packaging is designed to minimise impact damage, provide ventilation holes orientated for the air-conditioning systems employed in the cool chain, and to manage ethylene volumes to control the ripening process. LLDPE pre-packs are also used for certain lines of bananas (the ackaging format under study).

Cartons are palletised and then loaded onto refrigerated trucks. The banana ripening process is limited as they are transported through air-conditioning systems employed in the cool chain, as well as the management of ethylene volumes. Product is then distributed to retailer DCs loose inside the lined cartons, or in pre-packaged product formats in flow wrapping. Bananas are distributed to retail DCs based on demand and specifications. Growers supply product throughout Australia, resulting in long travel distances and diverse climatic factors.

Bananas are shipped to retail stores from DCs in either reusable or disposable bulk cartons, or as the pre-packaged flow wrapped product. Once delivered the ripening process accelerates.

4.7.2 Shelf life expectancy with and without packaging

As with other perishable product, shelf life is the key as it maximises the period where consumers can purchase and consume the product. Increased shelf life helps to reduce the volume of bananas that are disposed of to landfill due to over ripening. This is primarily controlled through the ripening process. As an interviewee commented about packaging:

> “Is it more worthwhile to not have as much packaging and throw a few more out? So I guess that depends on what you’re trying to achieve, but there is definitely, if you’re just trying to make the product last for as long as possible, a lot of pros to pre-packing it.”

Banana Interviewee 3

The normal shelf life of a banana is approximately 7-8 days in the supply chain. An interviewee suggested that packaging may increase this shelf-life by between 1-3 days. The model suggested as the normal time of purchase was 3 days from distribution, kept at 12-14°C.

4.7.3 Food waste, and impact of packaging on food waste

Banana waste is heavily focussed in the farm stage of production. Waste is typically recorded by weight differences throughout the process, rather than specific metrics. Waste can result from fruit that does not meet retail specifications, is damaged during growing i.e. marking from contact or due to weather, or damaged during harvesting.

Determination of out of specification fruit occurs as it is picked, or on inspection in the packing shed. Bananas are also weighed to determine if they are in specification in the packing shed. Damaged or out of specification stock may be processed for alternative markets i.e. puree, starch, flour, compost for farm fertilisation, or processed into frozen product.

The interviewees believe pre-packaged bananas are very good at preventing food waste through reducing the incidence of damage while the product is being transported. Most of the fruit in the pre-packaging would otherwise have been discarded as out of specification (smaller size bananas) and too expensive to transport, thereby the use of packaging further reduces food waste. Examples include smaller fruit which caters for smaller portions – such as for children in school lunch boxes, or oddly shaped fruit. As an interviewee put it regarding packaging:

> “The best thing about that product pre-packaged bananas is … there are absolutely no markings on it caused by transport. You could be as rough as you want with it. There’s no chance of it being thrown away. It’s such a good product. Because of that product, we’ve seen 10 to 15% growth year-on-year and I would say that’s lessening food waste, because the majority of that fruit, we would have thrown out. We would have thrown out at farm level, because there usually isn’t a home for it.”

Banana Interviewee 1

Packaging also helps minimise food waste throughout the process by preventing damage and enabling effective temperature regulation and ethylene limitation. Interviewees noted that very little, if any, waste occurs during/due to packaging between packing and delivery into the retail supply chain. The packaging is designed to prevent food waste and maximise shelf-life. Testing is conducted to determine the effectiveness of the packaging solutions over extended periods, and external factors which may impact this including transport route, road conditions, season variability, cool chain conditions, ethylene issues and humidity. The primary metrics for management of fruit through packaging are shelf-life, damage and moisture levels. In the rare situation where damage does occur due to or coincidentally involving packaging, a formal investigation is initiated, and any identified issues managed accordingly.

Another major source of food waste is forecasting demand and communicating this with suppliers. Waste can result from oversupply, which may cause the product to spoil and require dumping. This waste is measured in terms of volume and financial impact. By optimising forecasting and ordering, waste has been reduced. Testing is also conducted on every order, involving monitoring of ripening rates to refine the process and maximise shelf-life.

Shelf life is a key concern, as it maximises the period where consumers can consume the product, reducing the incidence of disposal after the bananas over ripen and expire. An interviewee mentioned that the specifications for retail are fair but can be a significant factor in determining what customers consider buying, in that;

> "A fair percentage of fruit is too long, too fat, or too short to be able to put into the chain-store system. That's the way they grow, unfortunately. We don't live totally in the tropics, so we don't have as good a handle on how things grow consistently because of our weather…..I think customers' perception and what they will buy is the biggest food waste issue in Australia."

Banana Interviewee 1

Packaging can also play a role here to help encourage purchases. As another interviewee noted that for some people, they:

> "…really like the plastic because they don't like people handling their food. So that's something that we've kind of observed."

Banana Interviewee 4

One interviewee was strong on the idea of the need for consumer education regarding how packaging plays a role in preventing food waste, arguing that consumers are the key factor in respect to food waste, both in what demand is generated (packaging options and specifications), and their own effective consumption of the product once they buy it. Packaging could be a good medium for such education, for example messages on the packaging could provide helpful hints about uses for over-ripe/under-ripe bananas.

4.7.4 Impact of packaging on sensory aspects

There was no difference at baseline between the packaged and no package bananas for firmness, splitting or ripe aroma (Table 13 and Figure 30). However, the packaged bananas were a lot greener in colour compared to the no package bananas and the packaged bananas also had slightly less blemishes on the skin too. There was no difference in splitting between baseline to day of purchase, or between packaged and no package bananas. There was an increase in colour for both the packaged and no package bananas from baseline to day of purchase, however there was a bigger increase in colour for the no package bananas compared to the packaged bananas. This was also the case for ripe aroma, with the no package bananas increasing more in ripe aroma compared to the packaged bananas. The rating for blemishes increased for both the packaged and no package bananas from baseline to day to purchase. Thus, although the no package bananas had a higher rating, they both increased proportionally to the baseline. Firmness of the packaged and no package bananas decreased from baseline to day of purchase, with the no packaged bananas decreasing more compared to packaged bananas (Table 13).

Table 13: Assessor's ratings of the packaged and no package bananas at baseline and day of purchase for each attribute

Attribute	Baseline		Day of purchase	
	Packaged	No package	Packaged	No package
Colour	0.1	5.5	2.8	8.05
Firmness	13.2	13.2	11.5	8.1
Blemishes	1.8	3.4	4.1	7.15
Splitting	1.2	1.2	1.5	1.5
Ripe aroma	1.6	1.6	3.6	9.3

From the observations at baseline, the no package bananas were mostly yellow with a green stem, compared to the packaged bananas which were smaller and very green all over in colour. Both packaged and no package bananas had minimal marks/ bruises and no splits. On day of purchase, the no package bananas were yellower in colour with more blemishes compared to baseline and the packaged bananas (Figure 31). The no package bananas were also softer to touch compared to the packaged bananas and easier to peel. The packaged bananas were described as having a few more black marks compared to baseline, but overall not very ripe. The packaged bananas also smelt unripe and felt crunchy when trying to cut them, compared to the no package bananas which smelt ripe and were easier to cut.

Figure 30: Packaged and no package bananas (respectively) at baseline

Figure 31: Packaged and no package bananas (respectively) at day of purchase

4.8 Apples and pears

The primary type of packaging for apples and pears differs depending on the size of the fruit. Larger sized fruit which makes up around 70% of the market is packed and sold loose in 12kg or 18kg cartons with smaller fruit that is less than 130 grams is sold in pre-packs.

Cartons are constructed as single use cardboard boxes, at various kilo capacities. The corrugated cardboard box has a fibre pulp tray at the bottom with indents to hold each piece of fruit in place. There are 2 layers of fruit per box. For instance, 70 apples per box would have 35 per layer. A lid is placed on top unless it is an open carton. Standard sizes are:

- 12kg standard carton for apples, 2kg open carton, and 18kg cartons for export
- 13kg carton for pears, 18kg carton, and single layer 6kg tray

More recently a reusable polymer crate has been introduced by Coles, Woolworths and Aldi. The retailer places the apples, directly from the crate onto the retail store display. The crates are washed and then returned to the fruit supplier to be reused.

Smaller apples and pears are sold in sealed, retail-ready PET punnets. Around 30% of apples and pears are sold in punnets in supermarkets. Between 7 and 12 pieces of fruit are packed per individual punnet, which are then flow wrapped. There are 8 punnets that are then packed into a crate. A sealed polymer bag is also used for some fruit, packed in 1 kg sizes.

Figure 32: Packaged apples and pears

4.8.1 Life cycle mapping

The assembled apple and pear product life cycle, with details on shelf life and waste aspects, including in relation to packaging, are visualised in Figure 33.

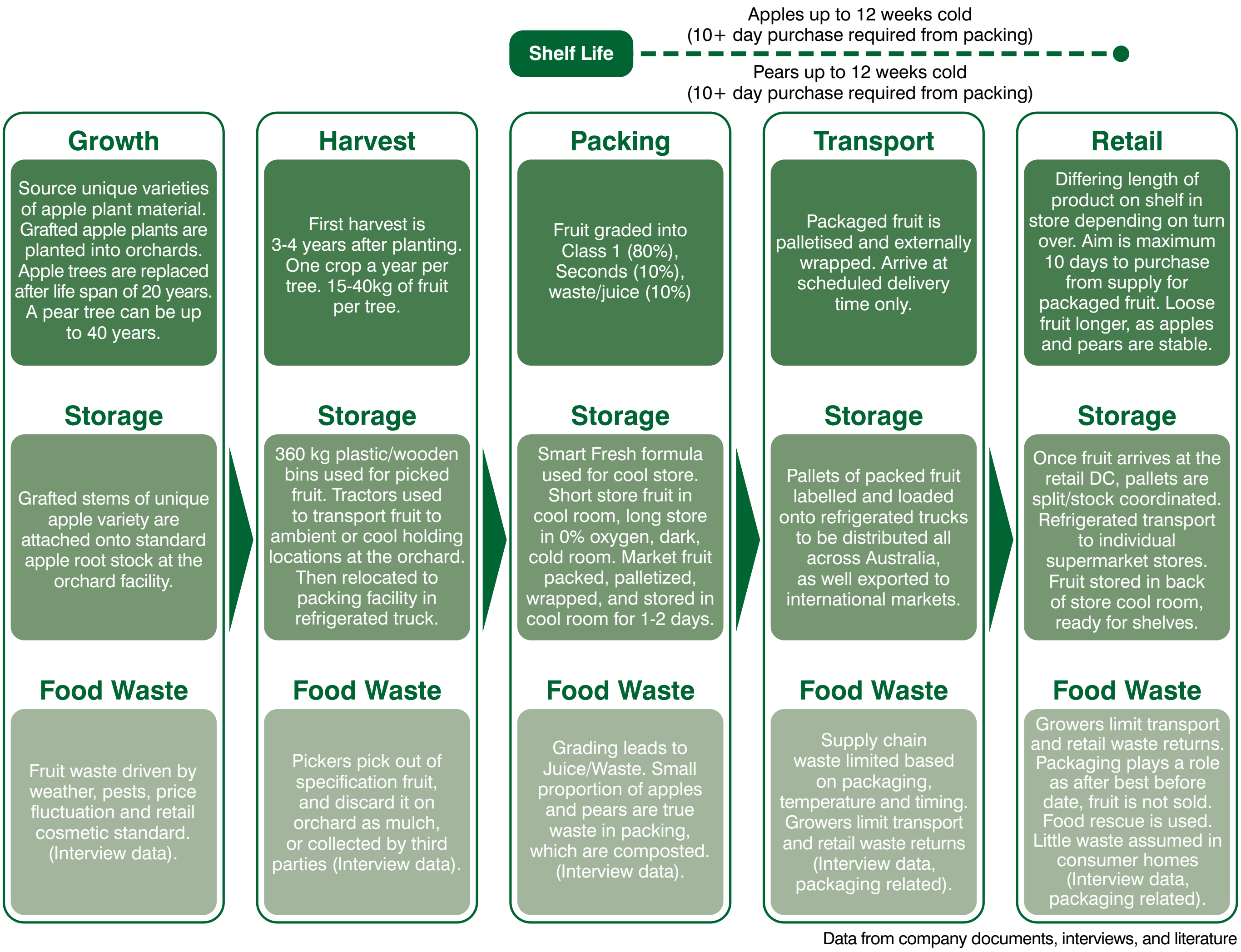


Figure 33: Apples and pears life cycle map

Apples and pears are grown at various sites in every Australian State. Growers source unique varieties of apple plant material, and graft stems onto standard root stock. Grafted plants are planted in orchard grounds, with apple trees having a life span of 20 years, and pear trees up to 40 years.

The first crops of apples and pears occur 3 to 4 years after planting a tree, with 1 crop a year per tree. Between 15kg and 40kg of fruit is harvested from the majority of Australian commercial apple and pear trees. The picked fruit is placed in 360kg plastic or wooden bins. Tractors are used to collect the bins, and harvested fruit is then transported to cold storage locations where the fruit is cooled to between 0-5°C and held in refrigerated conditions. Fruit is then transported from cold storage to the packing facility for grading. If there is a distance to the packing facility this transport is undertaken using a refrigerated truck.

Once in the packing shed, the product is graded with optical technology, based on count size and quality. Count size refers to the number fruit that will fit into a 12 kg carton. For example:

- Count 54 is the biggest that will go into a 12 kg carton
- Count 90 is the smallest that will go into a 12 kg carton
- Anything smaller than a count 90 will go into prepacks i.e. count 150 to count 216.

Grading occurs within the packing shed, as per Figure 34. Once packed fruit is loaded on to refrigerated trucks it is sent to supermarket DCs or wholesale markets. If fruit is shipped into fruit fly free zones, namely South Australia and Western Australia, methyl bromide and heat-treatment is applied.

Figure 34: Apples and pears grading levels

Apples and pears are seasonal, with the harvest period occurring between February and May. If not for the ability to store in a way that maintains fruit quality, such fruit would not be available all year round. Controlled atmosphere cold rooms have very low levels of oxygen and CO2, are dark, and kept at 0-2°C so the fruit ceases ripening. Apples that are stored in a controlled atmosphere cold room can maintain firmness, acid, soluble solids and nutritional value over the long term, contrary to a regular cold room at 2-5°C. The value of controlled atmosphere storage was explained by 2 interviewees:

> "It's reasonably common for an apple to be stored for up to 6 months, prior to consumption. Due to the storage techniques that we have, there is no deterioration in fruit quality in that period, from a nutritional point of view."

Apples/ Pears Interviewee 2

> "So, I guess the way that we manage that is through this controlled atmosphere storage … Without that sort of technology in place … you'd probably get 12 weeks to pack the apple, compared to a controlled atmosphere where we'd have 8 to 9 months at least, sometimes longer."

Apples/ Pears Interviewee 3

A treatment called Smart Fresh, which slows fruit maturity, can also provide 10-12 weeks extra storage time in a normal cool room. Treatment with Smart Fresh requires fruit to be put into a dedicated air tight cool room that has a gas applied, followed by a venting period of 24 hours. This process allows the fruit to be stored in regular air without deterioration.

Once ready for shipping to market, the fruit is packed in formats according to their grade and destination. It is palletized, wrapped, and cooled in a dedicated cool room until it reaches the desired temperature. Once an order is confirmed the fruit is loaded onto refrigerated trucks to be distributed across Australia. Product is also exported to international markets.

Once fruit arrives at the retail DC, pallets are split, and stock coordinated, ready to dispatch to stores. Refrigerated transport is used and the fruit is then stored in a cool room located at the back of the store, ready to put on shelves as needed.

Fruit for the export market will undergo a similar supply chain process as the Australian market. The difference is that the fruit will go into sealed, refrigerated containers for sea or air freight to the destination country. As an example, sea freight may take up to 8 weeks to reach the UK. Apples and pears travel this way, with some general points being:

- Air freight is generally reserved for more perishable fruit such as stone fruit. It may take only 2 days travel and can arrive at the destination faster than interstate travel within Australia.
- The type of packaging used may vary for export – additional packaging added.

4.8.2 Shelf life expectancy with and without packaging

Apples and pears have long shelf lives. For instance, apples can be comfortably shipped for 40 days to a foreign country to be sold. To contextualise this, a regular cold room can maintain apple quality for 12 weeks, whilst apples stored in controlled atmosphere cold rooms can maintain core quality attributes for 8-9 months. In Australia, the retail requirement is to have apples and pears purchased 10 days from the date of packing.

Apples and pears are generally sold loose in cartons. Past studies have shown that apples are robust, and paper mould trays and corrugated fibreboard limit spoilage but cold storage alone is beneficial (White and Stanmore, 2018, McEwen, 2014). Interviewees did note though that punnets with film over the top can assist with extending shelf life by limiting fruit bruising and lowering respiration rate. Sealed bags can also help with the latter. This is consistent with past studies, where non-perforated polymer bagged pears can extend the shelf-life for pears by 15 days (White and Stanmore, 2018, McEwen, 2014).

4.8.3 Food waste, and impact of packaging on food waste

Fruit may not be suitable for harvesting due to insect damage or other natural factors such as weather. For instance, apples need cool nights to colour up, so hot conditions can render them very pale. Day time heat can cause sunburn and rot. In cooler climates, fruit can be brown inside whereas this is less likely to occur in drier climates. Fruit may also have skin marks from rubbing against other fruit or against the tree. This fruit will not meet retail cosmetic expectations but is otherwise perfectly good for eating. Other forms of cosmetic damage include colour, shape and size. In these cases, fruit is left on the tree or thrown on the ground. Wasted fruit is mulched to create more nutrition for the trees.

Interviewees noted they don't keep track of the number of kilos wasted in the orchard but do know it is the most substantial volume of any stage of fruit growing and distribution within the business (before fruit is received by retail and consumers). There is an incentive to reduce food waste and turn it into value added products because this would reduce the amount of money spent on discarding fruit, whilst generating extra revenue for growers.

Once in the packing shed, fruit is graded. There are three grades for apples – Class 1 – Export and Australian retail (80%), Seconds – Normal market (10%), and Juice (8%) and waste (2%). Any fruit that has a cut, holes, open wounds or rot is relegated to waste grade. This is where the most waste in the packing shed occurs. To try and reduce the amount of waste, growers have developed value add products such as juice and cider. The majority of fruit that cannot be sold to retailers is processed into a value-added product. The percentage of fruit that can be reused depends on the type of fruit. For apples there is a greater opportunity with value-added product. This includes making apple juice, apple slices, filling for pies, etc. These apples are transported to the processor in 200kg or 400kg bins. A minor volume of apples and pears is considered as true waste, being rotted, deteriorated fruit that is unsafe to process. This waste is subsequently composted.

To ensure that the fruit meets supermarket specifications it must also be sampled. The sampled apples are cut open for testing and these will also go to waste, with 100 apples being the normal amount required per quality assurance test, and supermarket standards testing. Cosmetically inferior fruit is downgraded as they cannot be sold through a regular retailer. Based on such a small sample total, minimal waste occurs here as an interviewee explained:

> "We do a lot of sampling and testing of fruit as well. Whenever we're down to packing a new line of fruit you'll grab say a hundred, normal testing is a hundred apples. You'll check them all for what the sugar (level) is. You check them all for skin damage…. So, it's a smaller percentage (of waste), but all these quality checks you need to do."

Apples/ Pears Interviewee 3

If there is too much fruit at the orchard or pack shed, it will soften before it can be processed and therefore be unsuitable for sale to retailers. For example, this can occur if the fruit is not packed in time, or there is too much fruit to pick at a time. Fruit can sometimes fail to sell fast enough meaning its quality attributes do not meet the minimum retailer standards. In the packing process and at retail some fruit is not processed or sold before it reaches the best before date printed on the packaging. Fruit during the process stage that passes this date will need to be repackaged to maximise the value obtainable for the product. Apples stored in the wrong environment for too long can go soft and floury meaning they do not meet retail specifications. Under this circumstance the fruit is generally sent for additional processing. Fruit pressure is a retail standards test; therefore, older apples may not meet specification.

Packaging can positively impact shelf-life and therefore wastage based on protecting fruit in transit and retail. For instance, packaging that limits handling can reduce fruit bruising. Interviewees stated that, by introducing the plastic punnet for apples 5-10 years ago, they have witnessed an increased shelf-life and waste reduction. As an interviewee put it:

> "I think one of the most beneficial initiatives in the last 5 to 10 years, has been the advent of the plastic punnet for apples. The plastic punnet offers a rigid support structure to put the fruit in that then makes it easier to handle and ship. I think the amount of fruit that we were losing to issues like bruising and puncture during the transit and retail phase has possibly decreased if you compared that with the fruit that's put into a punnet."

Apples/ Pears Interviewee 1

It costs less to sell fruit loose/ unpackaged, but there is a perception the same consumers do not like picking up, or other shoppers handling, their fruit. Some people want fruit to be loose, so they can select their own fruit, however interviewees indicated handled fruit can also be damaged by bruising.

Short transport times and effective cold chain management is key to shelf life. Trucks are refrigerated circa 95% of the time with the other 5% being transported unrefrigerated from the orchard to the packing shed, which may be only a 10-minute journey.

The quality of the fruit is affected if subjected to repeated heating and cooling during transportation. The cold supply chain is critical in maintaining fruit quality. For example, fruit in the orchard may be exposed to 40°C conditions and become warm. The warm fruit will go into a refrigerated truck for transport; however the time in the truck is insufficient to remove the field heat from the fruit.

Each retailer has minimum quality specifications based on the way a fruit 'eats' based on sugar level and fruit pressure, and the fruit's appearance based on colour, marks and size. Fruit is rejected for not meeting specifications. There are slight variances to the standards from state to state, between retail DC to DC, and even individual inspectors. Each retailer has a quality assessor at the DC and they determine what fruit is accepted or rejected.

Other factors that determine flexibility, in the standard, include the urgency with which stock is needed, and the general market supply situation. Fruit that is delivered to the customer DC and rejected will be returned to a grower for assessment. Each box is opened to determine quality, for example checking if it is rotten or whether it is simply a colour issue. While some fruit is wasted, some may be suitable to send to other customers or to use in value add applications.

Retailer initiatives to sell oddly shaped fruit are commendable as they sell produce that is visually not to specification but perfectly edible. However, it only reduces part of the waste that occurs due to cosmetic issues.

The dilemma for producers is whether to sell an apple simply based on the way it 'eats', or also concentrate on perfecting appearance. An attractive appearance will attract a customer initially, but interviewees think the way fruit 'eats' is ultimately the key to getting repeat customers.

Apples and pears are predominantly sold to a retailer as loose items in a carton (to be sold to consumers loose). The retailer can sell that for any amount of time. However, if the fruit is packed in a plastic bag or punnet by the supplier prior to delivery to the supermarket, it is marked with a best before date – which is generally limited to more than 10 days from the date of packing. This best-before date is determined by the retailer. For apples, the best before date is set at around 10 days, but apples if refrigerated at the correct temperature can easily last for in excess of 30 days. If packaged fruit is approaching its best before date the retailer will typically discount the fruit in order to avoid it going out of date before purchase. If the item goes past its best before it is removed from the retail shelf. Interviewees assume that the majority of goods removed from sales because of passing the best before date would go to a food rescue organisation, so it doesn't necessarily go to waste, but there is limited data available to explain how much product is actually removed from shelf because of best before date expiration. Although the punnets serve a purpose in protecting the produce from punctures and bruising, the best before date may limit the time the fruit is sold compared to how long the fruit maintains its required specifications. Further, in comparison to loose fruit which carries no best before date, it is safe to assume that more prepacked product is unable to be sold. In addition, it is possible that best before dates may also increase the chances of premature wastage of food in the home. This could be an unintended consequence of date labelling of pre-packed whole fresh produce at retail.

Once fruit is purchased and taken home by consumers, an interviewee noted it is unlikely that apples and pears go to waste often due to their long shelf life and their ability to be used as an ingredient in meals and beverages. However, there is little consumer research to confirm how many apples and pears actually end up wasted, by the consumer, in the home.

4.8.4 Impact of packaging on sensory aspects

Laboratory analysis, including sensory observations was not undertaken for apples and pears, due to unavailability of sample produce. However, based on comments from interviewees about the stability of fruit long term, it could be assumed degradation is minimal except for cases of poor storage and handling conditions.

5.0 Discussion

5.0 Discussion

The following discussion points were considered pertinent in highlighting why packaging is used for certain fresh produce items, based on the results in this study.

5.1 Food waste discussion

There was a general consensus amongst interviewees, from farm to retail, that packaging is designed to protect product. This is perceived to limit food waste particularly from the packing of the product post-harvest to the retail shelf. There were no measured (quantified) food waste percentages, though qualitative information around the causes of food waste was collected. Food loss and waste occurs for many reasons across the supply chain from farm to retail. From a packaging perspective, interviewees identified reasons for waste occurring or being limited during packing, transport, DCs to retail. Some of these are related to packaging and some are not. The role of packaging was evident in interviewee explanations of these stages.

Packaging was identified as critical to reducing waste because of the following key factors:

1. Provision of protection in the handling and transport of the product from the farm gate to the retailer;
2. Management of respiration and expiration, including gas management for ethylene (in order to slow the ripening process in some produce);
3. Limiting access to stop people from touching/handling the product, including reducing the chances of bruising or damage;
4. Increasing shelf life compared to the same product having no packaging.

Practical examples of these factors include:

- **Small cucumbers in a PET punnet and flow wrap** – An interviewee noted the rate of water loss from the product is reduced thereby extending shelf life from 3-4 days, to up to 8 days.
- **Banana film packaging** – The placing of holes in the packaging provides ventilation to manage ethylene volumes. This controls the ripening process and extends the time frame in which a banana will likely be purchased, reducing the incidence of the product being disposed of to landfill.
- **Blueberry PET punnets** – Designed to ensure the product is not crushed externally, or from the weight of other packed product resulting in the blueberries being delivered to consumers intact.

According to producers, such packaging measures provide a greater chance of the food making it to the retail shelf and being purchased and consumed. This is in contrast to it being damaged or of such poor quality that the product must be discarded at some stage in the supply chain – matching the ‘protect and facilitate’ handling features as outlined in Lindh et al. (2016).

In line with the literature (FAO, 2018a, FAO, 2018b), cold chains were identified as integral to preserving product in the life cycle of produce. Great care was taken to optimise the way cold storage and transportation operated, by auditing, measuring and managing cold chain performance. Such activities were deployed in relation to the temperature needs of produce from harvesting to packaging through to being stored or transported, whether that is cooling produce down or limiting temperature fluctuations, to the absolute temperature required over time. Yet these issues must be designed specifically for each supply chain, as packaging to cold chain combinations do not always result in ideal outcomes. Such issues were observed through WRAP research for particular packaging and cold chain conditions for bananas, which blackened prematurely when refrigerated (White and Stanmore, 2018, Johnson et al., 2008). Therefore selecting the appropriate packaging and cold chain combination is critical to ensuring longevity and protection, one type of produce to another.

The interaction of packaging and the cold chain was also seen as something to be leveraged, namely to extend shelf life and minimise waste, in many instances.

For example, the ripening process of bananas is delayed in long transport routes from Queensland, with the packaging design allowing cool air to circulate around the bananas to facilitate the delay.

It was clear that new packaging formats assisted in the establishment of new markets for product that would otherwise end up as waste at the farm or packing shed stage.

This included:

- Prepacked small or oddly shaped bananas have found a niche market, such as for school children or environmentally aware shoppers.
- Promoting the compatibility of small cucumbers for school lunchboxes.
- Apples of a smaller size can be sold in pre-packed formats (those which do not meet Class 1 specifications), instead of being downgraded.

For produce which would have previously been discarded as out of specification, packaging has played a role in getting this product to market. Producers and retailers have worked to align that product with target audiences to further reduce food waste.

It also became evident that specifications and cost requirements for packaging can limit changes that could be made to packaging formats. Some producer interviewees thought this could be a barrier at times to implementing packaging that had the potential to save food.

5.0 Discussion continued

Retail planning and forecasting is also seen as a big factor in how much cultivated produce is used, and that optimising and/ or aligning to retail ordering is essential. Last minute order changes can lead to scrambles to find new markets for fresh produce. Yet it must be noted that producers expressed opinions that specification requirements were apt, as they principally derived from what consumers want. Whether that be based on how consumers purchase, or how their demands (or perceived demands) affect decisions further up the supply chain, their influence ultimately affects planning for producers.

Another packaging issue which was raised, involved the tension between packaging aimed at extending shelf life and consumer demand for more environmentally conscious packaging materials i.e. post-consumer recycling content, high recycling rates, or bio based/ compostability. With the rise in community demand for a reduction of packaging that impacts the environment, consumers are looking to source packaging that meets these standards. However, this poses a challenge as materials, such as plastic, are fit for purpose for many elements of extending shelf life. Therefore, such a shift in packaging materials/ formats can come with several wins, or alternatively trade-offs. While there remains significant research to be done, where practicable, identifying suitable alternatives to plastic, or ways to use less plastic including recycling of plastics, is a valid pursuit. The environmental credentials of such a move should be verified with life cycle assessment, as what is perceived as a good environmental choice does not always end up to be so.

It is evident that consumer and industry education about the balance between packaging that reduces the environmental impact of food waste, compared to reducing packaging environmental impacts, is both lacking and overdue. Customer education about the role of packaging is important in regards to food waste.

For instance, producers perceived a difference between what a best before date and expiry date are designed to communicate, and what consumers perceive the dates mean. Packaging has a part to play here. Firstly, if a fresh product is packaged, it can have a retailer or Food Standards Australia New Zealand requirement for a 'best before' or 'pack' date (depending on the produce, or how the produce is prepared). With a misunderstanding as to what that date means, interviewees noted that consumers may throw out food before they need to. Thus, either education on pack or through other communication may be required to address this gap between intention and perception. Also, by packaging fresh produce with a best before date, the product is often removed off the shelf by that date. In the instance of apples, this could be months before it is ready to be discarded, if pack dates align with the expected retail churn of product on shelf. Thus careful consideration of what the date is, the perceptions of what the date means, and the requirement of the pack functionally, must be balanced. Education of supply chain stakeholders may be required to get to a better position on date labelling outcomes, as well as their collaboration on such decisions.

Finally, interviewees noted very little is also known about the role that packaging plays in extending the life of food when stored by consumers at home.

Even if packaging has been designed to help consumers knowledge of whether those packaging features are used beyond the retail store is sparse.

Consumer education may be the antidote to communicate the role of packaging in tackling food waste, as well as providing the opportunity for producers and retailers alike to engage more deeply with their customers about such issues.

5.1.1 Food waste contingencies/ limitations

Our food waste research comes with a number of limitations. Our data analyses for food waste aspects of packaging drew from primarily qualitative data (Creswell and Poth, 2017). Therefore, we conducted a qualitative and descriptive analysis as per MacInnis (2011). In particular, we utilised a relatively small sample size of 29 in-depth semi structured interviews, with 31 key people involved in the fresh produce supply chain. The scope of interviewees was deemed adequate as they represented all stages of the food supply chains, from producers internally, retailers, and packaging companies, at various roles across those organisations. The narrow sample size is limiting, in that our research cannot be generalised across industry, or even produce supply chains. However, our approach was still deemed appropriate as we were able to build a rich and detailed description across and of specific supply chains in the time available. The study does not provide definitive measurements of food waste across industries. We report specific estimates of waste provided, where possible, for the organisations involved.

To build more credibility to the account, beyond the interviews, we also compared interview data with secondary data such as company reports, correspondence and literature. Some of the people interviewed were then provided the synthesis of those data to clarify their recollections (Taylor and Lindlof, 2002), and further verify and build richness to our account of fresh produce supply chains.

What our food waste research provides is contextual explanations of how and why food waste is happening in the supply chain, the role packaging plays in relevant scenarios, and some context specific quantitative estimates of waste that occurs.

5.0 Discussion continued

5.2 Sensory discussion

From a sensory perspective, observable changes occurred across all fresh produce categories from baseline to day of purchase, as well as between packaging types for the samples tested in the laboratory. These results varied between the types of produce with some maintaining quality in packaging, whilst others showing less significant differences in quality regardless of whether they were packaged or not. Key discussion points are:

- The quality of the **blueberries** declined from baseline to day of purchase with regards to an increase in the amount of bruising and wrinkling of the skin, and a decrease in bloom and plumpness. This is to be expected as fresh produce does decline overtime. However, greater negative changes were seen in the no package blueberries which showed more bruising and wrinkle, and a greater decline in plumpness and aging as a whole. This suggests that sensory quality of blueberries is better maintained under packaged storage compared to no packaging.
- Results were similar for the **raspberries**, with the no package raspberries showing a greater decline in firmness and collapsibility on day of purchase compared to the packaged raspberries which did not change from baseline. This again suggests that the quality of raspberries is maintained effectively in packaging, and not so well when there is no packaging. These findings are most likely due to berries having a fragile cell wall and are therefore easily damaged (Giuggioli, 2015).
- Similarly, **cucumbers** also maintained better quality when packaged compared to no packaging. Crispness did decline in both packaging types, however the decline was greater in the packaged cucumbers. This was similar to the amount of wrinkle, whereby both increased, however the no package cucumbers became wrinklier at day of purchase. Condensation was observed on the carton of the packaged cucumbers and this did increase overtime, however it did not seem to impact the crispness of the cucumbers. Whereas, the no package cucumbers became slightly limp and rubbery. It is important to note that these changes were moderate, however over a longer period it would be expected that these changes would be more rapid. This suggests that cucumbers are potentially able to maintain their sensory quality, specifically crispness more effectively when packaged compared to no packaging.
- The need for packaging was less obvious for **mushrooms and tomatoes** with regards to the sensory properties. For the tomatoes, the amount of wrinkle on the skin increased in both packaging types, but it was still rated relatively low, and firmness did decline, however this occurred for both packaged and no package tomatoes. Although the no package tomatoes did appear softer to touch and there was a slight amount of bruising and dents, the no package tomatoes were observed to be riper than the packaged tomatoes. Whether this is a positive or negative, depends on whether the distributors are requiring their product to be ripe on the day of purchase or not. As for mushrooms, firmness and white colour did decline in both packaged and no package mushrooms on the day of purchase, though the number of blemishes and slimy feeling did increase in both, but to a higher degree in the no package mushrooms. However, this was still quite a low rating. These findings suggest that packaging may be beneficial for prolonging the quality of tomatoes and mushrooms.
- For **cos lettuce**, there were inconsistencies with what was observed in the laboratory for cos lettuce, compared to what producers tested in-house previously. This may have been a result of inconsistent product provided for testing. For instance, it was observed that at baseline, the butt or stem of the packaged lettuce was noticeably brown, compared to the unpackaged lettuce which was white. It is uncertain why this was the case as both lettuce types were purported to be picked at the same time. The brown colour of the packaged lettuce cannot be explained, though may explain the inconsistences in results. As such, it is suggested that further sensory research is required for cos lettuce, especially as the packaging design has also been modified since this laboratory test was conducted (through continuous improvement processes applied by the producer to improve shelf life).
- The results from the **bananas** also suggest that packaging may not be required. This was difficult to evaluate as it seemed that the varieties of bananas were different; the packaged type being smaller in size compared to the no package bananas which were larger in size. The packaged bananas were also very green at baseline compared to the no package bananas. During storage both types did increase in yellow colour, however the no package bananas did have more of a ripe aroma on the day of purchase compared to the packaged bananas. It is difficult to tell whether this is due to the packaging, or more so since the packaged bananas were greener and less ripe to begin with. The firmness of the bananas also declined, with the no package bananas becoming less firm on day of purchase. It is difficult to determine if this was due to packaging or the ripeness level at baseline. A recommendation on whether packaging is beneficial or not for bananas cannot be provided due to the differences in types of bananas that were provided by the distributor as well as the marked difference in ripeness at baseline.

5.2.1 Sensory contingencies/ limitations

Strength lies in aligning sensory observations to what would be available to consumers at point of purchase in this research. To minimise sources of uncertainty, all fruits and vegetables were harvested directly from their source, immediately delivered to the testing laboratory for processing, and stored to simulate supply chain conditions for both package and no package products. Previous research has examined the effects of storage on fruits or vegetables by randomly harvesting these products from the same location to limit variability due to production area, harvest time and cultivar (see review by Rickman et al. (2007a)). While this enables researchers to directly understand the effects of storage on a specific product, it does not accurately represent the choice consumers have at the retailer. At the other extreme, some researchers purchase fresh products from the retailer and use these as the raw materials for studies (particularly on food processing), without adequate information on cultivar, maturity and production location (see review by Rickman et al. (2007a)). In these scenarios the product is likely to have already undergone a degree of oxidative degradation of micronutrients during handling, transport and storage.

A potential limitation of this study is that, although the conditions of the supply chain was simulated to the best of the testing laboratories ability, factors such as the use of a commercial walk in cool room (available at DCs and retailers) were not able to be replicated. It is unclear whether this would have influenced results as temperature stimulation was achieved; albeit in a standard fridge. In addition, the produce observations were only simulated until up to the point of purchase by the consumer. This time point was chosen as it is where the producer loses chain of custody over the product. Once the consumer purchases the product, the time and conditions in which the fruits and vegetables are taken home, and the subsequent time they are stored at room or refrigerator temperatures prior to consumption, varies between individuals. It is probable that following point of purchase further sensory changes will occur, while the role plastic packaging may play in this process is unknown. The use of sales and consumer behaviour data to predict and replicate variables that occur between purchase and consumption may assist in investigating this in the future.

Finally, sensory evaluations were only completed by 1 assessor. As such, it is all based on their solo opinion and ratings and no statistical analysis could be completed to see if these were statistically significant changes. It would be suggested that for future studies that multiple assessors evaluate the fresh produce. In addition, these evaluations were not carried out in a sensory laboratory under controlled conditions, and therefore variations in light may also affect the assessor's ratings of the fresh produce. In future it would be recommended that the evaluations take place in specifically designed sensory facilities, under controlled lighting. It is important to note that even though changes were seen in some of the attributes of the fresh produce, some of these were minor and were still rated quite low on the scale. Therefore, interpretation needs to be completed with caution.

6.0 Recommendations

6.0 Recommendations

The following recommendations are suggested, building upon, the previous discussion points.

6.1 Increased measurement of food waste is urgently needed

There is a lot of anecdotalknowledge about food waste rates held by stakeholders across the fresh produce supply chain, though little, if any, of these rates are measured or recorded. More measurement and recording of food waste throughout the supply chain is urgently needed, to better understand the scale of the issue accurately at each stage of the life cycle of fresh produce. The data and metrics collected should be shared along the supply chain to ensure transparency and effective responses to areas of concern. This should also highlight where specifications impact on food waste levels and perhaps facilitate greater flexibility.

6.2 Continuous optimisation of cold chain management

There have been achievements in cold chain management to extend shelf life of fresh produce. Continuing to optimise this aspect of supply, and the role packaging plays in this, should be a focus for supply chain stakeholders. There are opportunities for mutually beneficial collaboration between producers and retailers.

6.3 Leveraging good relationships for packaging optimisation

Collaboration, planning and ordering that already occurs constructively between supply chain partners, could be leveraged to include more work on the role of packaging in reducing food waste across supply chains. For example, the apparent range of perspectives from stakeholders on product and packaging specifications could be aligned through existing relationships, to create fruitful partnerships in driving packaging changes. The result could be a combination of further extended shelf life, good product protection, and consumer benefits within the home. The consumer component though is problematic based on increasing negative perceptions of packaging in the community, which we will touch on next.

6.4 Education of consumers on the role of packaging

Education of consumers on the role of packaging is needed, as there is a gap between why packaging is specified, and what consumers perceive. This is evident in the social movement against packaging with apparently little discourse about why it exists in the first place, from reducing food waste through to shelf life extension perspectives. This could include sharing experiences in efforts to test alternatives to plastics and talk about the trade-offs, failures and successes. Without accurate measurements of how packaging features can reduce food waste, such education will be difficult. Clear communication on pack that informs consumers on the ideal storage conditions for purchased produce, should also be a priority. It is imperative that consumer education is discussed alongside credible measurement of supply chain food waste saving measures.

6.5 The circular economy is an opportunity

Circular economy approaches to packaging may be beneficial to reduce the stigma that packaging currently holds with consumers, in tandem with communication about the value packaging brings to prolonging the life of fresh produce. Where feasible, reuse of packaging could be deployed and promoted as extending the value that packaging provides. This may require partnerships between producers, retailers, government, researchers and waste/ logistics organisations. It will also require education of, and engagement with, consumers.

6.6 Consumer waste levels need more clarity

More visibility is required in understanding consumer food waste levels. The role packaging plays in extending the shelf life of fresh produce in the home needs to be examined. Research is also required to explore and understand how packaging features designed to reduce food waste in the household are being missed or misunderstood by people. For example, best before dates that drive premature waste, or features such as flow wrap being discarded early leading to shorter shelf life for produce in the refrigerator. Further engagement with consumers on the value of packaging features should be commissioned.

6.0 Recommendations continued

6.7 Packaging to maintain food safety needs further research

For 'ready to eat' leafy salad mixes, it was revealed in the literature and the data that packaging is deployed for food safety through microbiological reduction. Pathogenic bacteria contamination of fresh-cut produce is a food safety threat. Reliance on sanitisation steps in pre-packaging, packaging integrity and temperature control, ensures the reduction of potential contamination and growth by microbial pathogens. Further research is required to investigate the value of packaging deployed for food safety, including in terms of any food waste reduction attributes of such strategies. Consumer education could also be used to demonstrate how packaging can help maintain food safety.

6.8 Packaging can be useful for sensory aspects

From the observational data collected, it is recommended that blueberries, raspberries and cucumbers are stored and transported in packaging to maintain the sensory properties and quality of the produce. It is also recommended that mushrooms and tomatoes are stored and transported in packaging also. Although the degree of decline in quality was not as rapid as it was for the berries and cucumbers, there were some declines seen in the tomatoes and mushrooms. The results suggest packaging may assist with prolonging the quality of the produce.

6.9 Sensory issues need further research

There were minimal differences between the types of storage from a sensory perspective.

It was difficult to determine a recommendation for bananas due to the differences in variety and ripeness of bananas at baseline. The no package bananas may ripen faster, however this was hard to determine. Packaging seems to be vital for some types of produce, not as vital for others, and potentially not necessary for others. Whether packaging is required or not is dependent on the specific type of fresh produce. There were also inconsistencies in the cos lettuce testing which meant more research may need to be done for this category.

Overall, the sensory component study is limited to only investigating sensory aspects of produce up until the point of purchase (when the producers chain of custody ceases). When produce is transported, stored, and prepared by a consumer was not investigated. It is recommended that these stages be studied to examine further effects of packaging on sensory aspects of fresh produce in the home.

Additionally, this study only included laboratory observations by the research team. Whether plastic packaging, by extending the shelf life and aesthetics of fresh fruits and vegetables, in turn influences purchasing decisions requires further investigation. This is of importance, as this may have a greater influence on consumer purchasing behaviour than food waste reducing attributes. Such research would be beneficial to test the preliminary observations in this study. To conduct this work would require consumer data conducted in specifically designed sensory facilities on the sensory aspects of packaging, with a sample of consumers representing statistical significance across the Australian population.

Future investigations are warranted to gain a more complete evaluation of packaging in the Australian fresh produce environment, and to determine whether alternative packaging could also be considered as worthy alternatives.

7.0 Conclusion

7.0 Conclusion

Minimising food waste is a global challenge. Organisations continue to strive to maximise quality control and the associated benefits to consumers. This research has examined the role that packaging fulfils in this pursuit. This was specifically achieved by:

- Mapping the life cycle of 10 fresh produce items, both with and without packaging. Specifically, this included describing the food supply chains, and projecting/estimating the shelf life of produce which is extended with packaging, compared to the shelf life without packaging i.e. sold loose.
- Describing product diverted from waste because of packaging, and product going to waste because of no packaging.

By conducting this research, it was determined that packaging plays an important role in food waste strategies in the supply chain, namely by:

1. Provision of protection in the handling and transport of the product from the farm gate to the retailer;
2. Management of respiration and expiration, including gas management for ethylene (in order to slow the ripening process in some produce);
3. Limiting access to stop people from touching/handling the product, including reducing the chances of bruising or damage;
4. Increasing shelf life compared to the same product having no packaging.

Such insights led to key recommendations regarding how to ensure packaging formats continue to provide protection and longevity for fresh produce, as well as what this means in the broader contexts of fresh produce supply chains. Further research is also suggested to this end, in order for industry players to continue to innovate to address supply, waste, and market challenges into the future.

8.0
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8.0 References

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Appendix A

Appendix A

Peer review report from Dr Lilly DaGama, and the responses from the research team.

#	Area	Comment	Response
1.	Discussion of environmental balance between food and packaging	Whilst not the complete focus of the paper, the environmental impacts of both packaging and food waste are referenced frequently enough that a short summary of these impacts may be worthwhile in a chapter one section. Where they are discussed throughout section 1.4, a concise summary may aid those with less knowledge in the area.	A sub section for this issue is clearly included up front in the literature review, in Section 1.3.1
2.		The literature review is very well written and interesting, highlighting the need to be mindful of the use of packaging. The links between this and the research being undertaken here could be laid out more explicitly, for example do you plan to explore the balance or are you simply providing rationale for the need to research the relationship between food and packaging waste further?	We have a statement up front now in Section 1, that explicitly describes a need to research the relationship between food waste and packaging specifically.
3.		The review of the literature surrounding the environmental balance of food and packaging waste is very comprehensive. However, it may be worth adding a short discussion on the difficulty in establishing the balance based on the food type. For example, Wikstrom and Williams (2010) is presented as an example for the many cases in which packaging levels can be increased to achieve a more sustainable product-packaging system. However they also highlight that ketchup is an exception to this owing to its low GWP, energy use and levels of eutrophication and acidification of the food product – highlighting the need to assess products on a case by case basis. It doesn't affect the overall points you make but provides a fuller picture of the relationship.	A sentence has been added to Section 1.3.1 to highlight that every food system is different, and the packaging – product relationship needs to be assessed food type to food type.
4.	Literature review	An excellent case is put forward for the role of packaging in extending shelf life and reducing waste.	Thank you, we appreciate your point here.
5.		The thesis of much of the discussion appears to be that an extended shelf life will result in food waste reduction, which is logical, however if you could add any research to the literature review which explores this, it would strengthen an argument which is currently a little implicit.	There is little research evidencing the link. However, we have made it clearer in Section 1.3.3 what the logical premise is, that with more time to purchase and store there is more chance food is consumed accordingly.
6.	Focus	At several points throughout the report it becomes unclear if the focus is on reducing food waste in the supply chain/retail level or in the consumer home, particularly due to the discussion in the introduction relating to the nutritional issues of consumers, the review of packaging's relationship with consumer food waste levels (which I appreciate informs some discussion later) and some points made in the data and discussion chapters which imply data collection which includes consumers. For example, the labelling of the lifecycle maps suggests the focus ends with produce waste within the retailer however details in some cases explored (e.g. berries, pp. 58) discusses a small amount of consumer behaviour. Whilst it is evident that data stemming from interviews included the discussion of potential consumer behaviour relating to packaging and food waste, it is necessary to establish that this is the perceptions of the participants rather than findings from data collection, the current methods would not allow for such. This is particularly the case in the introduction as it makes the focus going forward unclear.	The focus for this report is on farm to retailer for this report. We now make that clear up front in Section 1, but we do note that when the data allows, perceptions of the participants may cover consumer aspects (whilst not from direct data from consumers).

Appendix A continued

#	Area	Comment	Response
7.	Contributions	The literature review is informative and well-structured with clear links to the research topics. I particularly enjoyed the comprehensive table summarising research testing the impacts of packaging on shelf life, very well-articulated and impactful. Whilst not a report targeted at academic publication I still think there is scope for improving how well articulated the contributions and focus of this research are. Where some of the previous research discussed is similar in focus to the research at hand (particularly in section 1.3.3) the contributions of this paper could be better highlighted by including a brief discussion as to how this research differs from/builds upon these prior works. Additionally, establishing in the introduction that the research does not explore consumer food waste would increase clarity for the reader.	The contributions of this paper is better highlighted up front in Section 1, in brief discussion as to how this extends prior work in combining the value of supply chain actor insights with sensory testing of fresh produce categories with and without packaging. As per the previous point, the introduction notes that the research does not explore consumer food waste.
8.	Methods	The methods undertaken are indeed appropriate for the objectives set out, however I feel opportunities to highlight what exactly the individual methods specifically contribute are missed, particularly in the qualitative interviews. Aspects of the methods remain slightly vague such as the statement 'Our explanations remained incomplete by only looking at these secondary data. Hence, semi-structured interviews were carried out by the research team'. From an academic perspective it leaves me asking what was incomplete about the original conclusions and how interviews were decided upon to fill these gaps, in order to easily ascertain the appropriateness of the methods.	More clarity is included in the method Section 3.1, in terms of why we moved from primary to secondary data. For instance reports and internal testing were lacking specific causes of food waste in the supply chain, which interviews helped to clarify.
9.	Methods	In Chapter 4 the value of the semi structured interviews becomes abundantly clear, particularly in the mushroom section, as the decision making process surrounding the use of the given packaging format is explored in relation to food waste in the supply chain and in getting produce to consumers in good shape whilst retaining the maximum nutritional value. This is something the existing literature reviewed in the previous section does not seem to have included. is better highlighted	The contributions combining the value of supply chain actor insights with sensory testing of fresh produce categories with and without packaging, is better highlighted up front in Section 1.
10.	Supply chain	Additionally I believe the consideration of the role of cold supply chains and temperature management should be further highlighted in the introduction, literature review (if possible) and perhaps the title. It plays a significant part of in the discussion throughout the review, data analysis and discussion and as such should be noted as a key part and contribution of the research.	We have also highlighted the role of cold supply chains and temperature management up front in Section 1, to make it clear this emerged as significant.
11.		Dependant on the availability of data within your existing store, through further acknowledging the research's focus on cold supply chain there seems to be an opportunity to further relate this discussion the central issue of packaging and by doing so build on some of the literature discussed, this is done to a limited extent in the final sections but could potentially be over larger importance. Building on the WRAP research outlining the necessity for consistent temperatures in order for the packaging to perform correctly (highlighted in table 2) there appears to be an opportunity for some discussion of the packaging's role in mitigating worst impacts of cool supply chain difficulties or increasing the damage if the cool supply chain is not maintained at the correct temperature. Not having access to your data this is merely a suggestion but some suggestion of synergy between cold supply chains and packaging could be an additional contribution.	As per our discussion points in Sections 5.1 and 6.2, we do highlight the synergy between cold supply chains and packaging as a key contribution. We have also included some links to previous research into Section 5.1 (White and Stanmore, 2018, Johnson et al., 2008), to highlight the nuanced approach to packaging and cold chain, as it is not always straight forward.

Appendix A continued

#	Area	Comment	Response
12.		Generally the focus of the research on supply chain management/ food waste could be brought out further in the introduction and the discussion to highlight it as a contribution to the research. Currently the focus of the introduction on solely the relationship between packaging and food waste seems to undersell the contribution made through exploring and mapping the supply chain. Some incredibly interesting points, which are not pertinent to packaging, are brought out from focusing on the supply chain.	We highlighted the role of cold supply chains, temperature management, and supply chain collaboration up front in Section 1, to make it clear that these areas emerged as significant.
13.	Methods	If possible a greater level of detail on some decisions would increase the sense of transparency within the report, for example I would be interested to know what led to the decision not to sensory test leafy salads. And how/why were these produce types selected?	We have made it clearer that the reason leafy salads, apples and pears were not tested for sensory aspects, related to availability of produce.
14.	Discussion	The discussion points and conclusions drawn lead clearly on from the data analysis and are well articulated. One point made in section 5.2 however, seems misleading as it is stated that some produce showed no difference in quality whether packaged or not, but the tables in chapter 4 suggest that was a difference in each of the products observed, even if only in one quality. Additionally, as highlighted above, greater clarity could be given to statements surrounding consumer food waste and behaviour surrounding packaging as suppositions/suggestions as opposed to findings.	The sentence in 5.2 about some produce showing 'no' difference in quality has been, to stating 'less significant 'difference in quality. As previously mentioned, we make it clear up front in Section 1, that some perceptions of participants covers consumer aspects, rather than direct data from consumers.
15.	Limitations & Recommendations	The limitations and recommendations are thoughtful and thorough. I greatly look forward to seeing some of the suggested future research.	Thank you, we appreciate your point here.