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Removing plastic packaging from fresh produce – what's the impact?

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Abstract

There has been a rise in public awareness and scrutiny of the negative environmental impact of plastic pollution in recent years. Plastic packaging of food causes a significant proportion of the UK's plastic waste, and manufacturers and retailers are exploring alternatives to single-use plastics, particularly in relation to fresh produce, including increasing the availability of loose items in supermarkets. However, there is an important trade-off to consider when removing plastic packaging from fruit and vegetables, which is the resultant reduction in shelf life and therefore potential increase in food waste. Fresh produce is estimated to be the most highly wasted type of food in the UK and it is likely that food waste has an even greater environmental impact than the production and disposal of plastic. Full life cycle analysis is currently unavailable for some alternative types of packaging (such as edible films and coatings), which means the relative effect of these on the environment compared to plastic is unclear, and may in fact be worse. More research is required to fully ascertain the best solution for this complex issue. However, communicating strategies to the general public to minimise household wastage of fresh produce, including optimal storage conditions for different varieties of fruit and vegetables, is likely to be of benefit.

Keywords: food waste, fresh produce, fruit and vegetables, packaging, plastic, shelf life

Introduction

There has been a great deal of media attention in recent years around reducing the use of plastic, and in particular single-use plastics, due to the environmental impact of plastic waste (BBC News 2017; *The Guardian* 2018; *The Independent* 2019a). Heightened coverage of the so-called war on plastic is likely partly attributed to the 'Blue Planet Effect', that is increased awareness of the issue generated in response to the amount of plastic found in the sea by David Attenborough and crew while filming, as reported in the popular wildlife documentary series (European Commission 2019a; *The Guardian* 2019).

Most plastic is produced from fossil fuels, although some is produced using renewable, plant-based sources such as lignin, oils, starch and cellulose (termed 'bio-based' plastics) (van den Oever *et al.* 2017; WRAP 2018a), and some types of plastic can take hundreds or thousands of years to biodegrade (Shahnawaz *et al.* 2019; Simon 2019). Therefore, excess plastic that is not recycled can pollute the natural environment when littered and transferred to terrestrial and marine environments via different pathways (WRAP 2018a; Barnes 2019).

Packaging is the largest use of plastic in Europe (Plastics Europe 2019), and, though difficult to quantify, it has been estimated that UK supermarkets

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generate at least 800 000 tonnes of plastic per year (Eunomia 2018). Furthermore, eight of the ten most littered items reported in the *International Coastal Cleanup 2017* were directly associated with food and drink packaging, for example drinks bottles, carrier bags and food wrappers (International Coastal Cleanup 2017). The issue of single-use plastics found on beaches and in seas was also highlighted as part of the EU's landmark European Strategy for Plastics in a Circular Economy, adopted in 2018 (European Commission 2019b), with new rules banning particular single-use plastic items, such as drinks stirrers, for which alternatives exist on the market (European Commission 2019c). The strategy aims to improve the design of plastic products, increase the rate of plastic waste recycling, boost the market for recycled plastic and ultimately protect the environment (European Commission 2019b). While waste management infrastructure to support the collection and recycling of plastic is undoubtedly part of the solution (WRAP 2019a), plastic cannot be recycled indefinitely and not all plastics are easily recycled (Parliamentary Office of Science & Technology 2019; WRAP 2019a). This has meant that there have been calls to reduce unnecessary food packaging and increase reusable and alternative materials (Parliamentary Office of Science & Technology 2019). Indeed, the UK government's *25 Year Environment Plan*, published in 2018, sets out a target for eliminating avoidable plastic waste by the end of 2042 (HM Government 2018a), with proposed actions including use of the tax system or charges to reduce the amount of single-use plastic waste (HM Government & Defra 2019) and encouraging the development of bio-based, biodegradable and environmentally friendly plastic. The EU vision is that all plastic packaging placed on the market is either reusable or can be recycled in a cost-effective manner by 2030 (European Commission 2019d).

It is now a legal requirement for large retailers to charge customers a minimum of 5 pence for plastic carrier bags at checkouts (with some exceptions, such as those used solely for raw meat and fish) to encourage shoppers to bring their own reusable bags (Defra 2018). This has resulted in the use of carrier bags being reduced by 83% (HM Government 2018a). However, polyethylene bags are commonly supplied in fresh produce aisles free of charge. In response to increased public pressure, a variety of other initiatives have been put in place by retailers who have committed to plastic food packaging reduction as part of their own corporate social responsibility (CSR). The UK Plastic Pact, set up by the Waste & Resources Action Programme (WRAP) in 2018, is a collaborative initiative between the Department for Environment, Food & Rural Affairs (Defra), businesses (including food manufacturers and retailers) and non-governmental organisations (NGOs) (WRAP 2019b). Members of the Pact are responsible for 85% of the plastic packaging sold through UK supermarkets (WRAP 2019c). Targets set to be reached by 2025 are:

- to take actions to eliminate problematic or unnecessary single-use packaging items (disposable plastic cutlery; all polystyrene packaging; cotton buds with plastic stems; plastic stirrers; oxo-degradables that break down to create microplastics; plastic straws; PVC packaging; and disposable plastic plates and bowls) through redesign, innovation or alternative (reuse) delivery models. It is estimated that UK Plastic Pact members* sold 1.1 billion problematic or unnecessary plastic items in the UK in 2018 (WRAP 2019c);
- 100% of plastic packaging to be reusable, recyclable or compostable. It is estimated that 65% of UK Plastic Pact members'* packaging was practically, not just technically, recyclable in 2018 (WRAP 2019c);
- 70% of plastic packaging effectively recycled or composted (WRAP 2019a). The national recycling rate in 2018 was 44% (WRAP 2019c);
- 30% average recycled content across all plastic packaging (WRAP 2019a). It is estimated that 10% of UK Plastic Pact members'* plastic packaging was recycled content (by weight) (WRAP 2019c).

*Data relate to packaging sold by 55 businesses (WRAP 2019c).

Examples of steps being taken towards achieving these targets can be seen in the out-of-home sector, where many outlets are offering reduced prices to consumers who bring in their own plastic cup or container to purchase food or drinks. In addition, some manufacturers and retailers are providing compostable carrier bags, discontinuing their use of dark plastics, which are particularly problematic as they are often not recognised by the optical systems used in plastics recycling (WRAP 2011; Parliamentary Office of Science & Technology 2019), and exploring strategies to reduce plastic packaging in the fruit and vegetable aisle.

In the light of the recent media focus on efforts made by UK supermarkets to reduce their use of plastic packaging on fresh produce (BBC News 2018; BBC News 2019a; FoodNavigator 2019; The Grocer 2019a; The Grocer 2019b; *The Independent* 2019b; *The Independent* 2019c; *The Independent* 2019d; *The*

Independent 2019e; Retail Gazette 2019; Tree Hugger 2019), this paper aims to outline some of the challenges and complexities around its removal, as investigated in a 2018 evidence review (WRAP 2018c) and discussed elsewhere (*The Independent* 2019f; BBC News 2020), as well as highlighting some ways in which the wastage of fresh produce could be reduced from the retailer and consumer perspective.

Consumer attitudes towards food packaging

A 2011 survey of 1520 UK consumers showed that 94% of those polled reported they felt manufacturers should be reducing the amount of all plastic packaging and 93% felt that supermarkets should be doing the same. However, at this time only 23% reported that plastic packaging would be a barrier to purchasing products (Which? 2011). In 2013, a survey conducted by WRAP reported that packaging was a low priority for shoppers when choosing food, with higher concerns around price and quality (WRAP 2013a). However, when the issue was framed within the context of the environment, consumers' attitudes to packaging tended to be negative, with 81% believing that packaging is a major environmental problem and 57% seeing it is as wasteful and unnecessary. Consumers' concerns were most commonly associated with how easy it is to recycle packaging materials at home. More recently, a survey of 2000 British adults found that 91% supported the idea of having an entire aisle dedicated to the sale of products free of plastic packaging [Populus 2017 (on behalf of A Plastic Planet)] and further research has suggested that many consumers feel guilty about the amount of plastic they use and would pay more for eco-friendly packaging (YouGov 2019). Eighty-two per cent of people surveyed in a 2019 YouGov poll (n = 1023) were actively trying to cut down on their personal plastic use and, interestingly, by far the most commonly targeted item was fresh fruit and vegetables, with 81% trying to reduce their use of plastic in this area (YouGov 2019).

Initiatives to reduce single-use plastic packaging in the fresh produce section in UK supermarkets, such as increasing the availability of loose fruit and vegetables; providing reusable bags for loose fruit and vegetables, often made from recyclable materials; and offering financial incentives to customers bringing their own containers, are being introduced or trialled in the UK. Reducing the use of single-use plastic packaging may appear to be an ideal solution to environmental concerns, resulting in the obvious benefit of reducing plastic waste (Narancic & Connor 2019). However, plastic has a number of important functions as a packaging material for fresh produce (and indeed other types of food). This includes extending produce shelf life, prolonging freshness and food quality and ensuring safety; hence, the potential removal of single-use plastic could result in the knock-on-effect of increased food waste (Russell 2014). For example, the in-store shelf life of new potatoes can be extended by 3 days if packaged in a modified atmosphere plastic bag, 1.5 g of plastic wrapping keeps a cucumber saleable for 11 additional days, and selling grapes in trays or bags has reduced in-store waste by 20% (Verghese *et al.* 2013). It has been estimated that the environmental impact caused by food waste is likely to be greater than the impact of plastic pollution (Zero Waste Scotland 2019). However, there has been a simultaneous increase in food waste alongside the increased use of plastic packaging in Europe, suggesting that the use of plastic packaging is not a definitive solution (Schweitzer *et al.* 2018).

The scale and consequences of food waste in the UK

The term 'food waste' describes any food and inedible parts sent to food waste destinations including composting, incineration, landfill, sewers or crops ploughed in to fields (WRAP 2020). This definition excludes any material that is sent for redistribution to people, animal feed or conversion into industrial products (collectively referred to as 'food surplus'). Figure 1 illustrates the amount of food waste generated in the UK.

Food waste negatively impacts the economy and the environment, and, therefore, both government and businesses are setting targets to step up action on tackling food waste (see Box 1). The environmental impact of food waste is caused by the natural resources used to produce the food in the first place; the resources involved in transporting, storing and displaying food products, for example energy used to refrigerate goods; the methane released from decaying food in landfill (WRAP 2019d); and overall the sheer volume of food waste produced globally, which is estimated to be 1.3 billion tonnes per year (FAO 2019). Fresh vegetables and salad are estimated to be the most highly wasted type of food in UK households, accounting for 28% of edible food waste by weight (WRAP 2018b). It is estimated that around 1.3 million tonnes of edible fresh vegetable and salad waste and 940 000 tonnes of fruit waste (a third of which is edible) are generated per year in the UK (WRAP 2018b).

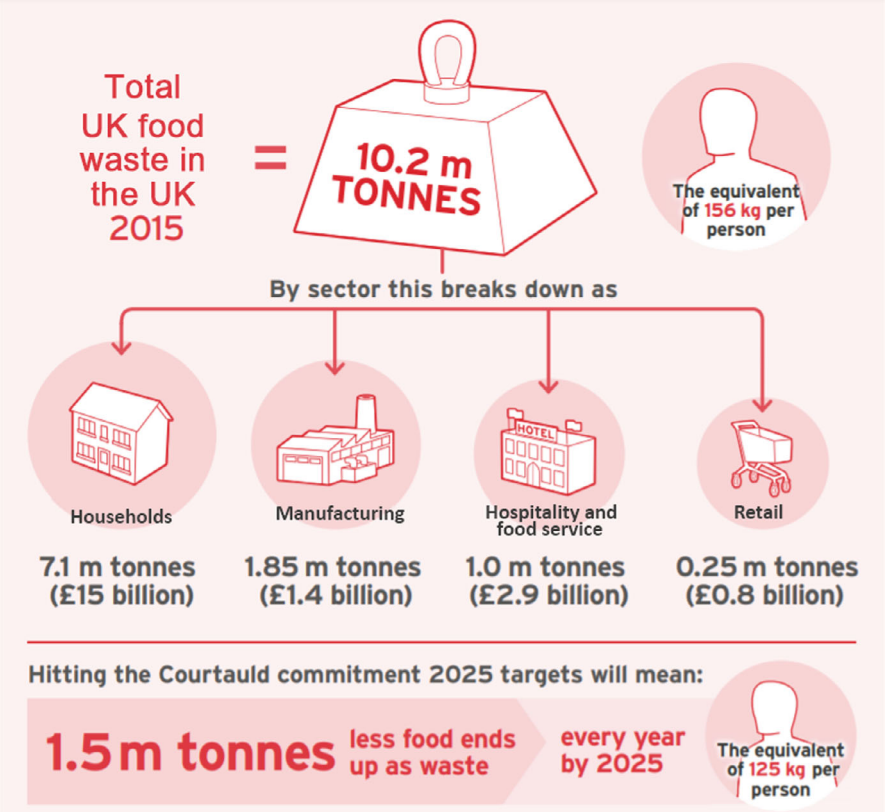

Figure 1 UK food waste by sector in 2015. Source: HM Government (2018b). [Colour figure can be viewed at wileyonlinelibrary.com]

Reasons for discarding food include the following: food 'not being used in time' (*i.e.* because it has become rotten, mouldy or otherwise unfit to eat or being past a labelled date); cooking, preparing or serving too much; accidents (*i.e.* food becoming contaminated, burnt or otherwise spoilt); and personal preference (*e.g.* health reasons or not liking certain foods) (WRAP 2018b). Fresh vegetables and salad waste thrown away due to 'not being used in time' costs consumers around £1.3 billion a year and account for approximately half of the total cost of fresh vegetable and salad waste in the UK (WRAP 2018b). The highest fresh fruit and vegetable contributors to UK food waste can be seen in Table 1.

In the UK, on average, we are not meeting the government recommendations of consuming at least five (80 g) portions of fruit and vegetables a day, with just 31% of adults (19-64 years) and a lower proportion of adolescents meeting these recommendations (Roberts *et al.* 2018). As well as the environmental significance, reducing fruit and vegetable waste may be particularly important for health (if it were to result in increased consumption) as meeting the 5 A DAY recommendation could help reduce risk of heart disease, stroke and some cancers (WHO/FAO 2003). Interestingly, analysis carried out using US data has indicated that those with a healthier diet actually generate more food waste than those with less healthy diets, likely due to the high perishability of fruit and vegetables (Yu & Jaenicke 2020). Higher income and food security was also associated with more food waste in this study. Low consumption of fruit and vegetables is typically particularly evident among those on a low income, with diet quality being one example of socio-economic health inequalities evident in the UK and elsewhere (Lockyer & Spiro 2019). Food waste occurring in a nation such as the UK in which individuals are experiencing food insecurity, evidenced by school holiday hunger and increased food bank use (The Conversation 2019), is difficult to reconcile. Being perishable, fresh fruit and vegetables are not normally offered by food banks but community fridges, some located in schools, mean that produce and other perishable food that is still safe to eat, but would otherwise be wasted, can be made available to individuals experiencing food poverty (BBC News 2019a, 2019b). Further initiatives include the collection and distribution by charities of would-be wasted

Box 1 The scale of the food waste problem, associated impacts and costs and targets for reduction

- Seventy per cent of household food waste is calculated to be edible food, defined as products (or parts of products) intended for human consumption (WRAP 2018b).
- Every year, UK citizens throw away 20% of the food and drink they buy, which could be worth up to £810 a year for a typical family or £230 per individual (WRAP 2018b).
- The greenhouse gas emissions associated with UK household food waste in 2015 are estimated at 22 million tonnes of CO_2 equivalent (WRAP 2018b).
- Preventing 1 tonne of food waste from going to landfill saves 5 tonnes of CO_2 equivalent (WRAP 2019d).
- Over 2 million tonnes of UK fresh produce are lost or wasted each year in the supply chain (WRAP 2019e).
- It has been estimated that nearly a third of world food produce is going uneaten annually and that this costs $940 billion and emits 8% of greenhouse gases globally (FAO 2015).
- *The Courtauld Commitment 2025*, a voluntary agreement launched in 2016 which is focussed on cutting food, carbon and water waste associated with food and drink, aims to reduce UK food waste by 20% by 2025, which is predicted to result in 1.5 million tonnes less food waste in 2025 compared with 2015 (WRAP 2018d; WRAP 2019f).
- The UK government is working towards no food waste entering landfill by 2030 by supporting local authorities to collect and recycle food waste. In addition, the government has pledged to provide funding for charities who redistribute surplus food from food businesses to those in need (HM Government 2018a; HM Government 2018b).
- UK waste policy has been largely dictated by EU legislation, such as the EU Waste Framework Directive (European Commission 2019e) and the EU Landfill Directive (The Council of the European Union 1999). This may change after the UK leaves the EU.
- The Landfill Directive (1999/31/EC) obliges EU Member States to reduce the amount of biodegradable municipal waste that they landfill to 35% of 1995 levels by 2016 (for some countries by 2020).
- The *United Nations Sustainable Development Goals* include a target of halving consumer and retail food waste by 2030 and reducing food losses in production and supply chains (SDG 12.3) (United Nations 2015).

fruit and vegetables that do not meet cosmetic standards (see 'Cosmetic standards for fresh produce and the impact on food waste').

What is the impact of reducing plastic packaging on the shelf life of fresh produce?

Plastic has many advantages for use in packaging for fresh produce, for example plastic can act as a barrier to oxygen, aromas and moisture, prevent contamination with foreign bodies and protect produce from physical damage, all reducing spoilage along with adding convenience for the consumer (Jabeen *et al.* 2015). Packaging can also be used to provide consumers with useful information to read at home, including optimal storage conditions. Types of packaging used for fresh produce vary. Plastic nets, for example, are often used for items such as onions, garlic and satsumas that have their own skin to protect them. For foods that are liable to water loss (such as broccoli, melons and tomatoes) (WRAP 2018c), plastic packaging such as polyethylene or polyester films can be used (Linke & Geyer 2013), and modified atmosphere packaging (MAP), which acts through changing the composition of the gases within the food packaging to ensure optimal conditions, is often used for highly perishable food that is stored at chilled temperatures such as salad leaves (Lee *et al.* 2015). Retailers have traditionally supplied brown paper bags for mushrooms as they are particularly prone to rot and discolouration (WRAP 2018c) (and some retailers have trialled offering these more widely for all loose produce in place of polyethylene bags). Due to the delicate nature and high perishability of fresh produce (*e.g.* compared to canned, frozen or dried goods), and potential confusion around how specific fruit and vegetables should be stored (WRAP 2008), the removal of packaging from produce may increase damage and reduce shelf life by accelerating spoilage, leading to increases in food waste.

Optimum storage conditions vary between different types of produce. For example, an evidence review by WRAP showed that storage advice, including type of

Table 1 The highest fresh fruit and vegetable contributors to UK food waste, adapted from household food waste: Restated Data for 2007–2015

Produce	Wasted food (edible parts, tonnes)	Cost (£ million)
Potatoes	710 000	555
Carrots	96 000	102
Apples	63 000	130
Lettuce	57 000	402
Other fresh vegetables and salad	49 000	315
Bananas	47 000	67
Onions	47 000	69
Tomatoes	46 000	128
Cabbages	43 000	65
Cucumbers	43 000	77
Soft berry fruit	42 000	210
Stone fruit	37 000	140
Oranges	29 000	56
Other root vegetables	29 000	57
Melons	24 000	59
Leafy salad	22 000	64
Other citrus fruit	18 000	52
Pears	18 000	33
Other fresh fruit	13 000	200
Pineapples	10 000	120

Source: WRAP (2018b).

packaging and temperature, would likely differ between each of the four varieties of produce generating the most waste in the UK (potatoes, carrots, apples and lettuce; see Table 1) (WRAP 2018c). For example, it is not recommended that potatoes are stored within the refrigerator as this can cause an increase in the amount of free sugars and acrylamide levels, known as 'cold sweetening'. For this reason, the current recommendations from the Food Standards Agency (FSA) are to store raw potatoes in a dark, cool place at temperatures above 6°C (FSA 2018a). However, research has shown an improvement in shelf life of carrots stored in the refrigerator compared with carrots stored at room temperature and there is evidence that shelf life would increase further if stored within plastic packaging (WRAP 2018c). Research into the most effective storage techniques for lettuce and other salad leaves showed that wrapping these in a dry paper towel and placing in a sealable plastic bag in the fridge, or placing in the crisper drawer in the fridge (an enclosed compartment designed to prolong the freshness of stored produce), extended shelf life by four and a half times compared with keeping salad leaves unwrapped in the fridge (WRAP 2018c). It has been estimated by WRAP that shrink wrapping could extend the shelf life of apples by up to 2 weeks and use of polyethylene bags can reduce weight loss. However, as apples have a relatively long shelf life of 3-4 weeks, they can be sold without plastic packaging and the advice is to store apples in a refrigerator set at below 5°C (WRAP 2018c). Despite this, apples are commonly stored in a fruit bowl at room temperature by consumers (WRAP 2008).

WRAP gathered evidence relating to 17 different types of fresh fruit and vegetables (WRAP 2008) and combined this with more recent evidence in their 2018 report comparing produce stored in plastic packaging and produce stored without packaging both at room temperature and refrigerated (WRAP 2018c). Evidence related to the most effective storage conditions for selected fruits and vegetables is summarised in Table 2, although for a more in-depth review, see WRAP (2018c). Overall, the findings revealed that refrigeration is vitally important in maintaining freshness and extending storage life in 13 of the 17 types of loose produce examined (*i.e.* apples, broccoli, carrots, grapes, lemons, kiwi fruit, melons, mushrooms, oranges, pears, peppers, tomatoes and strawberries), when compared to being stored at room temperature (22°C). This is important in addressing household food waste, as research shows that consumers often choose to store certain types of fruit and vegetables, such as oranges, outside of the fridge (WRAP 2008). It is important to note, however, that refrigeration is not recommended for all fruit and vegetables, with the results suggesting that onions, bananas (refrigeration causes skins to blacken) and pineapples should be kept cool but not refrigerated.

The evidence review also explored the effect of refrigerating produce stored within polyethylene bags (the type commonly supplied in the produce section of supermarkets). This method was predicted to help retain moisture and freshness, and increase storage life compared with refrigerating loose (uncovered) produce, based on research from 2008 (WRAP 2008). The data showed that keeping items in the fridge in a polyethylene bag only significantly extended the storage life (defined by WRAP as an increase in storage life of more than 3 days) of two of the 17 fruit and vegetables tested compared with keeping them in the fridge without a plastic bag. However, this practice did extend the storage life of some varieties of produce by 1-3 days [bananas (at room temperature), carrots and tomatoes]. Interestingly, the two items with extended storage lives of 4 or more days when refrigerated within a polyethylene bag were lemons and peppers, which are both commonly available to purchase loose. Compared with when stored at room

Table 2 Summary of the evidence for the most effective storage conditions for selected fruits and vegetables

Produce	Packaging methods typically used	Effect of packaging methods on condition and shelf life
Apples	Sold loose or in packaging, typically: • 'flow wrap' (polyethylene or polypropylene); • polyethylene bags; • plastic/polystyrene/cardboard trays.	• Polyethylene bags help to limit the weight loss over time, especially in varieties more prone to weight loss. • Paper mould trays and corrugated fibreboards can help to limit spoilage. • MAP can be beneficial in extending shelf life of fresh-cut apples, but only if combined with an anti-browning dipping treatment, and it has been suggested that the costs of using MAP for apples generally outweigh the benefits. • Shrink wrapping may extend shelf life by up to 2 weeks but may affect texture. • Use of binary-coated chitosan film may warrant further investigation.
Bananas	Sold loose or in packaging, typically: • polyethylene bags.	• Evidence suggests bananas lose their visual quality quicker when stored at 22°C compared with at 15°C; therefore, storing in a cool place is likely to be beneficial. • Storing within plastic bags may maintain visual quality and retain moisture for longer. • For ripening bananas, it is estimated that plastic packaging can benefit quality, firmness and colour. • Edible films and coatings may extend shelf life.
Broccoli	Sold loose or in packaging, typically: • cling wrap.	• Spraying with water, wrapping in paper towel and storing in a sealable plastic bag or keeping in a plastic bag in the crisper drawer in the fridge have been found to be more effective than covering in cling wrap.
Carrots	Sold loose or in packaging, typically: • high- or low-density polyethylene tied bags; • PET film.	• Storage within plastic bags in the fridge can help retain hydration and turgidity. • Although maintaining a high relative humidity is beneficial, MAP is not suitable. • Recent evidence suggested a potential benefit of a film based on chitosan and casein polymers in reducing spoilage of carrots.
Grapes	Sold in packaging, typically • PET box.	• Due to their fragility, it is likely that grapes will require some form of packaging. • It has been hypothesised that cardboard boxes could be used as a storage container. • There is some evidence that biofilms can aid preservation.
Mushrooms	Sold loose or in packaging, typically: • dark plastic punnets with PVC cling film; • purpose-designed paper bags.	• Purpose-designed paper bags are the most optimal method of mushroom storage as storage in polyethylene plastic bags leads to moisture accumulation through condensation, which increases the risk of rots and off-odours.
Oranges	Sold loose or in packaging, typically: • plastic netting.	• There is predicted to be little to no benefit of storing oranges in nets compared with storing them loose. • If oranges are stored at room temperature, there is benefit in storing within a polyethylene bag. • Edible coating may preserve shelf life.
Peppers	Sold loose or in packaging, typically: • 'flow wrap' polyethylene or polypropylene; • polyethylene bags.	• Studies have reported considerable differences in the shelf life of loose peppers. • Polypropylene wrap may be the best type of plastic packaging. • MAP (particularly combined with silica sachets) may extend shelf life. • Biofilms may be effective.
Potatoes	Sold loose or in packaging, typically: • polyethylene bags.	• Storing raw potatoes in a polyethylene bag (in a dark, cool place at temperatures above 6°C) prevents moisture loss.
Tomatoes	Sold loose or in packaging, typically: • plastic punnets covered in film or 'flow wrap'; • cardboard punnets.	• Due to their fragility, it is likely tomatoes will require some form of packaging. • While storage of tomatoes within plastic bags in the fridge may reduce weight loss, there is reportedly no significant effect on firmness or visual quality. • Packaging based on yam starch or glycerol may be of benefit, and there is emerging research on a number of other different coatings.

Source: WRAP (2018c). MAP, modified atmosphere packaging; PET, polyethylene terephthalate.

temperature, lemons retained freshness and quality for at least 7 days longer when stored in the fridge and for at least 14 days longer stored in a bag in the fridge. Peppers retained freshness and quality for at least 10 days longer stored in the fridge and for at least 14 days longer stored in a bag in the fridge.

Some fruits and vegetables, including broccoli, carrots, melons, oranges, peppers and tomatoes, lose moisture when refrigerated without packaging (WRAP 2018c). WRAP previously identified that the loss of water caused by the dryness in the refrigerator negatively affects perceived product quality and acceptability by consumers (WRAP 2008). In addition, consumers were found to have low awareness of the important role packaging plays in maximising home shelf life (WRAP 2013a). It was predicted that storing items that lose moisture when refrigerated in an airtight container is likely to have the same effect as keeping them in plastic packaging. Therefore, reusable airtight containers, such as strong, sealable and plastic boxes, used in the home could be a viable alternative to single-use plastic packaging (WRAP 2018c) to increase storage life of these products without having to compromise on produce quality. Overall, WRAP concluded that there remains a limited amount of research on the effect of packaging on the storage life of a number of commonly consumed fruit and vegetables and that more data are ideally needed (WRAP 2018c).

What can consumers do to reduce wastage of fresh produce at home?

In the UK, over half of food waste occurs in the home, as opposed to food wasted in parts of the supply chain such as on farms, by retailers and by food service providers (WRAP 2018b; see Fig. 1). Therefore, encouraging consumers to act to extend product storage life at home could make an important impact. One of the most effective ways to do this is to ensure the refrigerator is set to below 5°C and to store fresh produce in the fridge (with the exception of onions, pineapples, potatoes and bananas), which could reduce food waste by 70 000 tonnes and, taking into account the additional energy required to reduce fridge temperatures, save £200 million and reduce CO_2 equivalent emissions by 210 000 tonnes a year (WRAP 2013b). The work additionally suggested that storage lives of the majority of chilled foods would be increased if fridge temperatures could be lowered (*e.g.* from 7 to 4°C) and this is reflected in advice from the FSA (FSA 2018b). WRAP's *Chill the Fridge Out* campaign gives consumers information on how to adjust the temperature of the specific fridge that they have in their home (WRAP 2018e).

Storing produce within polyethylene bags or sealable plastic containers may extend shelf life even further in some cases and freezing produce to consume at a later date before it becomes spoiled will additionally prevent waste. Consumers can also reduce their wasted food by trying to avoid overpurchasing, not automatically throwing away produce past its 'best before' date and trying to cook an appropriate portion for meals (with any leftovers appropriately stored and consumed at a later time) (Priestley 2016). Recipes to inspire consumers to use leftovers and all edible parts of foods (including fruit and vegetable peelings, seeds, stalks and leaves) are available on the *Love Food, Hate Waste* website. The best methods of disposing of household food waste to prevent it going into landfill are to collect it separately from other rubbish using a kitchen caddy provided by some local authorities to facilitate the production of compost or biogas, or to create compost at home (Recycle Now 2019a).

Are alternative types of packaging preferable to single-use plastic?

In the light of its role in extending shelf life, plastic packaging may be viewed as a good option for fresh produce, provided it is recyclable. It is estimated that, in the UK, the recycling rate of all plastic packaging is currently 44% (WRAP 2019c). The recyclability of plastics that are labelled as recyclable is, however, complex, with the myriad of symbols present on packaging (Recycle Now 2019b) causing confusion among the public as to which plastics can be recycled and where they should be deposited (RECOUP 2019). The ease at which plastic packaging can be recycled by consumers ranges from:

- widely recyclable [*i.e.* as part of household kerbside collections by most local authorities (though this can be highly variable), for example fruit punnets. Currently, only around 10% of local authorities accept plastic film];
- recyclable at specialist points (*i.e.* recycling centres, including those offered at some supermarket premises, for example polyethylene bags used for fresh produce, bags used for frozen vegetables); to
- not easily recyclable (*e.g.* salad bags) (Which? 2019; Recycle Now 2019c).

In addition, there are a number of factors that can influence whether a piece of plastic packaging is ultimately recycled after being placed in a recycling bin,

such as if there is any contamination, for example with large amounts of food; liquid residue (*e.g.* oils); printing inks and labels; other plastics (multi-material packaging is common); and the cost and ease of recycling the particular type of plastic in question (Hahladakis & Iacovidou 2018; Iacovidou *et al.* 2019; Parliamentary Office of Science & Technology 2019; WRAP 2019a). In addition, the technologies used at the material recovery facilities, as well as reprocessing methods, can also impact on plastic packaging recyclability (Hahladakis & Iacovidou 2019). The types of materials that are permitted to be used in contact with food are dictated by legislation (European Commission 2017), meaning that films of different composition may need to be included within packaging as a barrier between food and any materials that are not suitable, and this decreases the potential for recycled plastic to be used within packaging for fresh produce (WRAP 2019g).

Some varieties of fresh produce require packaging of some sort for protection from damage [*e.g.* berries (Blanc *et al.* 2019)], and therefore, investigating alternatives to single-use plastics is a key area for future research. Alternative packaging materials, such as paper or cardboard, have been suggested, although one negative is, as with plastic, these can only be recycled a limited number of times (WRAP 2009). Innovative bio-based films such as chitosan film (sourced from shellfish waste products), film based on casein polymers and packaging based on yam starch or glycerol have also been considered as alternatives to plastic for packaging fresh produce (WRAP 2018c). There are also a number of post-harvest technologies, including physical (*e.g.* heat treatments and edible coatings), chemical (*e.g.* anti-browning agents such as citric acid) and gaseous (*e.g.* controlled atmosphere storage) treatments, which can be used to maintain produce quality and reduce spoilage (Dhall 2013; Mahajan *et al.* 2014). Modified atmosphere packaging commonly uses plastic made from fossil fuels, though there are efforts to use bio-based, biodegradable, sustainable and recycled materials to produce MAP (Wilson *et al.* 2019). The future may be the use of 'active' and 'intelligent' packaging systems that monitor the condition of packaged foods and communicate this information to consumers (Lee *et al.* 2015; Ghaani *et al.* 2016).

Life cycle assessment analyses are used to ascertain the environmental impact of food packaging (Russell 2014), and such analysis is still required for many of the alternatives to plastic that may be suitable for fresh produce (Parliamentary Office of Science & Technology 2019). Life cycle assessments can have limitations if key considerations are absent (Schweitzer *et al.* 2018) and a recent report highlighted calls for more standardised methodology (Green Alliance 2020). For example, alternative packaging will likely only have a net positive effect on greenhouse gas emissions if it can effectively reduce food waste, thereby offsetting the greenhouse gas emissions produced by food degradation in landfill, the transport and production of food that is wasted, the treatment of waste water and the incineration of waste (Dilkes-Hoffman *et al.* 2018), particularly as more resources and energy may be needed to produce alternative types of packaging in the first place (Parliamentary Office of Science & Technology 2019). Indeed, bio-based plastics have become popular for use in food packaging, yet are currently more expensive to produce than plastics produced from fossil fuels (Iacovidou & Gerassimidou 2018). It is also important to note that, just because a plastic is bio-based (or partially bio-based), it does not necessarily mean it will biodegrade (*e.g.* polyethylene is bio-based but will not biodegrade) (WRAP 2018a). Furthermore, even plastics that are labelled as biodegradable will not rapidly degrade in the sea (United Nations Environment Programme 2016) and it has been estimated that the use of such plastics will not result in a significant decrease either in the quantity of plastic entering the ocean or the risk of physical and chemical impacts on the marine environment (United Nations Environment Programme 2015). Despite this, evidence suggests that consumers view biodegradable packaging very favourably (The Grocer Vision 2019; INCPEN & WRAP 2019).

At present, it is likely that some packaging alternatives increase carbon emissions relative to plastic, especially if the product has a long supply chain (Pilz *et al.* 2010; Trucost 2016; Iacovidou & Gerassimidou 2018). Aside from potential reductions in product shelf life and associated increases in food waste, another reason for this is that plastic is lightweight compared to other materials [such as glass (Humbert *et al.* 2009)] and therefore relatively cheap to transport and so this aspect needs to be considered when searching for viable alternatives. Single-use paper bags can require more energy to produce than single-use plastic bags and also fare worse in relation to other environmental impacts. Furthermore, encouraging consumers to collect some products in their own refillable containers may reduce shelf life versus factory-sealed packaging (Green Alliance 2020). There may also be other negative consequences; for example, the production of bio-based plastics using food crops could

increase commodity prices and affect land use (Trucost 2016), though it was recently suggested that whether or not bio-based plastics are more sustainable than fossil fuel-based plastics still remains unknown due to a lack of data (though analysis indicates that bio-based plastics do have potential in this regard) (Spierling *et al.* 2018). Reducing the amount of plastic used within packaging or changing the type (*e.g.* from rigid to flexible) and making the manufacturing of plastic more sustainable may be better solutions (Trucost 2016; Karmaus *et al.* 2018). Overall, the picture is complex, with many potential impacts that need to be considered and further research is required to identify and produce cost-effective solutions that are truly better for the environment than plastic. Guidance for industry on sustainable packaging is available, for example from the Sustainable Packaging Coalition and The Ellen MacArthur Foundation, and the topic is also a focus of the Circular Economy Task Force (Green Alliance 2020).

What about selling fresh produce loose?

Some consumers may prefer to purchase produce that is devoid of any packaging (Which? 2011; YouGov 2019). Fruit and vegetables with their own natural protection, such as squash or aubergines, are robust enough to be sold loose (Schweitzer *et al.* 2018), a strategy that may also help reduce food waste, as consumers are able to purchase the exact quantity they need rather than having to buy a specific, packaged amount. This can be especially beneficial for those living in single-person households, who on average waste 40% more food and 34% more fresh fruit and vegetables per capita than other households (WRAP 2018b). Furthermore, schemes offering free fruit and vegetables to children in store are useful to encourage consumption of single, loose items of produce, such as bananas, which may otherwise be left on the shelves and wasted.

Although selling fruit and vegetables loose may be favoured by consumers, the materials used for transporting and displaying loose fruit and vegetables, which in some instances are single-use, need to be considered (Parliamentary Office of Science & Technology 2019). In addition, when offering loose fruit and vegetables, retailers are missing out on the opportunity to provide customers with advice on pack, such as information on serving sizes and optimal storage conditions (WRAP 2013a). Effectively communicating the benefits of using storage information can help consumers reduce food waste, especially as a large proportion of consumers (84%) report that they would be likely to use clear on-pack storage guidance if it was highlighted to them (WRAP 2013a). However, it was previously estimated that advice on storage, using methods such as tags, stickers or information printed on paper bags, was only provided on 6-19% per cent of loose produce (WRAP 2008). Information could also be provided on fixtures or posters within supermarkets; by training employees to advise customers; or supplying information online, as online grocery shopping is predicted to continue to increase (Mintel 2019a). One survey estimated that just 22% of consumers look at storage guidance on pack (WRAP 2013a) and so there may be larger scope in making storage information easily accessible and digestible for the consumer to increase understanding (FSA 2016). There may also be benefit in positioning at-home storage solutions, such as reusable airtight containers, next to produce in store although further research would be required to assess the effectiveness of this.

There is concern that 'best before' or 'display until' dates on packaging may prompt consumers to throw away produce unnecessarily due to confusion with 'use by' dates that indicate food safety (Lebersorger & Schneider 2014). This has led to calls to review consumer understanding and use of dates on produce to help reduce waste (WRAP 2017). Current guidance from WRAP recommends that 'best before' dates on fresh produce, excluding short-life products and where there is a limited time for consumption in the home, should be removed (WRAP 2017). However, the impact of such changes on consumer behaviour remains to be demonstrated (YouGov 2018).

Cosmetic standards for fresh produce and the impact on food waste

A proportion of fruit and vegetable food waste is attributable to produce that is safe for consumption, yet does not meet the aesthetic standards for the shape and appearance set by retailers and therefore will often not leave the farm or will not be sold within supermarkets (Canali *et al.* 2014). It is estimated that over a third of total farm production in the UK is lost due to this reason, up to an estimated 4500 kt^{-1} per year, equating to greenhouse gas emissions of up to 970 kt^{-1} of CO_2 annually (Porter *et al.* 2018). For example, it has been estimated that 5–25% of apples, 9–20% of onions and 3–13% of potatoes are rejected based on appearance (Porter *et al.* 2018). Estimates of

waste in primary production, however, may be higher than the reality, as fresh produce sent for use as animal feed is likely to be included, which would not be defined as food waste but is still considered an economic loss (WRAP 2019h).

Stringent standards may be based on consumer preferences; however, research suggests that consumers may in fact be willing to purchase produce deemed 'unacceptable' by retailers. For example, research conducted in Northern Europe concluded that a discounted price, proportionate to the level of cosmetic flaw, positively influenced consumer purchasing (De Hooge *et al.* 2017). Further research carried out in four countries, including the UK, reported that 73% of consumers stated that they were open to purchasing cosmetically flawed fruit and vegetables and 90% of retailers felt consumers would purchase imperfect produce if the price was discounted (Grow Wales 2018).

UK legislation states that so-called 'wonky', 'ugly' or 'imperfect' fruit and vegetables labelled in accordance with the UK food labelling laws that do not mislead consumers can be marketed how the retailer sees fit (Rural Payments Agency 2018) and many UK retailers do sell produce that is specifically labelled as such, at reduced cost compared to standard produce. Some retailers are also using cosmetically flawed produce within products such as soups and smoothies (Mintel 2019b). An estimated 1.7 million households were purchasing 'wonky' fruit and vegetables in 2016, with an increase to 7.7 million households in 2018 (Kantar Worldpanel 2018). However, more may need to be done to address negative consumer perceptions to consuming wonky fruit and vegetables (Jaeger *et al.* 2018). In 2017, the Environment Food and Rural Affairs Committee commented that while the sale of 'wonky' produce is a positive initial step, it would be preferable for retailers to relax their quality standards and start selling 'wonky' produce as part of their main fruit and vegetable lines, in order to normalise cosmetic flaws within food (The Environment Food & Rural Affairs Committee 2017). WRAP has produced guidance to aid businesses with setting and maintaining quality specifications for fresh produce, which highlights the importance of gathering customer feedback on their willingness to purchase cosmetically flawed fruit and vegetables and advice on how best to establish 'wonky' lines (WRAP 2018f).

Future research

More research is needed on the impact of different types of plastic packaging on reducing spoilage of fresh produce, especially as there are insufficient data for many commonly consumed fruit and vegetables (WRAP 2018c). There has, to date, been no substantial research investigating the wastage rates of packaged compared with loose fruit and vegetables (WRAP 2018c). Further work is also required on alternative approaches to plastic packaging, such as innovative films and coatings or bio-based plastics and indeed cardboard, glass and refillable containers. The progression of such alternatives could provide an important solution to many issues around using single-use plastics. However, it is important to consider economic, social and technical impacts when assessing their potential to provide a net sustainability benefit over conventional plastics. Overall, an improved understanding of the detail, options and unintended consequences of both recycling and removing plastic waste on the system as a whole needs to be considered, with a recent report highlighting a need for joined-up thinking in this space (Green Alliance 2020).

Conclusions

In order for a reduction in plastic packaging used by supermarkets to assist progression towards the targets laid out in *The Courtauld Commitment* and the *United Nations Sustainable Development Goals*, the long-term sustainability of alternative options must be considered, as outlined above. To aid retailers in making informed decisions with respect to packaging fresh produce (or not), more research investigating the impact of different types of packaging on the environment and the shelf and at-home storage life of fruit and vegetables is required as there are significant difficulties in extrapolating small-scale findings.

Research to date suggests that, in the case of many fruit and vegetables, storage within a refrigerator (rather than at room temperature) would have a similar effect on storage life as keeping the produce in plastic packaging in the fridge. However, a few varieties do benefit from extended shelf life if stored within plastic (*e.g.* peppers and lemons). There is also likely to be a benefit to food waste in reducing the temperature settings on the refrigerator to less than 5°C or, in the case of produce that loses moisture when refrigerated, storing them in a reusable airtight container. Promoting this information to consumers would likely have an impact on reducing household food waste and grocery spends. In addition, raising awareness of the need to wash plastic packaging in the home before placing in the recycling bin could help to reduce plastic waste.

The issue of removing plastic packaging from fresh produce is a complex one. What is clear is that a comprehensive life cycle analysis is required for every alternative solution to plastic packaging for fruit and vegetables and indeed other food products. It may be some time before the impact of recently introduced schemes to reduce plastic packaging on fresh produce in UK supermarkets are realised, and in the meantime, work may need to be done to communicate the message to consumers that getting rid of all types of plastic packaging for fresh produce may not always be the best solution overall.

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References

Barnes SJ (2019) Understanding plastics pollution: The role of economic development and technological research. *Environmental Pollution* **249**: 812–21.

BBC News (2018) *Co-op to replace plastic bags with compostable carriers*. Available at: https://www.bbc.co.uk/news/uk-45612315 (accessed 6 November 2019).

BBC News (2017) *Greenpeace wants new taxes on plastic for Wales*. Available at: https://www.bbc.co.uk/news/uk-wales-politics-41231743 (accessed 6 November 2019).

BBC News (2019a) *Bring your own containers, says Waitrose*. Available at: https://www.bbc.co.uk/news/business-48498346 (accessed 6 November 2019).

BBC News (2019b) *Primary schools give free food to hungry families*. By Sean Coughlan, 19 October 2019. Available at: https://www.bbc.co.uk/news/education-50088910 (accessed 6 November 2019).

BBC News (2020) *Plastic packaging ban 'could harm environment'*. By Roger Harrabin, 9 January 2020. Available at: https://www.bbc.co.uk/news/science-environment-51040155 (accessed 13 January 2020).

Blanc S, Massaglia S, Brun F *et al*. (2019) Use of bio-based plastics in the fruit supply chain: an integrated approach to assess environmental, economic, and social sustainability. *Sustainability* **11**: 2475.

Canali M, Östergren K, Amani P *et al*. (2014) *Drivers of current food waste generation, threats of future increase and opportunities for reduction*. Available at: https://www.researchgate.net/publication/297001052_Drivers_of_current_food_waste_generation_threats_of_future_increase_and_opportunities_for_reduction (accessed 6 November 2019).

De Hooge IE, Oostindjer M, Aschemann-Witzel J *et al*. (2017) This apple is too ugly for me!: Consumer preferences for suboptimal food products in the supermarket and at home. *Food Quality and Preference* **56**: 80–92.

Defra (Department for Environment, Food & Rural Affairs) (2018) *Carrier bag charges: retailers' responsibilities*. Available at: https://www.gov.uk/guidance/carrier-bag-charges-retailers-responsibilities (accessed 13 November 2019).

Dhall R (2013) Advances in edible coatings for fresh fruits and vegetables: a review. *Critical Reviews in Food Science and Nutrition* **53**: 435–50.

Dilkes-Hoffman LS, Lane JL, Grant T *et al*. (2018) Environmental impact of biodegradable food packaging when considering food waste. *Journal of Cleaner Production* **180**: 325–34.

Eunomia (2018) *Informing the Plastics Debate*. Available at: https://www.eunomia.co.uk/informing-the-plastics-debate/ (accessed 6 January 2020).

European Commission (2017) *Food Contact Materials*. Available at: https://ec.europa.eu/food/safety/chemical_safety/food_contact_materials_en (accessed 13 November 2019).

European Commission (2019a) *EU action on plastics*. Available at: https://www.bereadytochange.eu/en/about/ (accessed 6 January 2020).

European Commission (2019b) *European strategy for plastics*. Available at: https://ec.europa.eu/environment/waste/plastic_waste.htm (accessed 6 January 2020).

European Commission (2019c) *Circular Economy: Commission welcomes Council final adoption of new rules on single-use plastics to reduce marine plastic litter*. Available at: https://ec.europa.eu/commission/presscorner/detail/en/IP_19_2631 (accessed 6 January 2020).

European Commission (2019d) *A European strategy for plastics in a circular economy*. Available at: https://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf (accessed 6 January 2020).

European Commission (2019e) *Biodegradable Waste*. Available at: https://ec.europa.eu/environment/waste/compost/index.htm (accessed 6 January 2020).

FAO (Food and Agricultural Organisation of the United Nations) (2015) *UN FAO - Food wastage footprint & Climate Change*. Available at: https://www.fcrn.org.uk/research-library/un-fao-food-wastage-footprint-climate-change (accessed 26 November 2019).

FAO (Food and Agricultural Organisation of the United Nations) (2019) *SAVE FOOD: Global Initiative on Food Loss and Waste Reduction*. Available at: https://www.save-food.org/ (accessed 6 November 2019).

Food Navigator (2019) *Unilever unveils ambitious plans to cut plastic 50% by 2025*. By Oliver Morrison, 7 October 2019. Available at: https://www.foodnavigator.com/Article/2019/10/07/Unilever-vows-to-cut-plastic-packaging (accessed 6 November 2019).

FSA (Food Standards Agency) (2016) *Understanding NI Consumer Needs Around Food Labelling*. Available at: https://www.food.gov.uk/sites/default/files/media/document/consumer-needs-around-food-labelling_0_0.pdf (accessed 6 January 2020).

FSA (Food Standards Agency) (2018a) *Acrylamide*. Available at: https://www.food.gov.uk/safety-hygiene/acrylamide (accessed 6 November 2019).

FSA (Food Standards Agency) (2018b) *Chilling*. Available at: https://www.food.gov.uk/safety-hygiene/chilling (accessed 8 January 2020).

Ghaani M, Cozzolino CA, Castelli G *et al*. (2016) An overview of the intelligent packaging technologies in the food sector. *Trends in Food Science & Technology* **51**: 1–11.

Green Alliance (2020) *Plastic promises*. Available at: https://www.green-alliance.org.uk/resources/Plastic_promises.pdf (accessed 9 January 2020).

Grow Wales (2018) *Embracing Wonky*. Available at: https://www.tyfucymru.co.uk/sites/default/files/2018-07/180704%20ap%20issue1%20Wonky%20Vegetables%20Insights%20100159.pdf (accessed 6 November 2019).

Hahladakis J & Iacovidou E (2018) Closing the loop on plastic packaging materials: What is quality and how does it affect their circularity?*Science of the Total Environment* **630**: 1394–1400.

Hahladakis J & Iacovidou E (2019) An overview of the challenges and trade-offs in closing the loop of post-consumer plastic waste (PCPW): Focus on recycling. *Journal of Hazardous Materials* **380**: 120887.

HM Government & Defra (Department for Environment, Food & Rural Affairs) (2019) *Plastic packaging tax*. Available at: https://www.gov.uk/government/consultations/plastic-packaging-tax (accessed 9 January 2020).

HM Government (2018a) *A Green Future: Our 25 Year Plan to Improve the Environment*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (accessed 6 January 2020).

HM Government (2018b) *Our waste, our resources: a strategy for England*. Available at: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/693158/25-year-environment-plan.pdf (accessed 6 January 2020).

Humbert S, Rossi V, Margni M *et al*. (2009) Life cycle assessment of two baby food packaging alternatives: glass jars vs. plastic pots. *The International Journal of Life Cycle Assessment* **14**: 95–106.

Iacovidou E & Gerassimidou S (2018) *Sustainable Packaging and the Circular Economy: An EU Perspective*. Available at: https://www.sciencedirect.com/science/article/pii/B9780081005965224888?via%3Dihub (accessed 6 January 2020).

Iacovidou E, Velenturf A & Purnell P (2019) Quality of resources: A typology for supporting transitions towards resource efficiency using the single-use plastic bottle as an example. *Science of the Total Environment* **647**: 441–8.

INCPEN (Industry Council for Packaging & the Environment) & WRAP (Waste & Resources Action Programme) (2019) *UK survey 2019 on citizens' attitudes & behaviours relating to food waste, packaging and plastic packaging*. Available at: https://www.incpen.org/incpen-wrap-uk-survey-2019-on-citizens-attitudes-behaviours-relating-to-food-waste-packaging-and-plastic-packaging/ (accessed 9 January 2020).

International Coastal Cleanup (2017) *International Coastal Cleanup 2017 Report*. Available at: https://oceanconservancy.org/wp-content/uploads/2017/06/International-Coastal-Cleanup_2017-Report.pdf (accessed 6 November 2019).

Jabeen N, Majid I & Nayik GA (2015) Bioplastics and food packaging: A review. *Cogent Food & Agriculture* **1**: 1117749.

Jaeger SR, Machín L, Aschemann-Witzel J *et al*. (2018) Buy, eat or discard? A case study with apples to explore fruit quality perception and food waste. *Food Quality and Preference* **69**: 10–20.

Kantar Worldpanel (2018) *FPJ Live*. Available at: https://bit.ly/2QNFrce (accessed 26 November 2019).

Karmaus A, Osborn R & Krishan M (2018) Scientific advances and challenges in safety evaluation of food packaging materials: Workshop proceedings. *Regulatory Toxicology and Pharmacology* **98**: 80–87.

Lebersorger S & Schneider F (2014) Food loss rates at the food retail, influencing factors and reasons as a basis for waste prevention measures. *Waste Management* **34**: 1911–9.

Lee SY, Lee SJ, Choi DS *et al*. (2015) Current topics in active and intelligent food packaging for preservation of fresh foods. *Journal of the Science of Food and Agriculture* **95**: 2799–2810.

Linke M & Geyer M (2013) Condensation dynamics in plastic film packaging of fruit and vegetables. *Journal of Food Engineering* **116**: 144–54.

Lockyer S & Spiro A (2019) Socio-economic inequalities in childhood obesity: Can community level interventions help to reduce the gap? *Nutrition Bulletin* **44**: 381–93.

Mahajan PV, Caleb OJ, Singh Z *et al*. (2014) Postharvest treatments of fresh produce. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences* **372**: 20130309.

Mintel (2019a) *Brits spent £12.3 billion on online groceries in 2018*. Available at: https://www.mintel.com/press-centre/retail-press-centre/brits-spent-12-3-billion-on-online-groceries-in-2018 (accessed 6 November 2019).

Mintel (2019b) *Wonky Veg: culprit behind food waste or scapegoat?* Available at: https://academic.mintel.com/display/972860/?highlight (accessed 26 November 2019).

Narancic T & Connor KE (2019) Plastic waste as a global challenge: are biodegradable plastics the answer to the plastic waste problem? *Microbiology* **165**: 129–37.

van den Oever M, Molenveld K, van der Zee M *et al*. (2017) *Bio-based and biodegradable plastics – Facts and Figures*. Available at: https://library.wur.nl/WebQuery/wurpubs/fulltext/408350 (accessed 6 January 2020).

Parliamentary Office of Science and Technology (2019) *Plastic food packaging waste*. Available at: http://researchbriefings.files.parliament.uk/documents/POST-PN-0605/POST-PN-0605.pdf (accessed 6 November 2019).

Pilz H, Brandt B & Fehringer R (2010) *The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe*. Available at: https://www.plasticseurope.org/application/files/9015/1310/4686/september-2010-the-impact-of-plastic.pdf (accessed 6 January 2020).

Plastics Europe (2019) *Plastics – the Facts 2019*. Available at: https://www.plasticseurope.org/application/files/9715/7129/9584/FINAL_web_version_Plastics_the_facts2019_14102019.pdf (accessed 6 November 2019).

Populus (2017) *The Plastic Backlash*. Available at: http://www.populus.co.uk/insights/2017/07/the-plastic-backlash/ (accessed 6 November 2019).

Porter SD, Reay DS, Bomberg E *et al*. (2018) Avoidable food losses and associated production-phase greenhouse gas emissions arising from application of cosmetic standards to fresh fruit and vegetables in Europe and the UK. *Journal of Cleaner Production* **201**: 869–78.

Priestley S (2016) *Food Waste*. Available at: http://researchbriefings.files.parliament.uk/documents/CBP-7552/CBP-7552.pdf (accessed 6 November 2019).

RECOUP (Recycling of Used Plastics Limited) (2019) *Research Study Into Consumer Plastic Recycling Behaviour*. Available at:

http://www.recoup.org/downloads/info-required?xml:id=696&referrer= (accessed 6 January 2020).

Recycle Now (2019a) *What to do with food waste*. Available at: https://www.recyclenow.com/what-to-do-with/food-waste-0 (accessed 29 November 2019).

Recycle Now (2019b) *Recycling symbols explained*. Available at: https://www.recyclenow.com/recycling-knowledge/packaging-symbols-explained (accessed 25 November 2019).

Recycle Now (2019c) *What to do with: Plastic film & carrier bags*. Available at: https://www.recyclenow.com/what-to-do-with/plastic-film (accessed 25 November 2019).

Retail Gazette (2019) *Lidl joins the war on plastic with reusable fruit & veg bags*. By Sahar Nazir, 8 August 2019. Available at: https://www.retailgazette.co.uk/blog/2019/08/lidl-joins-war-plastic-reusable-fruit-veg-bags/ (accessed 6 November 2019).

Roberts C, Steer T, Maplethorpe N *et al*. (2018) *National Diet and Nutrition Survey: results from years 7 and 8 (combined)*. Available at: https://www.gov.uk/government/statistics/ndns-results-from-years-7-and-8-combined (accessed 6 November 2019).

Rural Payments Agency (2018) *Marketing standards for fresh fruit and vegetables*. Available at: https://www.gov.uk/guidance/comply-with-marketing-standards-for-fresh-fruit-and-vegetables (accessed 6 November 2019).

Russell D (2014) Sustainable (food) packaging – an overview. *Food Additives & Contaminants: Part A* **31**: 396–401.

Schweitzer J, Gionfra S, Pantzar M *et al*. (2018) *Unwrapped - how throwaway plastic is failing to solve Europe's food waste problem (and what we need to do instead)*. Available at: https://www.foeeurope.org/sites/default/files/materials_and_waste/2018/unwrapped_-_throwaway_plastic_failing_to_solve_europes_food_waste_problem.pdf (accessed 6 January 2020).

Shahnawaz M, Sangale MK & Ade AB (2019) Plastic waste disposal and reuse of plastic waste. In: *Bioremediation Technology for Plastic Waste*, (M Shahnawaz, MK Sangale, AB Ade eds), pp. 21–30. Springer Singapore: Singapore.

Simon E (2019). Plastics from a whole planet perspective. Field Actions Science Reports. *The Journal of Field Actions*, (Special Issue 19).

Spierling S, Knüpffer E, Behnsen H *et al*. (2018) Bio-based plastics-a review of environmental, social and economic impact assessments. *Journal of Cleaner Production* **185**: 476–91.

The Conversation (2019) *Food poverty: agony of hunger the norm for many children in the UK*. Available at: https://theconversation.com/food-poverty-agony-of-hunger-the-norm-for-many-children-in-the-uk-116216 (accessed 25 November 2019).

The Council of the European Union (1999) *Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste*. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:31999L0031 (accessed 6 January 2020).

The Environment Food and Rural Affairs Committee (2017) Food waste in England. Available at: https://publications.parliament.uk/pa/cm201617/cmselect/cmenvfru/429/429.pdf (accessed 6 November 2019).

The Grocer (2019b) *Iceland ended loose fresh fruit & veg trial after sales fell 30%*. Available at: https://www.thegrocer.co.uk/iceland/iceland-ended-loose-fresh-fruit-and-veg-trial-after-sales-fell-30/600000.article?utm_source=Daily%20News%20(The%20Grocer)&utm_medium=email&utm_campaign=2019-12-02&c= (accessed 5 December 2019).

The Grocer Vision (2019) *Grocery packaging in a sustainable future*. Available at: https://www.thegrocer.co.uk/whitepapers/grocery-packaging-in-a-sustainable-future/593939.article (accessed 9 January 2020).

The Grocer (2019a) *Morrisons to roll out plastic-free fruit & veg aisles in 60 stores*. Available at: https://www.thegrocer.co.uk/environment/morrisons-to-roll-out-plastic-free-fruit-and-veg-aisles-in-60-stores/593529.article (accessed 6 November 2019).

The Guardian (2018) *The plastic backlash: what's behind our sudden rage – and will it make a difference?* By Stephen Buranyi, 13 November 2018. Available at: https://www.theguardian.com/environment/2018/nov/13/the-plastic-backlash-whats-behind-our-sudden-rage-and-will-it-make-a-difference (accessed 6 November 2019).

The Guardian (2019) *The Blue Planet effect: the plastics revolution is just the start*. By Fiona Gell, 25 March 2019. Available at: https://www.theguardian.com/commentisfree/2019/mar/25/plastics-revolution-marine-life (accessed 7 November 2019).

The Independent (2019a) *MPs call for tax on all single-use plastic packaging*. By Phoebe Weston, 12 September 2019. Available at: https://www.independent.co.uk/environment/single-use-plastic-packaging-tax-mps-pollution-a9101466.html (accessed 6 November 2019).

The Independent (2019b) *Marks & Spencer to launch plastic-free produce aisles and introduce greengrocers*. By Katie O'Malley, 16 January 2019. Available at: https://www.independent.co.uk/marks-and-spencer-plastic-free-greengrocer-packaging-bags-a8731071.html (accessed 6 November 2019).

The Independent (2019c) *Asda trials pioneering coating technology that triples fruit shelf life to help reduce food waste*. By Sarah Young, 10 September 2019. Available at: https://www.independent.co.uk/life-style/food-and-drink/asda-coating-shelf-life-fruit-vegetables-peel-sciences-food-waste-landfill-plastic-packaging-a9098541.html (accessed 6 November 2019).

The Independent (2019d) *Sainsbury's announces plan to halve plastic packaging by 2025*. By Sabrina Barr, 13 September 2019. Available at: https://www.independent.co.uk/life-style/food-and-drink/sainsburys-plastic-packaging-waste-food-environment-milk-bottles-supermarket-a9103521.html (accessed 6 November 2019).

The Independent (2019e) *Tesco to ban brands that use excessive plastic packaging*. By Sarah Young, 22 August 2019. Available at: https://www.independent.co.uk/life-style/tesco-ban-excessive-packaging-plastic-waste-pollution-supermarket-a9074386.html (accessed 6 November 2019).

The Independent (2019f) *Why the answer to saving the environment isn't getting rid of all plastic food packaging*. By Manoj Dora and Eleni Iacovidou, 5 July 2019. Available at: https://www.independent.co.uk/life-style/food-and-drink/plastic-packaging-food-waste-global-warming-carbon-footprint-a8968541.html (accessed 29 November 2019).

Tree Hugger (2019) *ALDI says all packaging will be reusable, recyclable, or compostable by 2025*. By Melissa Breyer, 4 April 2019. Available at: https://www.treehugger.com/corporate-responsibility/aldi-says-all-packaging-including-plastics-will-be-reusable-recyclable-or-compostable-2025.html (accessed 6 November 2019).

Trucost (2016) *Plastics and Sustainability*. Available at: https://www.trucost.com/publication/plastics-and-sustainability/ (accessed 6 January 2020).

United Nations (2015) *Sustainable Development Goals. SDGs, Transforming our world: the 2030*. Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/RES/70/1&Lang=E (accessed 6 November 2019).

United Nations Environment Programme (2015) *Biodegradable Plastics and Marine Litter. Misconceptions, concerns and impacts on marine environments*. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/7468/-Biodegradable_Plastics_and_Marine_Litter_Misconceptions,_concerns_and_impacts_on_marine_environments-2015BiodegradablePlasticsAndMarineLitter.pdf.pdf?sequence=3 (accessed 6 January 2020).

United Nations Environment Programme (2016) *Marine plastic debris and microplastics*. Available at: https://wedocs.unep.org/rest/bitstreams/11700/retrieve (accessed 6 January 2020).

Verghese K, Lewis H, Lockrey S *et al*. (2013) *Packaging in Perspective*. Available at: https://www.readkong.com/page/final-report-the-role-of-packaging-in-minimising-food-4255473 (accessed 6 January 2020).

Which? (2011) *Which? unwraps packaging in supermarkets*. Available at: https://www.which.co.uk/news/2011/04/which-unwraps-packaging-in-supermarkets-250841/ (accessed 6 November 2019).

Which? (2019) *How to recycle in the UK*. Available at: https://www.which.co.uk/reviews/recycling/article/how-to-recycle-in-the-uk (accessed 25 November 2019).

WHO (World Health Organization)/FAO (Food and Agricultural Organization of the United Nations) (2003) *Diet, nutrition and the prevention of chronic diseases: report of a joint WHO/FAO expert consultation* Available at: https://apps.who.int/iris/bitstream/handle/10665/42665/WHO_TRS_916.pdf?sequence=1 (accessed 29 January 2020).

Wilson MD, Stanley RA, Eyles A *et al*. (2019) Innovative processes and technologies for modified atmosphere packaging of fresh and fresh-cut fruits and vegetables. *Critical Reviews in Food Science and Nutrition* **59**: 411–22.

WRAP (Waste & Resources Action Programme) (2008) *Helping Consumers Reduce Fruit and Vegetable Waste: Final Report*. Available at: http://www.wrap.org.uk/sites/files/wrap/WRAP%20RTL044-001%20Final%20report.pdf (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2009) *An introduction to Packaging and Recyclability*. Available at: http://www.wrap.org.uk/sites/files/wrap/Packaging%20and%20Recyclability%20Nov%2009%20PRAG.pdf (accessed 26 November 2019).

WRAP (Waste & Resources Action Programme) (2011) *Recyclability of black plastic packaging*. Available at: http://www.wrap.org.uk/content/recyclability-black-plastic-packaging-2 (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2013a) *Consumer attitudes to food waste and food packaging*. Available at: http://www.wrap.org.uk/sites/files/wrap/Report%20-%20Consumer%20attitudes%20to%20food%20waste%20and%20packaging_0.pdf (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2013b) *Impact of more effective use of the fridge and freezer*. Available at: http://www.wrap.org.uk/content/impact-using-your-fridge-and-freezer-more-effectively (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2017) *Fresh, uncut fruit and vegetable guidance*. Available at: http://wrap.org.uk/sites/files/wrap/Food_labelling_guidance_uncut_fruit_and_vegetable.pdf (accessed 25 November 2019).

WRAP (Waste & Resources Action Programme) (2018a) *Understanding plastic packaging and the language we use to describe it*. Available at: http://www.wrap.org.uk/sites/files/wrap/Understanding%20plastic%20packaging%20FINAL.pdf (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2018b) *Household food waste: restated data for 2007-2015*. Available at: http://www.wrap.org.uk/sites/files/wrap/Household%20food%20waste%20restated%20data%202007-2015.pdf (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2018c) *Evidence Review: Plastic Packaging and Fresh Produce*. Available at: http://www.wrap.org.uk/content/evidence-review-plastic-packaging-and-fresh-produce (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2018d) *Courtauld Commitment 2025 food waste baseline for 2015*. Available at: http://wrap.org.uk/sites/files/wrap/Food_labelling_guidance_uncut_fruit_and_vegetable.pdf (accessed 25 November 2019).

WRAP (Waste & Resources Action Programme) (2018e) *Chill the fridge out*. Available at: https://www.lovefoodhatewaste.com/article/chill-fridge-out (accessed 6 January 2020).

WRAP (Waste & Resources Action Programme) (2018f) *Delivering customer value in fresh fruit and veg*. Available at: https://wrap.org.uk/sites/files/wrap/Setting&MaintainingQualitySpecs_2018_0.pdf (accessed 6 January 2020.

WRAP (Waste & Resources Action Programme) (2019a) *Eliminating problem plastics*. Available at: http://www.wrap.org.uk/content/eliminating-problem-plastics (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2019b) *The UK Plastics Pact members*. Available at: http://www.wrap.org.uk/content/plastics-pact-members (accessed 25 November 2019).

WRAP (Waste & Resources Action Programme) (2019c) *The UK Plastics Pact report*. Available at: https://www.wrap.org.uk/sites/files/wrap/The-UK-Plastics-Pact-report-18-19.pdf (accessed 25 November 2019).

WRAP (Waste & Resources Action Programme) (2019d) *Why take action: the environmental case*. Available at: http://www.wrap.org.uk/content/why-take-action-environmental-case (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2019e) *Waste reduction in the fresh produce sector*. Available at: http://www.wrap.org.uk/content/waste-reduction-fresh-produce-sector (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2019f) *The Courtauld Commitment 2025*. Available at: http://www.wrap.org.uk/food-drink/business-food-waste/courtauld-2025 (accessed 6 November 2019).

WRAP (Waste & Resources Action Programme) (2019g) *Plastics Market Situation Report 2019*. Available at: http://wrap.org.uk/sites/files/wrap/WRAP_Plastics_market_situation_report.pdf (accessed 5 December 2019).

WRAP (Waste & Resources Action Programme) (2019h) *Food waste in primary production in the UK*. Available at: https://www.wrap.org.uk/content/food-waste-primary-production-uk (accessed 29 January 2020).

WRAP (Waste & Resources Action Programme) (2020) *Food surplus and waste reporting template*. Available at: https://www.wrap.org.uk/sites/files/wrap/food-waste-measurement-guidelines_0.pdf (accessed 6 January 2020).

YouGov (2018) *Will scrapping best before dates influence consumer behaviour?* Available at: https://yougov.co.uk/topics/consumer/articles-reports/2018/06/12/will-scrapping-best-dates-influence-consumer-behav (accessed 25 November 2019).

YouGov (2019) *Most Brits support ban on harmful plastic packaging*. Available at: https://yougov.co.uk/topics/consumer/articles-reports/2019/04/19/most-brits-support-ban-harmful-plastic-packaging (accessed 6 November 2019).

Yu Y & Jaenicke EC (2020) Estimating food waste as household production inefficiency. *American Journal of Agricultural Economics*. doi: 10.1111/ajae.12036

Zero Waste Scotland (2019) *Food waste worse than plastic for climate change says Zero Waste Scotland*. Available at: https://www.zerowastescotland.org.uk/press-release/food-waste-worse-plastic-climate-change-says-zero-waste-scotland (accessed 6 November 2019).