VEGETABLES AND FRUITS IN A CIRCULAR ECONOMY: PACKAGING CHALLENGES AND DESIGN OPPORTUNITIES

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ABSTRACT

Packaging of potatoes, vegetables and fruits (PVF) currently deals with the fragile opposition of food waste reduction and packaging resource consumption. In order to understand how designers can rethink this always negative balance and outcome of waste creation, research was done to understand packaging and preservation of PVFs from both a technological and consumer perspective. A mixed research approach was applied, including literature study, expert interviews, packaging analyses, consumer survey and photo study. In sum, we concluded that the main function of packaging is preservation, including both protection from outside influences and conservation in best possible conditions. Optimal preservation should consider each PVF's respiration and transpiration needs, and ethylene sensitivity. Consumers are mostly not aware of correct preservation methods. However, on the other hand, their awareness evokes an important tendency to ban plastics without considering their positive impact on food preservation. In the paper, design opportunities are formulated for new reusable packaging, reducing waste creation and offering higher quality in food preservation and consumer experience.

Keywords: Circular economy, Food waste, Design engineering, Ecodesign, Packaging design

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1 INTRODUCTION

Dilemma between packaging waste and food waste

Based on a study of the Ellen MacArthur foundation (Ellen MacArthur Foundation, 2016), it was found that yearly 311 million tons of plastics are produced, of whom 26% or 78 million tons can be assigned to the packaging industry. Half of this packaging is used in the food industry. This results in a yearly production of 30kg food packaging waste per European resident. This waste results on the one hand in a significant amount of CO2-emissions, caused by production and transportation, adding to global warming and on the other hand in litter impacting our natural and marine ecosystems. (European Parliamentary Research Service, 2019). This effects both our human and environmental health.

It can be questioned why fruits and vegetables are still sold in diverse types of packaging as they already have their natural packaging peel or skin. Nevertheless, the packaging used for potatoes, vegetables and fruits (further abbreviated as PVF) is fulfilling numerous functions (Ellen MacArthur Foundation, 2019) such as the elongation of the freshness (and avoiding food loss), grouping of small PVF, ease and comfort for the user (portion packs and pre-cut PVF), protection against dirt, bacteria, moisture, handling damage, transport impact, etc. Most importantly however, is the elongation of the freshness as it is known that packed vegetables can have an extended shelf life of up to three times longer than unpackaged variants (Schweitzer *et al.*, 2018). According to the UN Food and Agriculture Organization is yearly 1.3 billion tons of food is discarded worldwide (Jenny Gustavsson *et al.*, 2011). For Europe, this results in 88 million tons of food waste of which 17 million is PVF waste (Schweitzer *et al.*, 2018), which is about 35,3 kg per European.

It is noteworthy that food waste not only outweighs packaging waste in terms of mass, but also has a greater environmental impact, as several studies on this topic pointed out (Ellen MacArthur Foundation, 2019). However, the areas of impact are fundamentally different, mainly existing of the usage of energy, water and other resources needed for the harvesting process (Plastics Europe, 2021), which makes it hard to compare the two environmental impacts. Consequently, the dilemma between food waste versus food packaging is a complex issue. Furthermore, besides a technical debate on the impact of these waste streams, there is also a softer side to this topic, existing of the increased consumer environmental awareness (referring to the recent plastic attacks of consumers and the numerous complains of consumers regarding packed cucumbers and other vegetables) and overall consumer behaviour. This changing mindset is also reflected in a growing interest in food that is labeled as 'local', 'bio', 'seasonal', 'healthy' and 'plant-based', although this is not always directly translated into more sustainable behaviour. In addition to the conscious food consumption, another trend is zero waste lifestyle, including both food waste as well as packaging waste. The best-known example is the 'Too good to go' concept (van den Berge *et al.*, 2021). This is in big contrast with another trend that is noticed regarding ‘on -the-go living’, which results in more ready meals, prepared lunches, and smaller portion packs.

Fresh fruit and vegetables value chain

This research is executed in a Flemish research context, where the complex value chain of fresh food products is in general passing the following stakeholders. Although, it is not possible to draw a single value chain that fits every situation, as shown in Figure 1, the main stakeholders of most value chains are farmers, auctions, storage and packaging firms, retail, consumers, and waste management.

The commercial transportation and trade process of fresh food and vegetables is optimised to assure a full cold chain and ideal conservations circumstances until they are bought by the consumer ((Duret *et al.*, 2019). In most cases, to enable full cold chain, refrigerated transport is done to ensure the best possible conditions. Only during its last mile, the products are exposed to uncontrolled conditions (Fancello *et al.*, 2017). A hot car ride or running other errands after shopping (such as going to the bank, library, etc.), causes the fruits and vegetables to be exposed to less-than-ideal conditions for an extended period. Whereas for frozen foods, consumers do bring an insulation bag and make sure they drive straight home, less attention is paid to this for fruits and vegetables (Fillion and Kilcast, 2002). It

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is known that the consumer is currently the weakest point in the optimal food preservation chain. Surprisingly, it is also the less known and most heterogeneous stakeholders.

Figure 1. typical stakeholders and their interactions in the value chain

In each step of the value chain, food is lost, and waste is generated. However, there is a crucial difference between food loss that is the result of reduction of food throughout the value chain (mainly for quality reasons) and food waste that originates after discard by consumers (Fillion and Kilcast, 2002; Jenny Gustavsson *et al.*, 2011). Based on a report of (European Commission, 2018), we noticed that 54% of our produced food is effectively consumed, which means that almost half of it (46%) gets lost along the value chain. Based on the research of Schweitzer et al. (2018), we found that the biggest reason of this loss is due to failed harvesting and over production (together 20%). In addition, another 5,5% gets lost during the processing and 7,5% during the transportation and distribution process. 13% of the food waste is generated at the consumer's place.

Aim of the research

The aim of this research project was to consider this dilemma of food waste versus packaging waste from a designerly perspective. This means that our interest was to understand how the added values of fresh product packaging (mainly focussing on food preservation) can be kept while eliminating the waste that is currently created. In other words, the objective is to understand the existing packaging situation in order to be able to translate it to a more sustainable and circular solution where both packaging waste as well as food waste are avoided or strongly reduced. In here, we consider sustainability and circularity from the perspective of waste reduction and highest value retention, i.e., focussing on reuse rather than on recycling. The designerly perspective includes a more holistic view, looking beyond technical requirements and challenges that are mostly touched by packaging engineers, and involving the whole value chain and especially the consumer to successfully understand the needs for reusable packaging design. The aim of the research is to build upon the technological understanding of the current packaging systems and the insights of the value chain, by adding the level of understanding of the consumers' relation to the purchase and usage of fresh products is needed.

To extend the existing state-of-the-art knowledge, following sub-questions were formulated:
RQ1. What are the existing perceptions of food packaging? Does this differ in relation to the sustainable awareness of the consumer?
RQ2. What is the human-product relationship of the fresh food packaging during usage? What can we learn from peoples' at home storage of PVF?

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2 UNDERSTANDING (FRAGILE) FRUIT AND VEGETABLE NEEDS

Each type of fresh food has distinctive characteristics and needs different treatment to elongate its freshness. After harvesting, the fresh foods are still 'alive' as they respire, perspire, and emit ethylene. To understand the needs for packaging, more insights in these fresh food activities are needed.
Respiration of fresh food (but also of animals and humans) can be described by a chemical reaction in which energy (heat) is transformed by glucose into CO2 and water (Bartz and Brecht, 2002). To realize this, oxygen from the air is used. After harvesting, no new nutrients can be used, which means that the stored glucose will be used as food reserve. The fresh food keeps 'alive' until all glucose is consumed. At that moment, decay starts. Respiration speed is highly variable per kind of food and evolves over time. In Table 1, an overview is given of a selection of fresh fruit products based on their respiration speed. Lower respiration speed elongates the shelf-life of the fresh food. Control of respiration speed is a known way to extend the freshness of fruit and vegetables (Hardenburg *et al.*, 1990). This speed can be slowed down by lower temperature, lower oxygen concentration, adjusted CO2 concentration (some products need lower concentration, others prefer higher for longer shelf life), avoiding internal stress or damage (Péneau, 2006). Too low temperature and absence of oxygen result in a respiration stop, which is also undesirable as it triggers fermentation and decay. Lastly, the respiration is also depending on the phase of ripening.

Table 1. Respiration speed (in mg CO2 kg-1 hour-1 (at 5°C).

Respiration speed	Fresh fruit products
Very slow (< 5)	nuts, dried fruit
Slow (5 - 10)	apples, citrus fruits, grapes, onions, potatoes, garlic
Average (10 - 20)	banana, cherry, pear, fig, lettuce, tomato, apricot, peach, nectarine, plum, cabbage, carrots
Fast (20 - 40)	strawberry, cauliflower, avocado, raspberry, black currant
Very fast (40 - 60)	artichoke, sprouts, spring onions
Extreme fast (> 60)	broccoli, mushrooms, spinach, corn, asparagus, peas

Transpiration can be described by the gradual loss of moisture after harvesting, caused by the evaporation of the fluids from the skin (Becker and BA Fricke, 1996). A high loss of moisture leads to shrivelled fruit and vegetables and creates changes in taste. This loss can be slowed down by lowering the temperature and increasing the humidity (which increases the air water vapor pressure towards the level inside the fruit). Non-(moisture)-permeable foils and other peel "coatings" can also reduce transpiration. This is the main reason why cucumbers - that have a very high transpiration speed - are often packed with a shirk film. This film can elongate the lifetime up to 3 times longer (Barlow and Morgan, 2013). in addition to external factors, the transpiration speed is also influenced by specific fruit-related characteristics: surface structure, permeability of the skin, damages of the skin.

Lastly, ethylene production and sensitivity also influence the ripening and so shelf life. Ethylene is essential to achieve a sweet taste and soft texture (Mal, 2016). Two types of fresh fruits can be distinguished (Hardenburg *et al.*, 1990; Mal, 2016): (i) climacteric fruits, such as bananas, pears, or avocados, start to ripen after harvesting and have a middle to high ethylene sensitivity (by both own ethylene production as well as from other fruits). Consequently, the ripening process can be speed up by placing the fruits next to other types that produce lots of ethylene. Ripening can also be slowed down by means of ethylene absorbing pads. (ii) non-climacteric fruits do not ripen further after harvesting, are less sensitive to ethylene and produce also less ethylene. Transport of this type of fruits is much more delicate due to the ripeness and sensitivity; Examples are citrus fruits, grapes, berries such as strawberries and raspberries.

Combining these three factors in packaging is essential to elongate the shelf life of product. This means that optimal packaging should include control of temperature, relative humidity, oxygen, and carbon dioxide concentration (Rojas-Graü *et al.*, 2009). In addition, also light, orientation, concentration of other gasses and bacteriological burden can have influence on the shelf life of

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specific products. Nevertheless, this ideal combination is different per type of fresh fruit and should be applied accordingly.

Table 2. Overview of large categories with comparable preservation conditions (based upon the most important variables of temperature and humidity)

	'Low' humidity (85-95%)	High humidity (90-98%)
Cold (0-2°C)	Strawberry, Apricot, Apple, Avocado, Blueberry, Blackberry, Grape, Raspberry, Pomegranate, Cherry, Kiwi, Coconut, Melon, Nectarine, Pear, Peach, Plum, fruit, Fig, Black currant	Endive, Artichoke, Asparagus, Beetroot, Cauliflower, Kale, Broccoli, Mushroom, Pea, Sprouts, Cabbage, Corn, Parsnip, Leek, Turnip, Rhubarb, Radish, Arugula, Celery, Lettuce, Chard, Spinach, Brussels sprouts, Fennel, Cut vegetables, succory, carrot
Cool (7-10°C)	Pineapple, Eggplant, Beans, Chili Pepper, Lemon, Butternut Squash, Cucumber, Lime, Mandarin, Mango, Paprika, Passion Fruit, Grapefruit, Orange, Cranberry	
Warm (13-18°C)	Potato, Banana, Ginger, Garlic, Melon, Pumpkin, Tomato, Onion, Watermelon, Sweet potato	

3 MATERIAL AND METHODS

To support the optimal reduction of both food waste and packaging waste from a designerly perspective, research must be executed to extend the value chain and technological insights on packaging with a consumer perspective as well as. Within this research, the relation between the consumer and their fresh foods were studied in depth. To support this process, the three different phases were studied in a different manner to ideally understand the process: the first phase, where consumer and fresh food meet is the pre-purchase phase, was investigated through a survey. Next, a photo study was used to get insights from the situation at the consumers' homes regarding preservation, preparation, consumption, and discard of fresh food.

Consumer research

The consumer research was executed by means of an online survey on Oct-Nov 2019. The survey of 39 questions was completed by n=440 respondents. These questions were focussing on the overall consumer behaviour regarding fresh food and its packaging, and were ranging from purchase, to transportation, to preservation, preparation, consumption, and finally discard as waste. In addition, the environmental consciousness was questioned using the NEP scale (Dunlap *et al.*, 2000). The survey was set up in Dutch and survey was distributed through snowball sampling using various social media and personal networks in Flanders. The aim of the survey was to determine specific frustrations, pains, … in the mentioned phases. Also, investigation was done to discover any relation between the consumer behaviour and food waste.

To get more insight in the demographics: 349 women (79.3%) and 91 men (20.7%) completed the survey. Different arguments can cause this division: more women were approached through the online survey, but it could also be that women are more willing to fill in online surveys (Mulder and Bruijne, 2019) or in majority women were the responsible for grocery shopping in the reached households (it was asked to fill in the survey if you were responsible for the groceries (van Droogenbroeck and van Hove, 2020). The distribution amongst the age categories is equal and comparable to the literature insights, with a relatively large group of 18–24-year-olds, 25–34-year-olds, and 45–54-year-olds.

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Photo study

In addition, focus was put on the actual fresh food handlings at home, i.e., conservation/preservation, preparation, consumption, and discard. This was done by means of a photo study method. Participants were recruited during the former survey by allowing them to indicate if they would like to further participate in the research. These participants could leave their mobile phone number and were contacted through WhatsApp with the question to take pictures of (i) where they keep their food at home, (ii) how they prepared the food, (iii) how they discard the waste. The participants were asked to send back the pictures accompanied with a small text of additional explanation of what could be seen on the picture. In the study, 28 consumers participated of whom 20 complete photo studies were received. The other 8 participants were excluded from the results due to the limited amount of data that was send. The photos were analysed semantically to understand the underlying typical behaviour regarding fresh food actions.

4 RESULTS

Understanding users' expectations and perception regarding PVF packaging

Descriptively, based on the survey, we could distinguish findings regarding purchase, preservation, consumption, packaging waste and food loss. Regarding the purchase phase, 45,7% of the respondents indicate to buy fresh fruits on a weekly basis, 43% buys fresh fruit 2-3 times a week and 8,6% indicates to buy fresh fruits daily. 84,4% of the respondents buys fruits and vegetables in the supermarket, 7,7% in a fruit and vegetable shop and 4,1% on a local market. The choice of supermarket is determined by (i) distance, and (ii) prices. Respondents who do not buy their fruit and vegetables in a supermarket do this for quality and freshness reasons. Based on the survey, the most important reason to buy prepacked food is convenience (both pre-cut as well as portion size) and because it is not offered without packaging. 227 respondents indicate that they are not happy with the current packaging offer. Most remarks are related to the plastic-tiredness and the fact that no package-free alternative is available. It was also mentioned that people prefer to buy in a local fruit and vegetable store, at a farmer's place or at a local market, but are hindered due to timing issues. Therefore, it is preferred to do all groceries at the same place. Respondents also indicate their willingness to buy more seasonal and local products but indicate not to be informed to make this selection in a supermarket.

Regarding preservation, 50,2% immediately puts their packaged fruits and vegetables in their storage place. 36,7% first removes the packaging and 11,1% does only buy packaging free, so does not have this issue. Fresh vegetables are mostly stored in a fridge (87,7%). Other indicated storage places are at room temperature, in a garage or cellar. Potatoes, onions, and garlic are stored at room temperature by 58,6% of respondents, 19% in a garage and 13,8% in a cellar. Fruit is stored by 45% in a fridge, 44,8% on room temperature in the kitchen and for the other respondents it depends on the kind of fruit. On average, the respondents indicate to eat daily 2.69 portions of vegetables (potatoes not included) and 1,77 pieces of fruit. The share of vegetables in a self-prepared meal is for 37,7% of the respondents 50%. 33,3% of respondents indicate that only 1/3 and for 17,6% it is 2/3 of their meal.

Regarding the packaging waste, almost half of the respondents discard the packaging waste in the rest bin, 30,1% uses the plastic fraction in the PMD bag. The remaining respondents indicate not to have packaging waste or to bring it to the recycling park. Fruit and vegetable waste is discarded by 42,6% in the organic fraction, 23,5% composts it at home and 23,3% discard through the rest bin (which prevents optimal recovery of resources). In the survey, it also was asked how quickly people are inclined to throw away food. Almost half (47,5%) indicates that food was only thrown away if it is really decayed (rotten, mouldy). Another 47% does it already if it lost its freshness (overripe, coloured, very soft) and only a minority of 5,2% already discard it as soon as it looks less fresh (limp, slightly overripe). On average 2.15 pieces of fruits and vegetables were thrown away. Respondents indicate that this number could be reduces by increasing the freshness. Also optimized portioning and increased information on optimal preservation would reduce the food loss.

The youngest category of respondents has the largest percentage of "very environmentally conscious" consumers (using the NEP scale). In the oldest category, this is just reversed, they have the largest percentage of "very non -environmentally conscious" concrete people. However, no connections could

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be demonstrated between purchasing behaviour and environmental consciousness, or between purchasing and preservation behaviour on the one hand and food waste on the other.

Understanding the actual preservation behaviour at home

The photos offered an interesting insight in people's behaviour regarding food storage and preservation, as is shown in Figure 2. Consumers take steps themselves to keep their fresh products as long as possible. For example, special cans for lettuce are used, some vegetables are left in their packaging, vegetables are stored cool and dark, and leftovers are eaten the day after for lunch or dinner. Fruit is usually stored together at room temperature, in fruit bowls or right on the counter. In addition, it was prominent that most vegetables are put in the vegetable drawers of the refrigerator. Furthermore, most people incorrectly use these drawers. For example, diverse types of vegetable and fruit that should not be stored together are placed in the same container. Other products (such as drinks, sauces, cheese, etc.) are also stored in these drawers. The refrigerators are very often stuffed, which reduces the respiration possibility of the fresh products. In addition, it leads to loss of overview what can be the basis for food waste.

Figure 2. selection of photos from the photo study, showing (left to right) a crammed refrigerator, improper use of vegetable drawer, and mixed fruit kept together on the counter in the kitchen

The most important conclusion from these "Photo Study" is that only few participants know how to use the vegetable drawers in their fridge as optimally as possible. There seems to be little knowledge about the correct storage and needs of each type of PVF. This is also confirmed by literature, e.g., a study by Bosch (2010) shows that 55% of the Americans investigated do not know how to use the "Crisper Drawers" correctly. These are the plastic fruit and vegetable drawers underneath most contemporary refrigerators, are specially designed to be able to store fresh fruit and vegetables longer (for example, the temperature is the lowest and the compartmentalization makes it possible to separate species). They found that 42% would keep fruit and vegetables together in the same compartment, while vegetables actually require a moister environment than fruit. In many of these compartments you have the option to open a ventilation mat. Opening provides more ventilation and therefore a lower air humidity (Bernot, 2018). The closing ensures that the humidity (created by the vegetables that emit moisture themselves) are stored. This is especially necessary with leaf vegetables and vegetables and fruit with thin skin. In addition to regulating humidity, an important function of the two separate drawers is also the separation of strong ethylene-producing fruits (accelerates the maturation) of other pieces that you do not want to mature quickly (Bernot, 2018). With the strong ethylene-producing fruits, the ventilation can best be opened so that the gas can be bothered.

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5 DISCUSSION AND CONCLUSIONS

Although most food loss occurs during the farming/ growing process, the share/part of the consumer caused by incorrect behaviour is not to be overlooked (desire for variation, overconsumption, non-optimal preservation). In general, food loss prevention at the upstream part of the value chain is more manageable as technological interventions can create optimised conditions tailored to specific food preservation needs. We found that preservation at the other stakeholders' places is optimised, (i.e., auctions, transportation, storage, retail), but they lose lack of control on these optimal conditions as soon as the product leaves the store.

This paper aimed to gain insights into the complexity of designing reusable packaging for fresh food products. A value chain perspective is needed to capture all necessary design requirements to create a viable, feasible, desirable, and sustainable reusable packaging. Literature has the tendence to focus on technical requirements for food packaging to avoid food and packaging waste, while the consumer perspective and related consumer behaviour can have an equally substantial impact. By involving the user and context as well, a more systemically addressed packaging design can be created, resulting in a more successful implementation and outcome when trying to minimise impact.

In sum, from the user research, we can conclude that most consumers are not aware of correct preservation methods and tend to overload their fridges' fruit and vegetable drawers. On the other hand, consumer awareness evokes an important sensitivity for single-use plastics and the tendency to ban plastics without considering their positive impact on food preservation. Simultaneously, the research shows that consumers often buy packaged fruit and vegetables because of the ease or lack of alternatives. As no packaging cannot be achieved for all fruits and vegetables, a specific reusable packaging is needed that combines consumers' sustainable awareness, their lack of preservation knowledge and ideal respiration and ethylene protection to extend the shelf life. Combining this optimal preservation with sustainable packaging offers interesting design opportunities to tackle both food and packaging waste.

Design solutions are needed:

- To optimize the last mile' phase of fresh fruit and vegetables from the supermarket to home. It is at that moment that the products first enter a less optimal environment, often even for a few hours (if consumers do not immediately go home after the supermarket).
- To protect those fruits and vegetables that are too fragile to be sold without packaging. For example, berries or mushrooms. Here, only prefilled reusable packaging can be used as enabling consumers to fill their own packaging would result in a high food waste creation during this activity due to fruit damages while spooning.
- Reusable packaging solutions are also needed for the popular meal kits, multi-fruit packs, packed cut fruit and vegetables, snack berries and vegetables and pre-made salads, which react on consumers' needs for efficiency and comfort, but which also have an even lower shelf life and cannot be sold without packaging.
- To cope with consumers' lack of insights on optimal preservation. Design could enable consumers to regain this experience and optimise the different humidity and temperature needs at home for teach type of PVF.
- Reusable packaging has the potential to increase the qualitative impression of the packaging and so of its content and could improve a positive experience and increase the unconscious handle with care approach and restore the value of the PVFs.

Future research is needed to understand the economic feasibility of reusable packaging and the effect of legal nudges towards optimised PVF packaging.

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