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Packaging Weight, Filling Ratio and Filling Efficiency of Yogurt and Relevant Packagings Depending on Commercial Packaging Design, Material, Packaging Type and Filling Quantity

Dejan Kostic [1,†], Udo Hoffmann [1], Siegfried Fürtauer [2], Tanja Fell [2], Cihat Yilmaz [1], Dirk Burth [1] and Sven Sängerlaub [1,2,*,†]

[1] Department of Building Services Engineering, Paper and Packaging Technology and Print and Media Technology, Munich University of Applied Sciences HM, Lothstraße 38, 80335 Munich, Germany
[2] Fraunhofer Institute for Process Engineering and Packaging IVV, Giggenhauser Straße 35, 85354 Freising, Germany
* Correspondence: sven.saengerlaub@hm.edu
† These authors contributed equally to this work.

Abstract: Yogurt is a diverse dairy product category. It is available in different packaging designs made of different materials. To identify potential for improvement for these packagings, a better understanding about used materials and packaging efficiencies is necessary. For this study, 150 dairy products and some yogurt relevant desserts were bought from various supermarkets, street markets and discounters in the Munich region (Germany) in spring 2022. Commercial types of packaging are cups, buckets, pouches, bottles, glass packagings and bricks. The filling ratio of most packagings is above 70%, the rest of the volume is headspace. Poly(1-methylethylene) (PP) and poly(1-phenylethene) (PS) dominate as main materials for the different types of packaging. For bottle packagings, poly(ethylene terephthalate) (PET) and polyethene high-density (PE-HD) are used. Interestingly, poly(lactic acid) (PLA) is not found. Closures (caps) are responsible for 5 to 30% of the total packaging weight. Typical filling efficiencies are 20 to 40 g food product packaged in one gram of packaging material. For glass packagings, the values are 1.5 to 2 g food product packaged in one gram of packaging material. Therefore, plastic packaging results in an at least ten-times lower packaging use per unit of food, at single use packagings. With increasing product weights, we observe a tendency towards higher packaging efficiencies. By using paper/carton wrapping at cups, plastic use is reduced for the whole packaging.

Keywords: yoghurt; dairy packaging; dairy products; filling volume; packaging weight-ratio; cups; thermoforming; injection moulding; plastics; glass; material efficiency

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1. Introduction

1.1. Relevance of Packaging for the Environment

Food packaging is mandatory to enable handling, transport and storage of food. Food packagings inform consumers about necessary information (food type, ingredients, nutritional value, shelf-life etc.). They fulfil marketing needs, and furthermore, packaging prevents food from contamination and spoilage, thereby saving resources during the whole life cycle, particularly resources used for food production [1–3].

Apparently, many food packaging materials exhibit several ecological drawbacks, e.g., hindered effective separation and recycling, and non-biodegradability when leaked into the environment. As a countermeasure, new packaging materials such as poly(lactic acid) (PLA), other biobased polymers and composites have been developed [4–7]. PLA is biomass-derived and it is associated with greenhouse gas (GHG) emission savings [8]. However, on a worldwide scale, packaging material use is more than ever seen with concern or even critical [9,10], since packagings consume for example 40% of annual plastic production. Therefore, different regulations and policies have been initiated [11–14]. Programs such as the 'Plastic Strategy for Europe' [15] or the 'German Packaging Waste Law' [16] assign core responsibilities to food packaging manufacturers. To evaluate the environmental impact of food packaging, tools such as life-cycle assessment (LCA) have been developed [6,17–24].

As not much data are available in the scientific literature about efficiencies and types of packaging material used for certain food groups, this work will provide some valuable insights. It will support decision-makers in their choice for the most appropriate packaging.

1.2. Packaging Consumption in Germany

This study focuses on products available in Germany. Packaging material use in Germany was 227.5 kg/(year person) in 2018 and 2019 [25]. In Germany, in 2018 8.3 Mio. t paper and board, 3.4 Mio. t wood, 3.2 Mio. t plastic, 2.9 Mio. t glass, 0.51 Mio t. tinplate, 0.35 thin sheet and steel, 0.13 Mio. t aluminium and 0.03 Mio. t others such as cork, rubber, ceramic and textile were used [26,27]. The overall packaging use in Germany in 2019 was 18.91 Mio. t [28]. Approximately half of it was used by private consumers with an amount of 8.59 Mio. t [28].

1.3. Materials and Packaging Production Process for Yogurt Packaging

Yogurt is available on the market in different categories, diversifications and varieties such as dessert, drink-yogurt, Skyr, cream cheese and curd [29–34]. These address different consumer segments, such as the 'the green packaging segment', the 'price sensitive', 'brand loyal[s]' and 'convenience seeking' [35]. It is typically cold stored at temperatures around 4–5 °C [33,34]. It is eaten by spoon, or the viscosity is so low that it is drunk directly, e.g., as drink-yogurt. Some drink yogurt specialties contain menthol as aroma substance that migrates into the PET-packaging material (flavour-scalping) [36,37]. In Germany 673.800 t yogurt were produced in 2020 [38]. Yogurt is sold in different types of packaging: Cups, jars, bottles, pouches and in bigger quantities in canisters [32,39]. Often plastic packaging is used because 'people much appreciate and routinely use plastic' [40].

Cups are made of poly(1-methylethylene) (PP) [41] known as 'polypropylene'; poly(1-phenylethene) (PS) [41,42] known as polystyrene; poly(ethylene terephthalate) (PET) and PLA [43–46] by injection moulding (PP) [47–49] or thermoforming (PP, PS, PET, PLA) [49–58]. Thermoforming is often supported by pre-blowing and pre-suction [59]. A part of the PET is recycled (rPET). Canisters are made by injection moulding. Cups are closed with aluminium foil, paper laminates or a plastic film. Some cups are wrapped by a paper or carton sleeve. Plastics often contain additives such as pigments [60]. It is worth to mention that PS is discussed in the literature due to possible migration of styrene into food products [42,61–66] besides other substances that can migrate [66].

Jars and other glass packagings are made of glass with a metal closure containing a plastic sealing compound. Glass jars are either for single-use or multi-use.

Bottles are made by two processes. When injection-blow-moulding is applied, first a preform is produced by injection moulding and then blown [49,67]. For this process, PET [68–70], rPET [71–74] or PS is used. PET-bottles for oxygen sensitive beverages can contain oxygen scavengers [75–77]. However, their use is not obvious by visual inspection of PET-bottles. The other process is extrusion blow moulding [49,78]. The main polymer used there is polyethene high-density (PE-HD) [79,80]. Bottles are routinely wrapped by shrink sleeves made of oriented plastic film.

Pouches contain a spout. The pouch itself is a laminate made by co-extrusion and lamination. The spout is made by injection moulding.

Bricks are made of beverage carton. Such packagings and materials are known from beverage packagings and from milk packagings. These are multilayer materials made of carton that is extrusion coated with polymer layers.

Packagings are decorated by direct printing, labelling with printed paper or plastic labels or in-mould labels [81]. For in-mould labelling, the label is inserted into the mould before forming and it fuses with the plastic cup [82]. Paper/carton and shrink sleeves for the cups are printed.

In Figure 1, typical packagings for yogurt are shown. A food bundle of yogurt cups is also depicted. These are preferred by some consumers and provide advantages in marketing [83,84].

Figure 1. From left to right: cup directly printed, cup with paper label, cup with printed carton sleeve, cup with shrink sleeve, cup with sleeve.

1.4. Packaging Efficiencies

It is generally expected that smaller packagings have a poorer packaging efficiency (ratio of the packaged food weight/packaging weight) than larger packagings [85]. These relationships have scarcely been investigated systematically. One described finding was that an increasing bottle size correlates with a better packaging efficiency [86]. However, at further increasing bottle sizes, the packaging efficiency starts to decrease. Another finding was that packaging efficiencies improved in past decades [87].

1.5. Intention of This Study and Hypotheses

Packaging materials are highly discussed in public for their environmental impact. However, not much data are published about packaging efficiencies that can be found at real packagings on the market. Such information is of value for decisions how to choose certain packaging materials, different types of packaging and sizes, for better sustainability. Lower amounts of used packaging material lead to a better scoring concerning sustainability of the packaging material [88].

We chose yogurt for our study because many different products in different types of packaging and materials are found on the market.

Our hypotheses for this study were: (1) With increasing filling quantity, the packaging efficiency improves. (2) Glass packagings are more heavy than plastic packagings at the same filling quantity. (3) Cups made by injection moulding are less efficient compared to cups made by thermoforming. Thermoforming allows thinner materials and therefore more efficient packaging materials. (4) Cups made by thermoforming with fibre-based sleeves require less plastic compared to pure plastic cups. The paper/carton sleeves stabilise the plastic cups. Therefore, these can be made thinner.

2. Materials and Methods

2.1. Sample Acquisition

Samples were bought in January 2022 in the Munich area from German supermarkets (ALDI, LIDL, EDEKA, Netto, Kaufland, Neckarsulm, Germany), food chains (Yormas, Hofpfisterei, Germany) and small bakeries for yogurt to be eaten as snack. Few cups were bought in 2021, two in 2020 and one in 2018. In addition, some dessert and yogurt muesli food preparations as well as a soya-drink and a coconut-drink were included because these foods are packaged in yogurt relevant packagings.

2.2. Sample Processing

The packagings were fully emptied and cleaned with water and then dried overnight at 23 °C and circa 50% RH. Product information was noted from the receipt, ingredient list and before-date printing: product name, brand, shop, product weight, costs, best-before-date and date of buying.

2.3. Packaging Classification

The products were classified for the analysis and information was taken as follows.

- Category: yogurt, dessert, drink yogurt, Skyr, cream cheese, curd, drink, yogurt alternative such as soya-drink or coconut-drink;
- Packaging: Cup, bottle, glass jar and other glass packaging, bucket, pouch, brick made of beverage carton;
- Materials: PP, PS, PE-HD, PET, rPET, paper laminate, glass single-use and multi-use
- Lid material: aluminium, PP, PET, metal, paper laminate, PE-HD;
- Decoration and decoration material: direct printing, plastic label, paper label, shrink sleeve, carton sleeve, secondary packaging;
- Label category: in-mould label, carton-plastic combination;
- Secondary packaging material: carton, plastic, plastic and aluminium lid, lid made of PET- or PP-film;
- Secondary packaging: sleeve, lid, top-up, separate cup (e.g., for honey);
- Production method: thermoforming, injection moulding, film extrusion, injection-blow-moulding, extrusion-blow moulding, extrusion coating, lamination, glass forming;
- Shape: round, cornered, pouch;
- Optical properties: white, transparent, brown, multi-colour;
- Board type: FSC-mix, primary fibre, pulp, secondary fibre;
- Marketing aspects: health claims (‘Actimel’), surrogate product, Ayran, fruit yogurt for children, Greek yogurt, yogurt with corner, yogurt with foot-segment at packaging (‘Zott’), yogurt with top-up, kefir, ‘Müllermilch’, curd, ‘Quetschies’ (yogurt in pouch), Skyr, street-food to go, drink yogurt;
- Disposal note: all disposal notes, post-consumer recycling system, green dot, carton sleeve to be separated from cup, deposit information, no information about disposal.

Following information was not found on all packagings, but taken if available.

- Company of cup production;
- Recycling advice, remarks, certificates;
- Printing techniques;
- Light transmission (visual evaluation);
- Pressure resistance (haptically evaluation).

2.4. Measuring of Weights

The measurements were carried out with an analytical balance (Sartorius, Germany, model BP 221 S, with a weighing range of 220 g and accuracy of 0.1 mg). For heavy glasses and the determination of the rim full volume (packaging totally filled to the edge), another balance was used (precision balance from Kern & Sohn GmbH, Germany, model KERN 572, with a weighing range of 8100 g and accuracy of 0.1 g).

Measured properties were:

- Cup weight without label;
- Cup weight with fixed label (with IML or paper label);
- Lid weight, label weight;
- Outer packaging weight; and
- The maximum rim full volume of the container.

At bundles, the total packaging weight per packaging unit was calculated by summation of the total packaging weights for the entire product and division by the number of cups or number of packaging units.

To determine the rim full volume, the empty packaging was placed on the scale and the scale was zeroed. Then tap water was filled in, using a measuring beaker until the packaging was filled to the top rim (maximum filling amount before overflow) and the measured weight of the water was noted. The deviation that occurred due to surface tension during filling was marginal and was neglected if, after visual inspection, the measurement was legitimized by looking at it from the side and the water surface is flush with the beaker. The used tap water with a temperature of around 20 °C was assumed to have a density of 1 g/cm^3. Therefore, the measured weight was equal to the volume and the rim full volume can be expressed in the units mL or in g. Consequently, the ratio of rim full volume or weight/package weight has the unit mL/g or g/g. The total volume of the food product at bundles was the rim full volume of a unit, multiplied with the total number of units.

The most important parameter of our evaluation is the ratio of the rim full volume or weight (maximum filling volume up to the edge of the packaging) in mL or g to the packaging weight in g. The ratio is the same for a packaging unit and the total food product. The ratio of the food weight to packaging weight was not always meaningful due to the different densities of the food products.

The plastic type of cups, whose plastic type was not declared on the cup base or outer packaging, can be determined by means of density differences in the float/sink method and distinguished between polyolefins/PP and PS/PET [89]. The density of PP is between 0.90 and 0.91 [90,91], PS 1.05, PLA 1.24 g/cm^3 [92], and PET 1.37 g/cm^3 [93]. An additional method is infrared identification and separation [94]. However, these methods of characterization were not applied in this study.

3. Results and Discussion

3.1. Product Categories, Packaging Means, Bundles, Filling Weight Distributions, Filling Ratios, Materials and Processes for Packaging Production

3.1.1. Product Categories

In Figure 2 the analysed product categories are shown. Information was taken from the labels. Every product category represents one type of packaging. 58% of all samples were (spoonable) yogurt, 10% drink yogurt; 18% Skyr, fresh cheese, curd, yogurt surrogates (plant yogurt) and drinks (e.g., flavoured milk) and 14% dessert such as ‘Creme Brulee’, ‘Mango Passione’ dessert and similar. Drinks and desserts were included in this study when these products were packaged in packaging means that could be used also for yogurt. Some of the desserts were packaged in glass packagings, which allowed correlations with such kind of packagings.

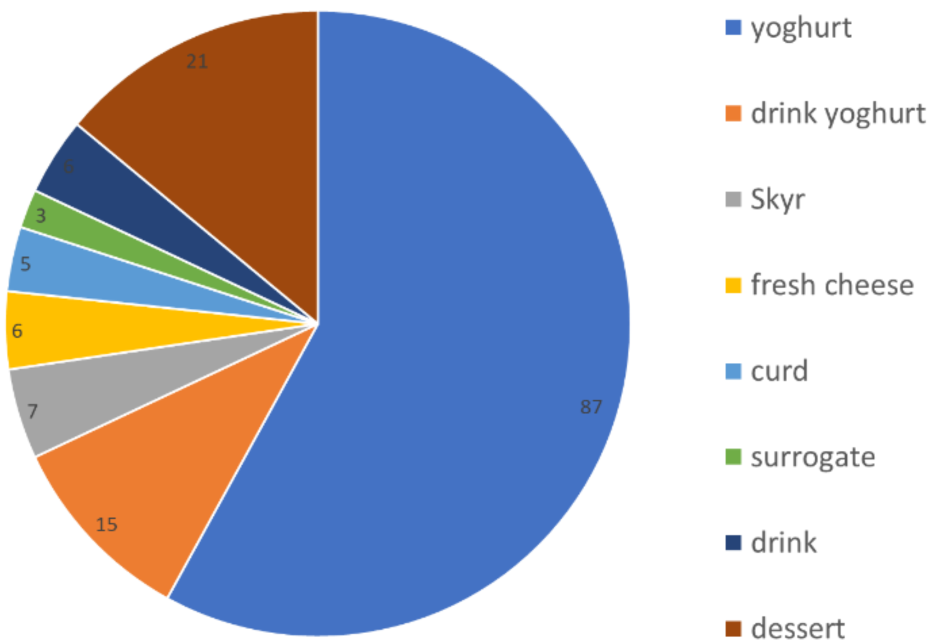


Figure 2. Analysed product categories; numbers: number of samples, n = 150.

3.1.2. Packaging Means

In Figure 3 the amount of packagings in each packaging mean classification are shown. The depicted packagings are all different. However, in shops the same packaging mean can be used for different flavours of yogurt.

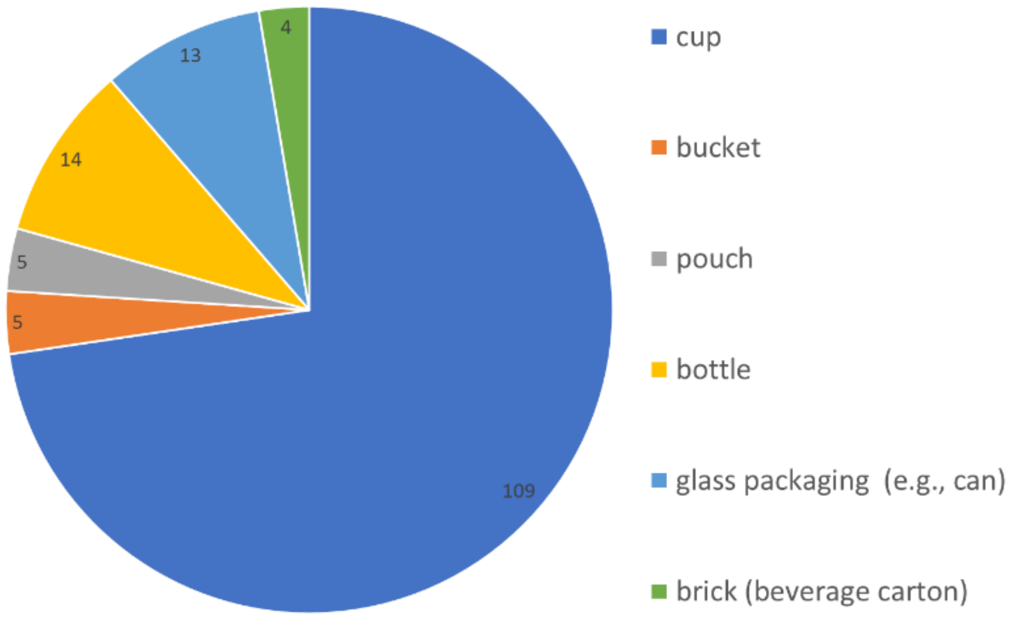


Figure 3. Analysed packaging mean categories; numbers: number of samples, $n = 150$.

The most often found packaging means were cups. The reason is the established production method thermoforming (see Section 3.1.6) and existing and well-developed (aseptic) filling lines at manufacturers. It is worth to mention that the number of packagings in each category does not represent how much volume is sold on the market. Several packagings are positioned in niche markets with low selling quantities. Surprising was that cups made of deep drawn or pulled fibre material or coated fibre material were not found, even though such materials have been subject of intensive research [95–117]. Only one packaging was found (not depicted) that consisted of formed, coated and sealed paper. (However, it was not deep drawn or pulled fibre material.)

Interestingly, only a small part of the analysed packagings were made of glass ($n = 13$), despite its advantages. Glass packagings are perceived as more pleasant and sustainable by consumers [118]. Saint-Eve et al. found better aroma preservation of flavoured stirred yogurts in glass packaging, compared to PS- and PP-based packaging [119], explained by higher barrier in case of glass packagings. Restricted use of glass is probably influenced by higher weight, higher packaging price, higher logistic costs due to packaging weight and volume (often not stackable) and safety concerns (glass breakage) at production sites.

Pictures of packaging means are shown in the Supplementary Materials Figure S1.

3.1.3. Bundles

In Figure 4, the amount of single packaging units per bundle is shown. Most packagings were sold as single packaging (124), 17 in bundles of 4 smaller units and the rest in bundles up to 2, 6, 8 and 12 smaller units. Bundles often require a secondary packaging. Bundles are perceived differently by consumers compared to single packagings [83], which is relevant for marketing [120].

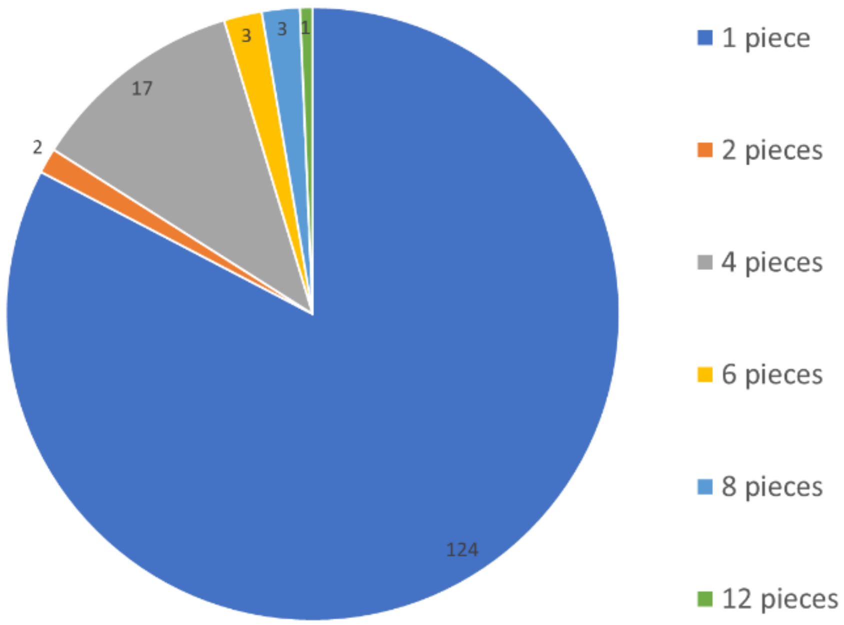


Figure 4. Amount of single packagings (1) and single packagings in bundles of 2, 4, 6, 8 and 12 smaller units; numbers: number of samples, n = 150.

3.1.4. Filling Weight Distribution

In Table 1 the filling weights in g product per unit primary packaging are shown. The filling weights are widely distributed between 50 g and 1000 g. Filling weights of 150 g occur most often, followed by 500 g and 200 g for single packagings. For buckets, only one filling weight (1000 g) was observed.

3.1.5. Filling Ratio

A packaging is considered as a 'deceptive packaging' (in German 'Mogelpackung') when it contains more than 30 vol.-% of headspace [121,122]. In Figure 5 the filling ratio is shown. It is calculated from the product weight in the packaging and the rim full weight. For simplification, the density of the food was assumed as 1 g/cm^3.

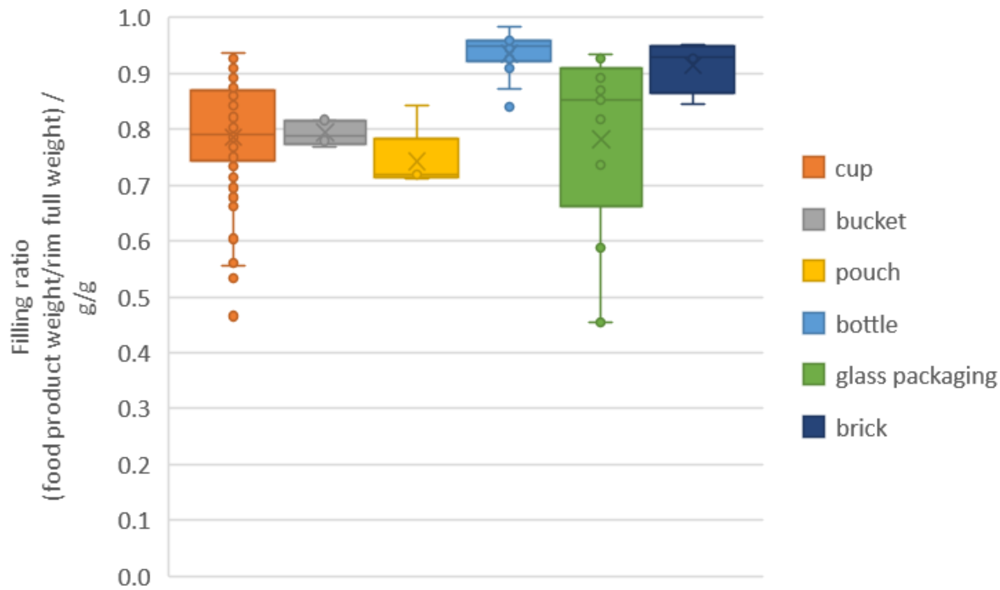


Figure 5. Filling ratios of different packaging categories, simplified density of product 1 g/cm^3, n = 150.

Table 1. Filling weight distribution of different packaging means; number in field: amount of packagings.

Filling Weight/g	Cup	Bucket	Pouch	Bottle	Glass Packaging	Brick	∑
50	2						2
60	1						1
65				1			1
70			1				1
75	1						1
80			1				1
90			1		1		2
100	5		1	1	4		11
115	4						4
120	1						1
125	3			2			5
130	1						1
150	29				1		30
160	2						2
175	5						5
180	2						2
200	14		1				15
230	1						1
250	8			1	2		11
255	1						1
300	3						3
330				1			1
375					1		1
400	8					1	9
423				1			1
450	1				1		2
500	16			7	3	2	28
1000	1	5				1	7

Values for pouches and bricks underestimate the filling ratio. These packagings are flexible and buckle when filled with water to determine the rim full weight. Therefore, real filling ratios might have higher values there when filled with real products.

Low filling ratios of cups are associated to foamed products. At foamed products such as mousse and whipped cream the density is lower than 1 g/cm^3.

Cups, buckets, bottles and glass packagings always have a head space volume. Therefore, filling ratios are always below one. Considering the previous mentioned restrictions for the interpretation (plastic) bottles have the best filling ratio with a mean value of 0.95, followed by bricks with a measured mean value of 0.93. For cups and glass packagings the filling ratios vary most, which is attributed to the variations in the packaging design. Flat packagings have a worse filling ratio. Overall, the filling ratio was above 70 wt.-% or vol.-% in almost all cases. Therefore, most of the analysed packagings cannot be considered as deceptive packagings.

3.1.6. Materials and Processes for Packaging Material Production

The dominating materials for cups (Figure 6) were PP (60%), followed by PS (32%). PET and rPET represented around 4% each. Only one sample was made of coated fibre material. Four samples could not be assigned to a certain material. This finding is interesting, since PLA was hardly or not at all present on the market, even though it has been a subject of research and development for packaging for several decades [123–134]. A possible explanation is that the bioplastic PLA is not seen by consumers as more sustainable as conventional plastics. The willingness to pay more for packagings perceived by consumers as non-sustainable is restricted [135]. PLA can be assumed to be a more expensive polymer. Moreover, recycling of PLA is not established (yet), even though, current regulations require higher recycling rates.

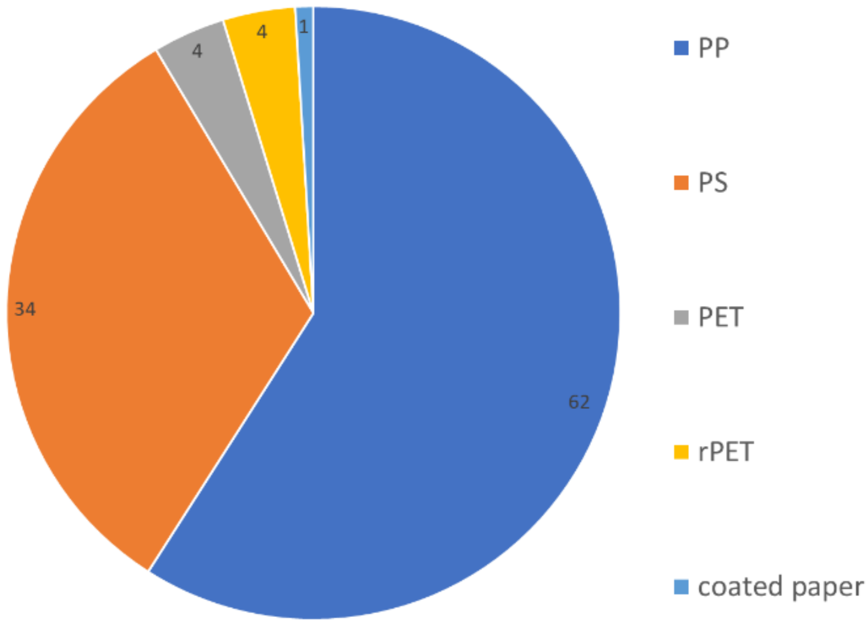


Figure 6. Polymers used for cups; number: number of samples, n = 105.

The minor part of cups (n = 13) was produced by injection moulding. These were made of PP. The rest of the samples were produced by thermoforming (n = 95). The fibre-based cup was made by lamination.

Dominating closures were aluminium lids with 86 % (n = 94). Moreover, PET (n = 6), rPET (n = 2), PP (n = 2) and cellulosic fibre materials (coated and sealed paper) were used (n = 1). In four samples, the material was unclear.

PP- and PET-packagings are well recyclable if they are transparent and clear [136–140]. For PP-recyclates, a commercial market exists [141], as well as for rPET. For PS a solvent-based recycling process is relevant [136,142]. Post-consumer recyclates often contain odour active substances [143–148]. A source for unpleasant odours is the filled good. Such must be considered when foods with volatile aroma components are packaged that migrate into the plastic material.

In Figure 7 the decoration of the cups (excluding lids) is shown.

Slightly less than half of the packagings had decoration that can be removed by consumers (shrink sleeves made of plastic film, thickness 40 to 50 µm; paper/carton wrappings with a thickness of 250–540 µm and paper wrappings at bundles) or had no decoration. Such packagings are considered as more recycling friendly if consumers remove the shrink sleeve and wrappings and dispose them separately. No decoration was observed at packagings sold at street shops for direct eating. Printing inks from direct print are potentially problematic for recycling since it required additional efforts to remove them.

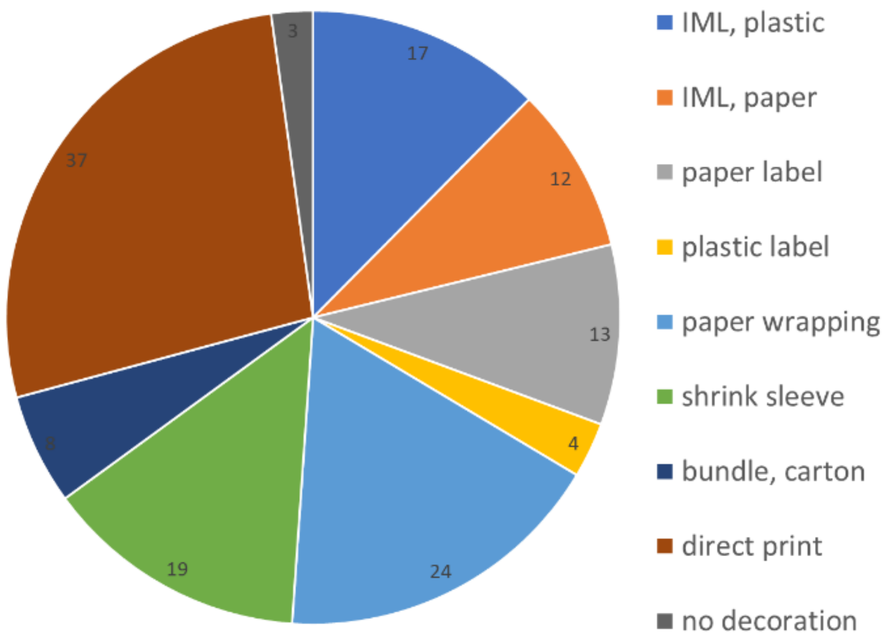


Figure 7. Decoration used for cups, without glass packaging; number: number of samples, IML: in-mould label, n = 137.

One reason for different decoration materials (paper and plastic) is that different packaging materials are perceived differently concerning its sustainability and these may influence the perceived taste and quality [149]. Furthermore, decoration is relevant because printed claims on the decoration can influence 'perceived taste' and the 'amount consumers were willing to pay for the product' [150]. Decoration and its design is therefore a part of the marketing strategy [151,152]. Wang et al. found for yogurt packagings, that 'consumers presented the highest preference for yogurt packaging shape, followed by graphics, label text and packaging colour' [153].

All analysed buckets (n = 5) were made of PP by injection moulding. The lids were also made of PP. Decoration were in-mould labels.

All analysed pouches (n = 5) were multilayer films made of unknown plastic types. Possible production methods were film extrusion and lamination. Decorations were directly printed on the films. The closures were made of plastics either. In one case, the secondary packaging was made of cardboard.

From the analysed bottles (n = 14), ten were made of PET via injection blow moulding. Two bottles were made of PS, one by injection moulding and one by extrusion blow moulding, two bottles were made of PE-HD by extrusion blow moulding. A total of 12 of the 14 bottles had a printed plastic shrink sleeve, one a paper label and one a plastic label. In case of bundles, a carton sleeve was used. The closures were made of PE-HD closures made by injection moulding (n = 10), PE (n = 1) and aluminium lids (n = 3).

Glass packagings (n = 13) were for multi-use (n = 4) and single use (n = 9). The closures were lids of metal (n = 8) presumably coated metal sheets, aluminium (n = 2) and plastic (n = 3). Glass packagings had a printed paper label (n = 7), a printed paper/carton wrapping (n = 4), a printed wrapping for a bundle (n = 1) or a printed plastic label (n = 1).

Bricks (n = 4) were made of directly printed beverage carton made by extrusion coating. The closures were made of PE-HD (n = 4).

The cardboard types of the paper/carton wrappings and folding boxes are based on 40% FSC MIX and have different compositions of primary and secondary fibres (Figure 8). The other part is 37% secondary fibres and 24% primary fibres. In total, 54 cartons were considered.

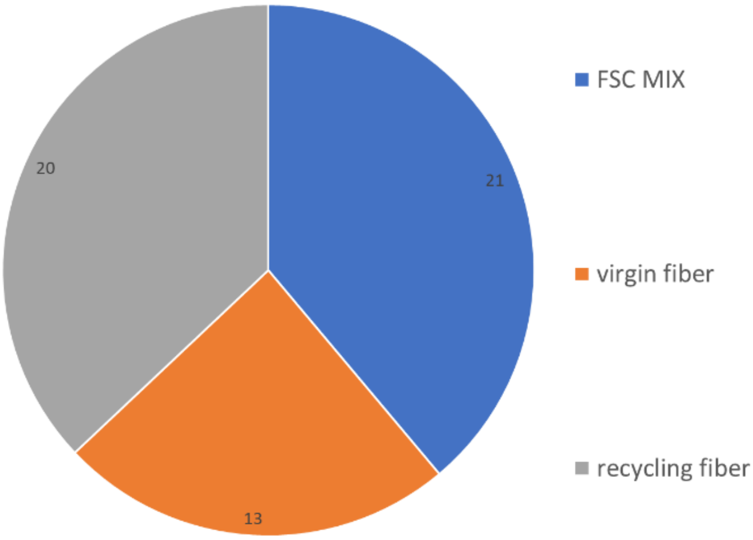


Figure 8. Used fibre material for fibre-based packagings; numbers: number of samples, n = 54.

For recycling, the appearance is an important aspect, as sorting works via various scanning systems using near infrared radiation (NIR) [94,154–166]. Apart from black, colouring is negligible in sorting, but it does influence the colour results of the recyclates and it reduces their value. The appearance of the analysed packaging (packaging body, not labels; Figure 9) is mainly white (66%) or transparent (27%). A few products are coloured (4%) or brown (3%).

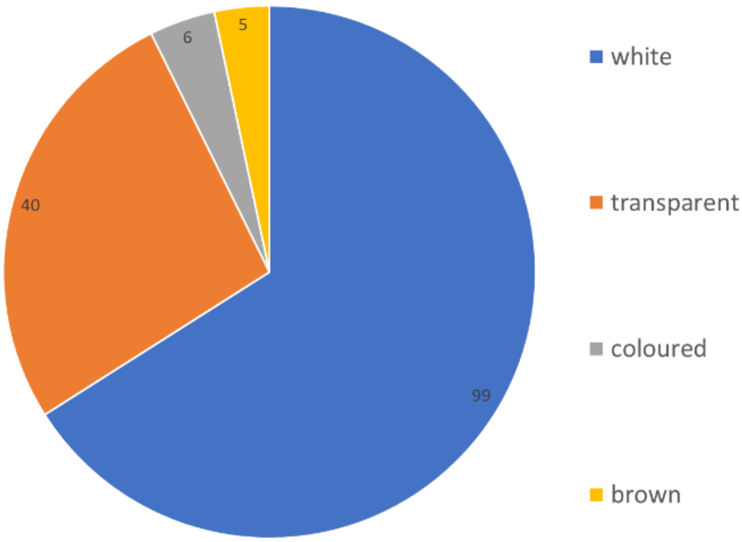


Figure 9. Colour of the plastic body of the packaging; numbers: number of samples, n = 150.

The colour and transparency is also of relevance because light-induced quality changes can occur [167,168]. These are explained by oxidation and were observed also at other dairy products [169–171].

3.2. Closure to Packaging Weight Ratio

An interesting property is the ratio between closure and packaging. In Figure 10, the closure weights are compared to the weights of the packaging, including lid, possible shrink sleeve, and possible shrink labels. In a simplified manner, a straight-line equation with origin 0 was applied. As expected, the closure weight positively correlates with the packaging weight.

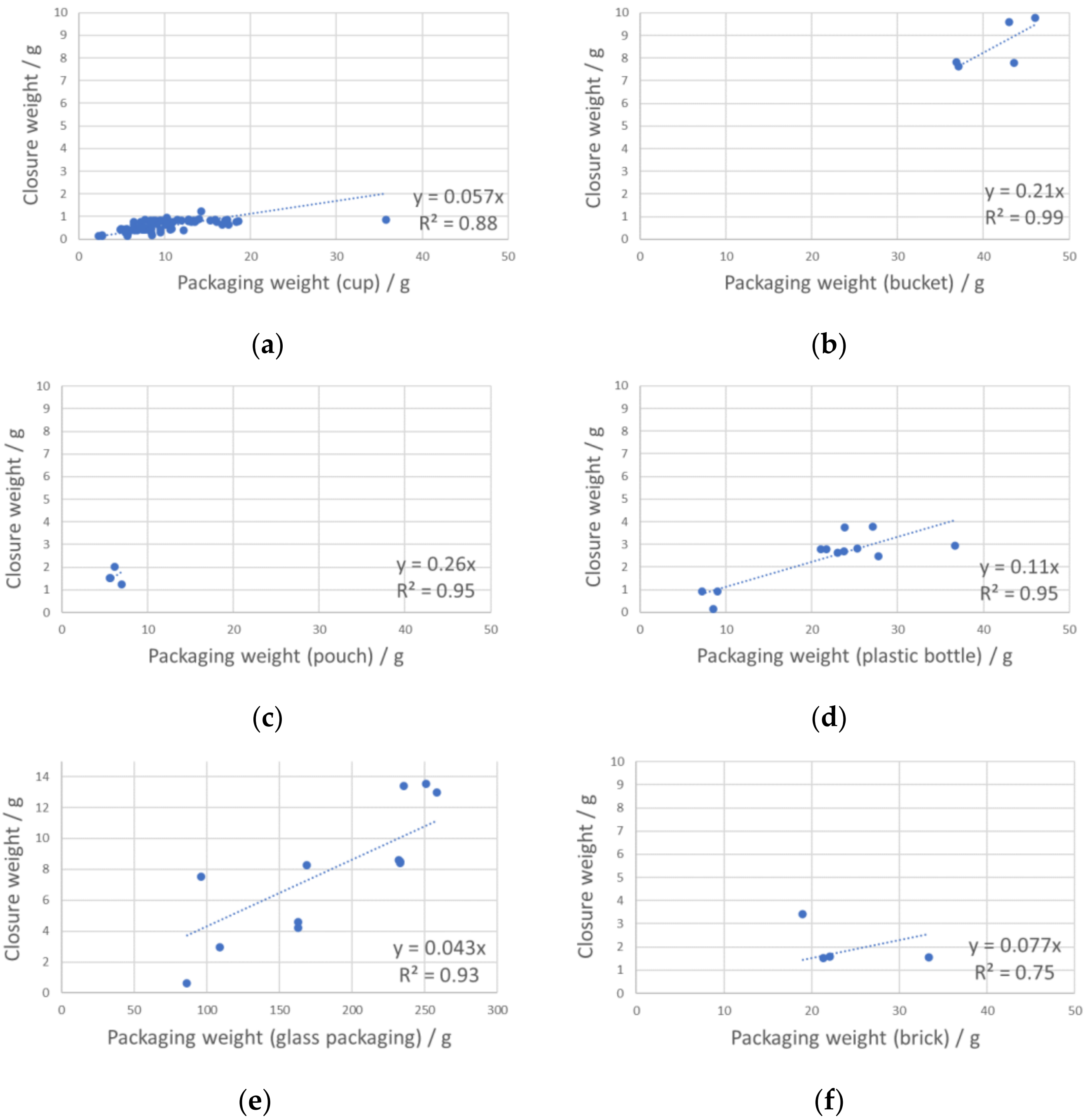


Figure 10. Closure weight versus packaging weight (all parts including wrapper and shrink label if applicable), (**a**): cup, (**b**): bucket, (**c**): pouch, (**d**): plastic bottle, (**e**): glass packaging, (**f**): brick; straight line equation with origin 0 applied.

In Figure 11, the ratio of closure weight to the packaging weight is depicted as box plot. The packaging weight includes sleeves (at bundles, weight divided by single packagings) and shrink labels. For heavy packagings, the closure has the smallest share of the overall packaging weight. For pouches, which are thin and light materials, the closure takes a bigger part of the overall weight, as expected.

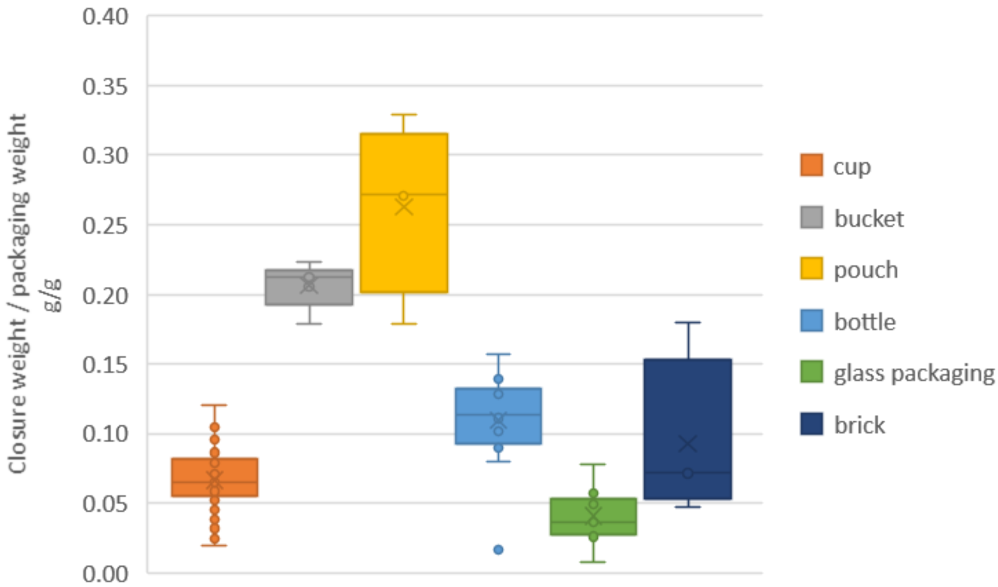


Figure 11. Ratio of closure weight to packaging weight (all parts including wrapper and shrink label if applicable).

3.3. Packaging Efficiencies at All Different Types of Packaging

Packaging Efficiencies Related to Food Product Weight

In Figure 12 the food product weights (packaged food) versus the packaging weights are shown. The food product weight was taken from the packaging declaration, e.g., labels or prints (the results for the body without closure, but with in-mould label, because it could not be removed and with all packaging parts used for a single packaging, are depicted in Supplementary Materials, Figure S2). In case of bundles wrappings are distributed evenly to each packaging. For representation, a linear correlation is included.

By the results is shown that the packaging weight and the product weight have no strong correlation. Because of the different packaging means used, different packaging weights can be found in one packaging category. (Also, the density of product can cause different results even for the same filling volume. This was not further examined). This data was used for the calculation of the packaging efficiencies (see next paragraph).

The food product weights were divided by the packaging weights (Figure 13) to be able to compare packaging material use efficiency. Up to almost 40 g food could be packaged in one gram of packaging material. Most packagings enable to package 15 to 25 g of food in one gram of packaging material. The values scatter highly especially for cups, which is caused by different foods packaged and different packaging means used. Best efficiencies are observed at some cups, bricks, buckets, and pouches. Glass packagings had the lowest efficiencies due to the high weights required (1.6 g to 1.7 g product per 1 g of product). Glass has a high density with 2.5 g/cm^3 (soda-lime glass) [172,173] and it is a brittle material. Therefore, the wall thickness must be higher compared to the other types of packaging. When the values are calculated for the packaging bodies only (separatable elements excluded), the packaging efficiencies become even slightly better (see Supplementary Materials, Figure S2). Such values are interesting because separatable elements can be substituted by well recyclable fibre-based materials.

The 'GVM Gesellschaft für Verpackungsmarktforschung mbH' showed in a study from May 2022 that yogurt in plastic cups had a packaging efficacy of 41.7 g yogurt packaged in one gram of packaging material valid for the year 2020 [87]. For the year 1998, this value was worse with 35.6 g yogurt packaged in one g of packaging material. For glass packagings, they reported 1.52 g yogurt packaged in one gram of packaging material. Even though, it is not clear if these efficiencies were calculated for the packaging materials with or without labels and closures, these values are the range of the results of our study.

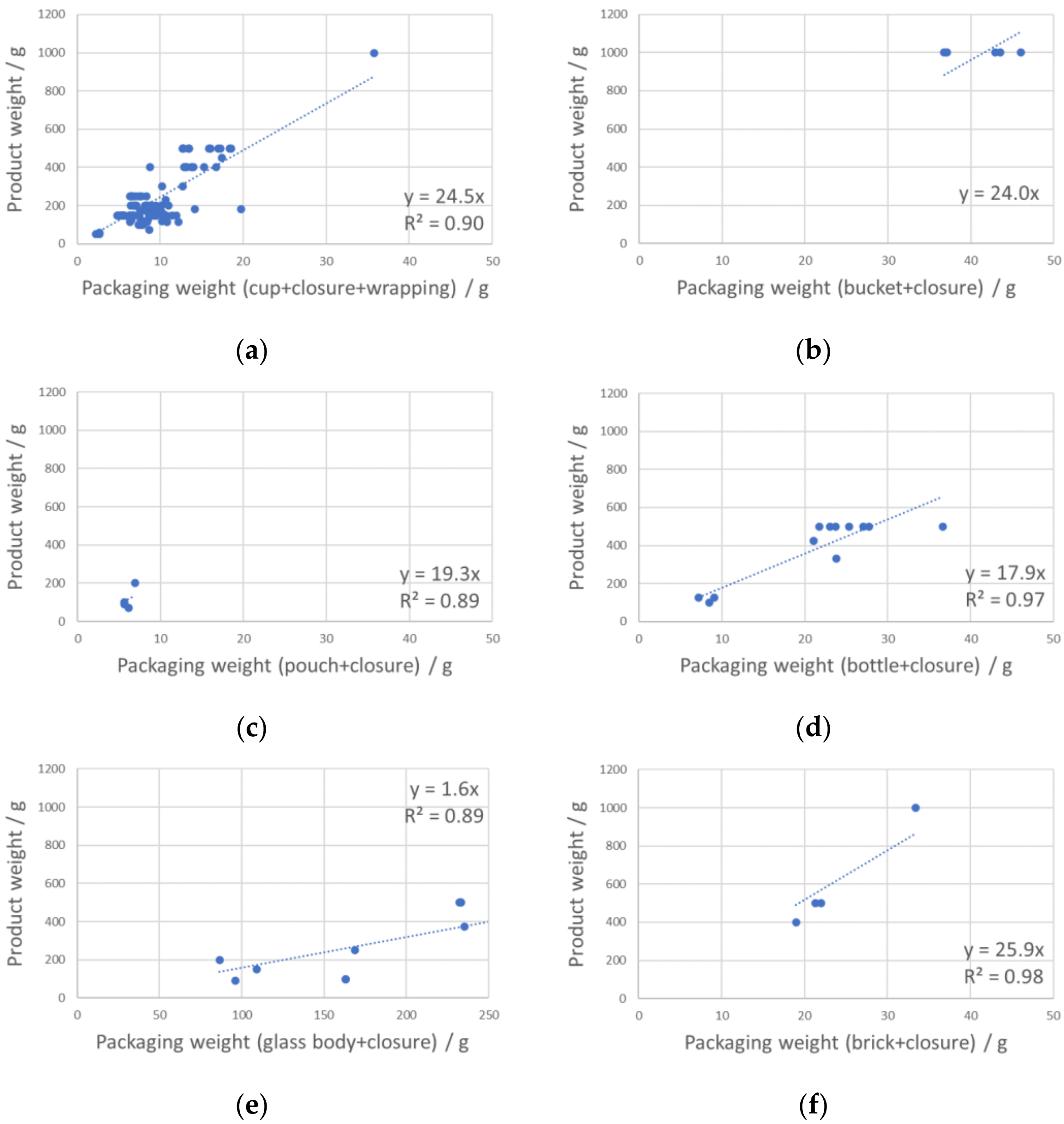


Figure 12. Food product weight (from packaging declaration) versus used packaging weight, all packaging components used (e.g., labels, wrappings, shrink sleeves); (**a**): cup, (**b**): bucket, (**c**): pouch, (**d**): plastic bottle, (**e**): glass packaging, (**f**): brick; straight line equation with origin 0 applied.

Klooster et al. showed for glass bottles a ratio of similar values of about 2 g beverage per 1 g of glass packaging [174]. Another study found a packaging use of all packaging at yogurt between 10 and 20 g of food packaged with 1 g packaging material [175]. For beverages (not in glass bottles), a ratio of circa 25 to 35 g of packaging material use for 1 g of packaging was found [176]. The packaging efficiencies found in our study, for both cups and bottles, were therefore slightly better than that reported in the literature.

An important question is, if a higher filling quantity causes a better packaging material use efficiency. To analyse this correlation, the efficiency (filled food product weight/required packaging weight) is depicted as function of the product weight (Figure 14). Even though the results scatter highly for cups, bottles and bricks, it can be concluded that the packaging material use efficiency improved with higher weight of filled good. In Supplementary Materials Figure S2, the values referring only to the packaging bodies are shown. Results for this evaluation are similar.

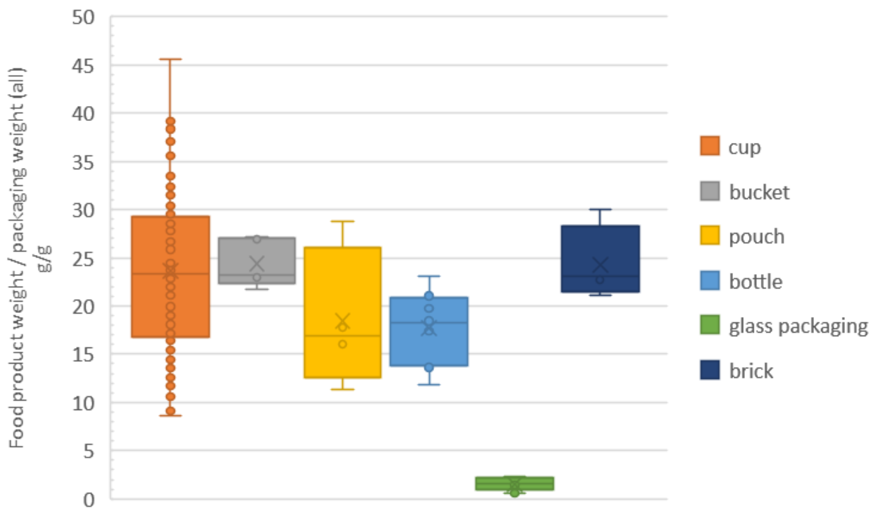


Figure 13. Packaging efficiencies for different types of packaging; packagings include all packaging components (labels, wrappings, shrink sleeves, lid).

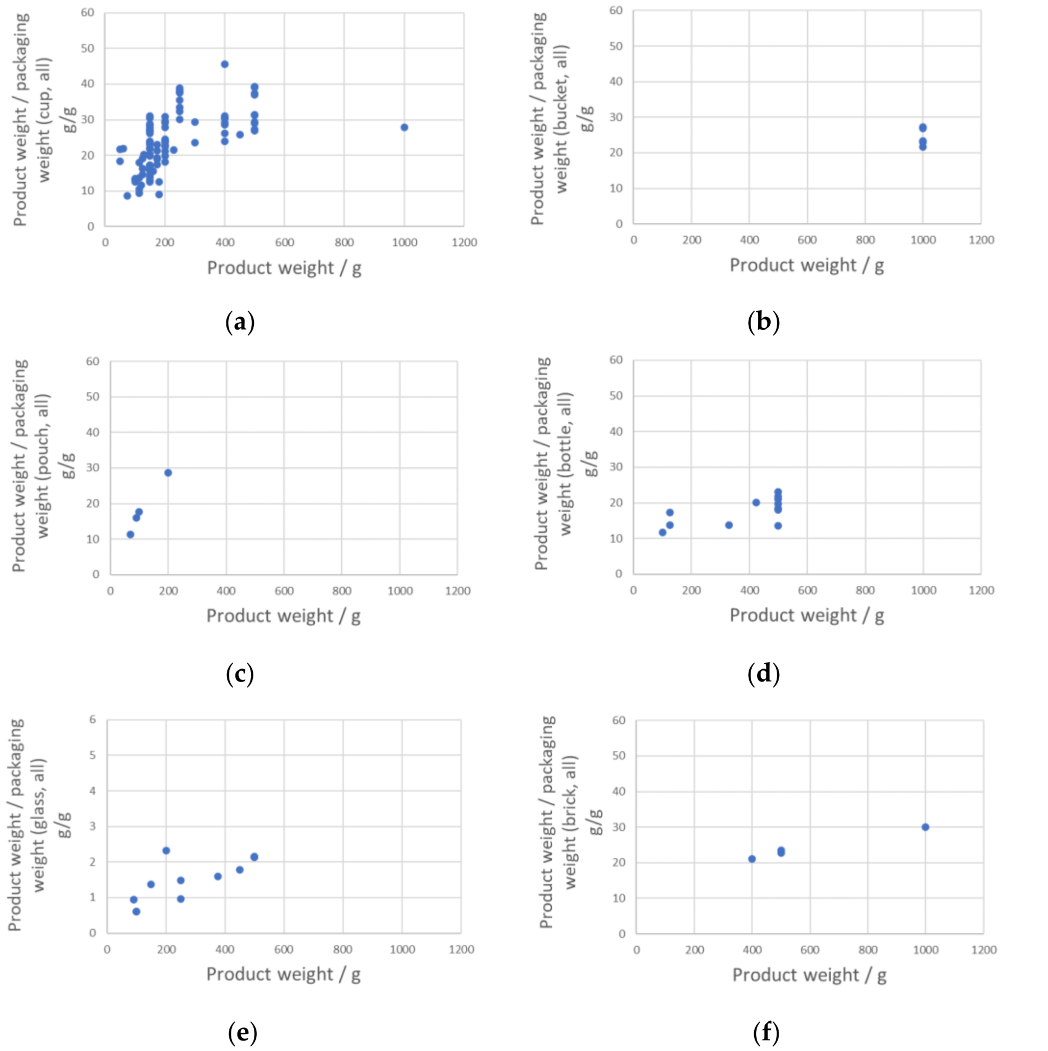


Figure 14. Packaging efficiencies over increasing product weights for different types of packaging, all packaging components are included; (**a**): cup, (**b**): bucket, (**c**): pouch, (**d**): plastic bottle, (**e**): glass packaging, (**f**): brick.

3.4. Packaging Efficiencies of Cups

Cups can be differentiated by their types of packaging, applied polymers and production methods. Therefore, this packaging type was investigated in more detail. Because food products of different densities were packaged in cups, the results in this chapter are correlated to the rim full weight of water of the packagings. Packaging consisting of separate elements such as 'top-ups' filled with product were not considered in this evaluation.

In Figure 15, rim full weights (filled packaging to edge with water) of water divided by the packaging weights are shown. In Figure 15a, the ratio of the rim full weight divided by the overall packaging weight (including the lid and wrapping) is shown. In Figure 15b, the ratio of the rim full weight divided by the cup body only is shown. This allows to evaluate if a paper/carton wrapping causes less plastic use. As expected in Figure 15a, the efficiencies are lower than in Figure 15b because all parts of the packaging are counted.

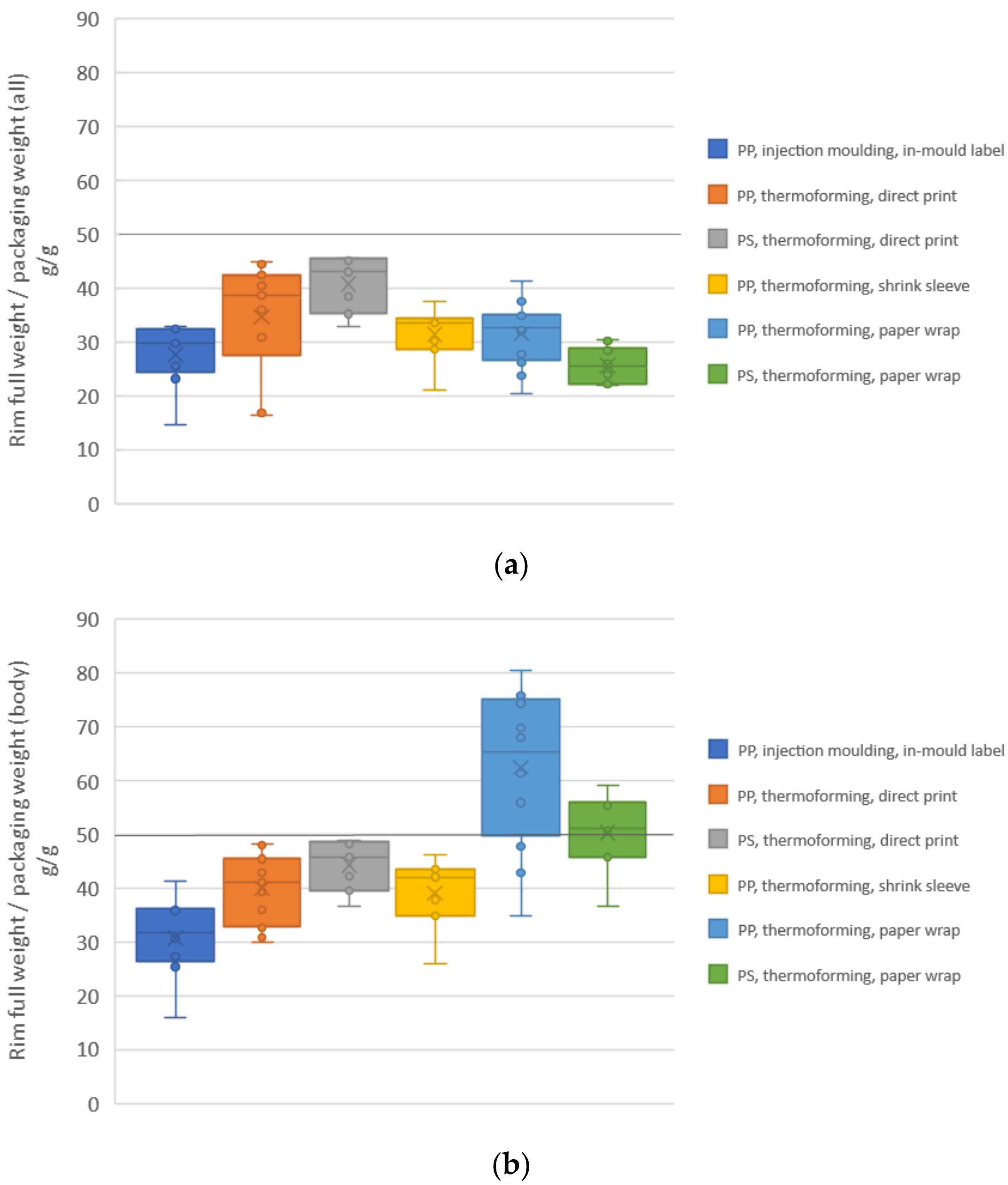


Figure 15. Packaging efficiencies (rim full weight divided by packaging weight; packagings filled with water) for different types of packaging, (**a**): all packaging components included (with labels, wrappings, shrink sleeves if applicable), (**b**): only body (separatable components are excluded).

Direct printing resulted in the best efficiencies when all packaging components are included (Figure 15a). For direct printed thermoformed cups, PS as used polymer was slightly more efficient than PP.

Injection moulding as well as wrappings and shrink sleeves causes less efficient packaging and more packaging material use (Figure 15a).

However, if the rim full weight is divided only by the weight of the cup body (excluding the paper/carton wrapping and lid), the cups made by thermoforming with paper/carton wrapping yield the best results. That is explained by the properties of the paper/carton wrapping. It provides stiffness and higher mechanical strength. Therefore, the plastic cup wall thickness can be reduced. The plastic use is significantly reduced (Figure 15b). That is an important result since many companies try to reduce their plastic use. However, as discussed before, when the paper/carton wrap weight is considered for the calculation of the packaging efficiency (Figure 15a), the packaging material use efficiency is reduced. Hereby, it is worth to consider that the paper/carton wrapping can be separately disposed into the paper recycling stream. Disposal advice was found at almost all such packagings (see Section 3.5). At cups with paper/carton wrapping for 1 g of cup-material (plastic), circa 0.9 g of wrapping-material (paper) and 0.1 g of materials for the closures were used. A shrink sleeve at PP did increase packaging material use efficiency. However, not as much as paper/carton wrappings.

Similar results as in this study for yogurt cups with paper wraps were found before by Aggarwal et al. with a slightly higher use of PP compared to PS for cups [128]. In his study it is reported that 46 g and 43 g of yogurt are packages for every one gram PP and PS cup material (only body, without paper wrap). PLA resulted in 63 g yogurt for one gram of PLA. The paper/carton sleeve thickness presented in Aggarwal's study was 153 µm and 393 µm. In our study we found carton sleeve thicknesses of 250 to 520 µm.

3.5. Disposal Advice on Packagings

Interestingly, most (54 %) of the packagings had no exposed advice for recycling. The other packagings had various recycling advice (Figure 16).

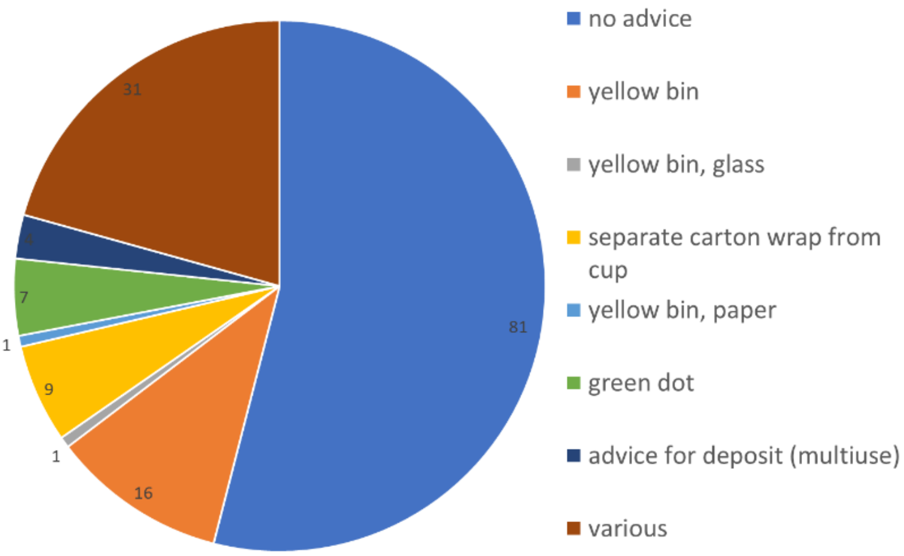


Figure 16. Recycling advice on packagings, numbers: number of samples, n = 150.

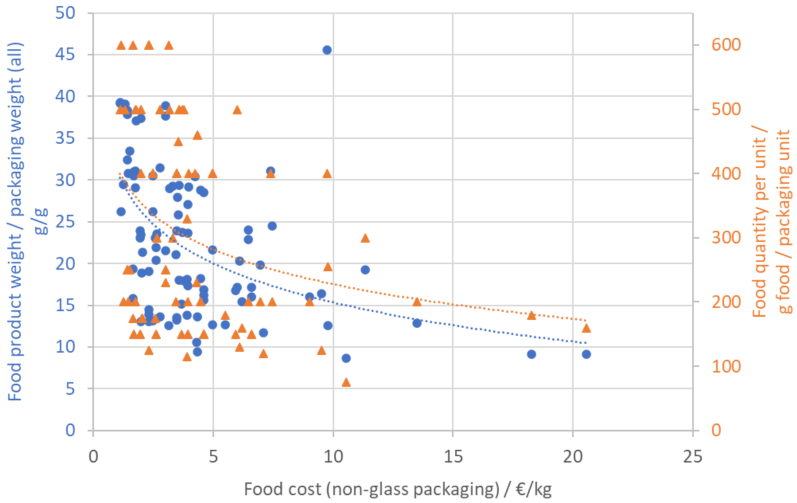
The packagings without advice for recycling were decorated by an in-mould label (n = 11), a label (n = 12), direct print (n = 13) and a shrink sleeve (n = 3). We assume that it is expected that such packagings are disposed by consumers to the post-consumer packaging collection systems for further recycling. Advice for separation would in this case only be of value for the lid. The rest had no decorative label, e.g., as street food.

Only one sample with paper/carton wrapping had no disposal advice. Disposal advice for packagings with paper/carton wrappings are important since all components (cup, lid, wrapping) must be separated. For single cups with paper/carton wrapping, the paper and the plastic body of the cup are glued with few glue-points. For recycling it is important that the paper wrapping is separated from the plastic body and of the cup, as well as that lid is separated. The paper should be disposed in the paper stream.

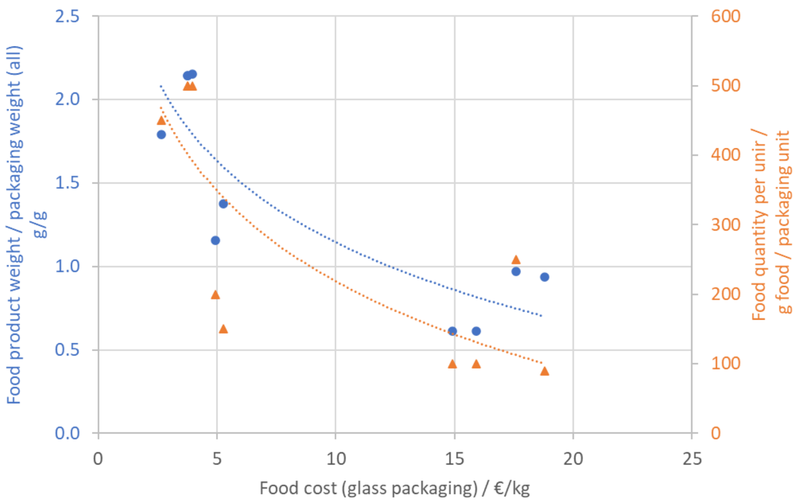
More than half of these packagings had disposal advice for all parts (n = 14), the rest for the paper wrapping only (n = 9) or no advice at all (n = 1). Some pictures of disposal advice can be found in the Supplementary Materials, Figure S3.

3.6. Correlation between Product Cost and Packaging Use

An interesting aspect is the correlation between the food cost and the amount of packaging material use per food filling weight. In Figure 17 the packaging efficiency (food product weight versus used packaging weight) is correlated with the product cost. The higher the cost of the food the lower is the packaging material efficiency. More packaging material is used to package the same amount of food. An explanation is that more expensive foods are packaged in smaller units with less food weight per single packaging.



(**a**)



(**b**)

Figure 17. Packaging use related to food costs; (**a**): non-glass packaging, (**b**): glass packaging.

4. Conclusions

Our study provides indications that a higher filling amount results in a better packaging material use efficiency. In addition, our results show that a paper/carton wrapping reduces overall required plastic use. However, it also reduces the packaging efficiency of the whole packaging when the paper/carton wrapping is included. Injection moulding causes more material use compared to thermoforming and it was therefore slightly less efficient in terms of plastic usage. At least ten-times higher packaging weight per packaged food unit was seen when glass is used. Overall, our hypotheses were proved by the study.

Alternative packaging materials made of PLA, pulled or deep-drawn fibre materials (paper, carton, paperboard) or other biopolymers were not found. This result is interesting because much research has been done on these materials.

Our results are a valuable input for the calculation of life cycle assessments, in which packaging weights play an important role. Recycled plastics, here only rPET, for yogurt packagings was identified only at four products in our survey. Interesting for future investigations is a comparison of our results with results from other countries, since product types and materials might differ.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/dairy3030046/s1, Figure S1: Pictures of samples, Figure S2: Packaging efficiencies related to product weight, Figure S3: Disposal advice on packagings, Table S1: Raw data.

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Informed Consent Statement: Not applicable.

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