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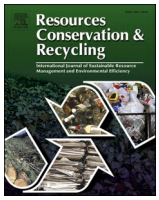

Review

Packaging solutions for household food waste in the context of the food/beverage–packaging industry: A comparative review of empirical literature and industry press releases

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ABSTRACT

Interest is increasing among researchers and industry regarding packaging's potential to reduce household food waste (HFW). Researchers have recommended packaging solutions and the food/beverage–packaging industry have developed packaging solutions; are the recommendations and developments related? This review paper connects academic recommendations to industry practice by identifying and comparing packaging solutions from industry press-release articles to the HFW drivers and packaging solutions identified in primary consumer empirical studies. The review covers a 16-year timespan from 2006–2021, globally, to collect data on packaging functions/formats, materials, and food groups. The analysis shows that industry developments differ from research recommendations. While most of the packaging functions/formats suggested in the empirical literature have precedence for commercial availability, many packaging solutions developed by industry are not acknowledged in the empirical literature. Combining the unique contributions of research within and external to industry creates a fuller picture of HFW, supporting more effective implementation of packaging solutions to help reduce it. There is an opportunity for industry to implement a greater number of packaging formats aligned to the most frequently reported HFW drivers. Enabling greater collaboration between the research community and industry by bringing together this literature in a critical review is a major contribution of this paper.

1. Introduction

The United Nations Sustainable Development Goal (SDG) 12.3 calls for global action to halve food waste (FW) by 2030 (United Nations General Assembly, 2015). Approximately one-third of all the food produced for human consumption globally is discarded, bringing significant environmental, economic, and social damage (Gustavsson et al., 2011; Hanson and Mitchell, 2017). Across the world, a substantial proportion of FW occurs at the consumer level and especially in households (Flanagan et al., 2019). Household food waste (HFW) accounted for 61% of all global FW in 2019 (Forbes et al., 2021), so an effort to reduce HFW is therefore likely to contribute significant progress to the UN SDG Goal. The potential benefits of action are significant as food systems consume nearly 30% of global available energy (FAO, 2015). This contributes to the larger SDG 12 on responsible consumption and production.

This comparative literature review will support the 'act' stage of the Target-Measure-Act approach by providing direct information to assist the development and implementation of packaging solutions to help reduce HFW for a more sustainable future. The Target-Measure-Act approach helps to drive action to reduce FW by setting FW reduction goals, measuring FW, and implementing reduction strategies (Champions 12.3, 2020). Packaging plays a role in sustainable food systems as it helps to reduce FW (Verghese et al., 2012), preventing waste of the land, water, and energy resources required to produce, process, manage, and deliver food to consumers (FAO, 2013). This paper provides critically-assessed, aggregated information from empirical studies and industry developments for researchers and the food/beverage–packaging industry to take action to reduce HFW. In comparison to previous studies, the combined researcher-industry perspective links specific packaging products developed by industry to reduce HFW (from industry press releases) to the specific HFW drivers (from empirical research) these packaging address. This paper therefore facilitates

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greater collaboration between the researchers and industry to design/-implement packaging solutions to more effectively reduce HFW.

1.1. Positioning this review in context of the Target-Measure-Act approach and extant literature

The Target-Measure-Act approach helps to drive action for reducing FW (Champions 12.3, 2020). 'Target' helps to set ambition and motivation by encouraging governments and companies worldwide to set goals aligned to SDG 12.3, including the National Food Waste Strategy (Commonwealth of Australia, 2017) and the Farm to Fork strategy (European Union, 2020). 'Measure' relates to identifying specific areas that need action and can be partly achieved through FW empirical studies. 'Act', which provides the focus for this review, is the process of developing and implementing strategies from these areas. Suggested strategies to mitigate HFW are varied, ranging from behavior change campaigns, food management education, to packaging solutions (Reynolds et al., 2019; Wikström et al., 2018). Of the many solutions, packaging's potential to reduce HFW is gaining recognition within industry and external research (Fisher et al., 2018; Wikström et al., 2018; Williams et al., 2020). Packaging can reduce HFW by physically protecting food from damage, providing an environment conducive to extended shelf-life, and communicating optimal storage conditions and recipe ideas (Butler, 2012; WRAP, 2007). Packaging has the potential to reduce 20%-25% of HFW (Fisher et al., 2018) so it is an important strategy to act on.

Much academic research into HFW focuses on uncovering HFW drivers (see Principato et al. (2021) for an overview) and these drivers are important to address when developing HFW-reduction solutions. HFW is complex as multiple drivers can contribute (Quested et al., 2013), ranging from consumer behavior and attitudes (Koivupuro et al., 2012), to situational context (Hebrok and Heidenstrøm, 2019), food knowledge (Aydin and Yildirim, 2021), and packaging (Williams et al., 2020). These drivers can be interpreted as areas to target action—aligning to the 'measure' stage—to reduce HFW. It is beneficial to align consumer needs to packaging functions when designing FW-reduction-packaging (Wikström et al., 2019). Information on HFW drivers within extant studies can assist researchers and industry to identify and contextualize these needs, highlighting their value. However, there are limitations to the ability of these studies to support the 'act' stage for implementing HFW packaging solutions. Fewer HFW studies mention packaging solutions (compared to non-packaging solutions) as the focus is on HFW drivers. When mentioned, it rarely pertains to industry packaging developments to reduce HFW. This is an opportunity, as the food/beverage–packaging industry plays a key role in the development and market availability of packaging, and thus the ability of consumers to benefit from packaging formats with FW-reducing potential.

Very little published research focus on improving packaging specifically to reduce HFW. Within the packaging literature, some studies document the development of packaging technologies to improve food safety and extend shelf-life, which can help to reduce FW. Packaging technologies explored include modified atmosphere packaging (MAP), vacuum packaging, active packaging, and intelligent packaging (Soltani Firouz et al., 2021; Tørngren et al., 2018; Wilson et al., 2019). While these studies offer valuable contributions to packaging development, they rarely address the potential of packaging technologies to reduce HFW—hence an opportunity for a study that links packaging developments to HFW drivers.

Very little published research focus on documenting industry packaging developments to reduce HFW. WRAP (2007) (Waste Resources Action Program) conducted a market survey of packaging solutions with the potential to reduce HFW. The survey, however, is limited to packaging formats available at certain supermarkets in the USA, France, and Portugal in December 2006—hence an opportunity for a study with greater geographic and time coverage.

1.2. Aims of this review and key contributions

This comparative literature review will compare and discuss—from a global context spanning 2006–2020—the packaging drivers and solutions documented in HFW primary consumer studies (empirical studies/literature hereupon referred to as EMP) with the packaging solutions for HFW developed by the food/beverage-packaging industry as documented in industry press release articles (PRs). PRs are appropriate to identify packaging solutions because industry utilizes them to communicate packaging developments; they also contain useful details including technical properties and publication dates that allow a timeline of packaging development to emerge.

This review aims to explore and compare:

- Packaging functions/formats identified in the EMP and industry PRs with potential to prevent HFW—with information on what foods they are for and which year/geographic regions they pertain to.
- HFW drivers identified in EMP and if they are addressed by packaging solutions in the EMP and industry PRs.
- Barriers to implementing packaging to prevent HFW, from the perspective of material sustainability.

In doing so, this review makes two major contributions. First, it helps to connect HFW EMPs and industry packaging developments, supporting the transition of HFW packaging solutions from suggestions found in EMP to implemented packaging solutions. Second, it identifies opportunities for packaging related HFW research and development by highlighting food–packaging combinations to focus solutions on. It also highlights that acknowledging existing policies and societal attitudes relating to material sustainability can support the successful design and implementation of packaging solutions to reduce HFW.

The review shows that packaging functions/formats suggested in the EMP and PRs have a different focus. It is beyond the scope of this study to explore the reasons for this difference, but a divergent focus between researchers and industry is no surprise and has been long described within related disciplines (including industrial/product design) as the 'research–practice gap' (Norman, 2010; Zielhuis et al., 2022). Hence, what matters is facilitating researcher–industry knowledge transfer, which can be facilitated by presenting research findings in a way that is conducive to helping both researchers and industry to identify areas of relevance and to act upon them (Rynes et al., 2001; Zielhuis et al., 2022). This paper contributes in that regard by providing recommendations on combining the unique contributions of researchers and industry to help facilitate more effective implementation of packaging solutions to help reduce HFW. Greater collaboration between the research community and the food/beverage–packaging industry to research/develop and implement HFW packaging solutions is therefore encouraged.

2. Method

2.1. Literature search

Two sets of literature relevant to HFW and packaging solutions were gathered: (1) primary consumer HFW EMP, and (2) PRs from the food/beverage–packaging industry. A total of 412 PR articles and 60 EMP studies were identified for use in this review. For the EMPs, there were 47 journal articles, 2 conference papers, and 11 reports. Eligible literature was published in English within the timeframe 2006–2021, providing a 16-year snapshot of key developments within academic/industry research and practice. This period covers when the first HFW EMPs were published as papers (Porpino, 2016).

An online search of English-language EMPs suited to this review was conducted using a combination of the keywords 'household', 'consumer', 'food', 'waste', and 'packaging'. The EMPs were inclusive of peer-reviewed journal articles, conference papers, and technical reports

to reflect food waste research published as academic and grey literature. The journal articles and conference papers were retrieved from the databases Science Direct, SpringerLink, ProQuest and Wiley Online. These databases were chosen as they include a comprehensive number of peer-reviewed publications that cover the many research disciplines (including sustainability, materials science, and human behavior) relevant to FW and packaging research. Grey literature is important to include for a balanced view, as relevant research has been conducted by governmental, non-governmental, and research organizations with comprehensive knowledge pertaining to FW and packaging. Thus, this literature review included technical reports published by the FAO (Food and Agricultural Organization of the United Nations), WRAP (Waste Resources Action Program) in the UK, and the FFWCRC (Fight Food Waste Corporate Research Centre) in Australia. While other organizations have conducted food waste and packaging related research, these included organizations have specifically conducted packaging related primary consumer HFW research relevant to this study.

Publications were selected to address a key aim of this review, which is to assess if extant packaging solutions by the food/beverage–industry align with HFW drivers. The EMPs reviewed were packaging related primary consumer studies that contained information on HFW drivers and solutions. HFW is generated by consumers, so these studies are more likely to provide nuanced insights into why food is wasted in addition to what is wasted, as opposed to bin-audit studies (focusing on quantifying waste) and studies that utilize computer modeling to predict consumer FW behavior. Connecting what food is wasted to why it is wasted is important when assessing the suitability of packaging solutions to address HFW drivers, justifying the focus on primary consumer studies for the EMP.

To identify relevant industry foci and solutions, 23 English-language food/beverage and packaging industry online PR magazine platforms were searched for eligible articles with the same keywords used for the EMP search. A list of the platforms is provided in Appendix A, with the number of PRs identified from each platform. To meet eligibility criteria, the PR needed to mention a packaging product that helps consumers to prevent HFW. PRs are an appropriate way to identify what packaging solutions have been developed by the food/beverage–packaging industry to reduce HFW because PRs are used by industry to communicate and promote packaging developments within the industry, and a comprehensive record of these PRs is readily accessible online. The PRs often include information on the technical properties of the materials used and the benefits of certain packaging formats for specific applications, so these publications contribute valuable information to this study. Furthermore, PRs contain publication dates, enabling an overview of how HFW packaging solutions have developed over time.

2.2. Literature comparative analysis

An approach based on the Systematic Quantitative Literature Review method by Pickering and Byrne (2013) was used to extract and analyze information in the literature; it is specifically beneficial as it helps to reveal trends. Three spreadsheets were used. One focused on HFW drivers from EMP, the other two focused on packaging related HFW solutions from PRs and EMP. Each spreadsheet was used to collect and collate information on the publication year, geographic location, food type, packaging functions, packaging materials, and sustainability claims; with information within each referred to as a 'category'. A '1' was marked under the corresponding category each time relevant information was mentioned. Different packaging drivers/solutions were marked in separate rows, with each row counting as an 'entry' to be tallied for analysis.

The packaging solutions and HFW drivers were sorted into 30 packaging categories/functions and 28 food categories. This enables a detailed indication of which categories are most mentioned and which have potential for further packaging developments. A considered approach was used to decide which food/packaging categories to focus on, involving an initial list that was refined. For packaging functions, the initial list is based on Lindh et al. (2016b). Lindh's study identified thirteen packaging functions to reduce product/food waste, making it an appropriate starting point. The initial list of food categories is based on an HFW study by Brook Lyndhurst (2011), for its comprehensiveness in identifying key food groups. Additional categories were added to these lists after identifying food and packaging related themes from the literature through an inductive approach to coding. This approach involves identifying patterns/themes within a set of data which are sorted into categories/codes, so that insights can emerge (Denzin and Lincoln, 2018). A benefit is that the insights are generated from the data, so learnings can be applied back to the general context these insights originated to help solve a problem or improve a situation. Here, this approach assists to identify opportunities to improve packaging solutions to reduce HFW. A glossary of the packaging functions used to categorize the packaging solutions from the reviewed publications is provided in Appendix B.

The categories were tallied for analysis after separating and merging certain entries. For the EMP, duplicate packaging solutions within the same publication were merged unless the same solution was recommended for different foods. Each food counted as a separate entry. Similarly, for the PRs, if a packaging solution for the same brand and application was identified in multiple PRs for the same year then it was merged. However, if a PR describing an identical packaging solution was published in another year or the packaging solution was for a different food/brand, then each instance was counted separately. This process ensures that the data reflects the breadth of the packaging drivers and solutions identified in publications for the different food categories over the years.

The tallied spreadsheets were used to create tables and graphs to interpret the data and identify trends. Patterns were identified within each publication group for what (food/packaging-function/material) was mentioned and the frequency they were mentioned, then compared between the publication groups. Some of the graphs are presented in the results section next. A table of all the HFW drivers and packaging solutions from the publications—as separate entries by publication source—is presented in Appendix C.

3. Results

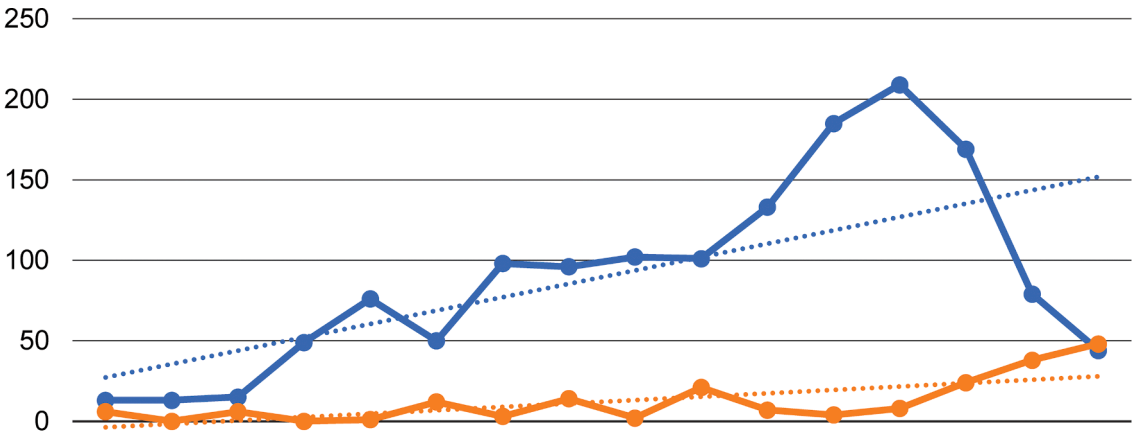
3.1. Number of HFW drivers and packaging solutions identified and publication context

3.1.1. Number of HFW drivers and packaging solutions identified

Consistent with the aim of this review, HFW packaging solutions were identified from both EMP and PRs, where information on HFW packaging drivers was collected only from the EMPs. A total of 1497 entries for HFW packaging solutions were identified from the PRs. Over 80% of the 60 EMP discussed both HFW drivers and packaging solutions. There were three times as many entries for HFW drivers (909 entries) than for packaging solutions (306 entries). This result was unsurprising as nearly 70% of the EMPs focused on uncovering reasons for HFW; many solutions were suggested but packaging related solutions were least mentioned. Non-packaging related (or 'other') HFW solutions are beyond the scope of this study. So too, is exploring drivers for researchers' decisions on research focus.

3.1.2. Number of packaging solutions identified by year

Fig. 1 shows the number of HFW packaging solutions from the EMP and PRs graphed by year. Packaging solutions in both publication types increased over the past sixteen years. The number of solutions from PRs rose at a greater rate than in EMPs, exponentially increasing during 2006–2018. Yet during 2019–2021 solutions from PRs sharply decreased to levels comparable to 2009. PRs generally reported significantly more solutions per year than EMPs, but in 2021 there were fewer solutions. It is beyond the scope of this study to explore the reasons for



	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Press releases	13	13	15	49	76	50	98	96	102	101	133	185	209	169	79	44
Empirical studies	6	0	6	0	1	12	3	14	2	21	7	4	8	24	38	48

Fig. 1. Number of entries for packaging solutions over the years from 412 press releases and 60 empirical studies.

this decrease. For EMPs, a slower increase in solutions during 2006–2018 gave way to a significant increase during 2019–2021.

3.1.3. The geographic regions the HFW drivers and packaging solutions are relevant to

A similar overall geographic distribution was observed for both the PRs and EMPs, with majority of the packaging solutions relevant to Europe, North America, and Oceania. From the most to least, the number HFW packaging solutions commercially available in a geographic region are Europe (210 solutions, with 119 from the UK), North America (84), Oceania (42), Asia (16), South America (11), Middle East (7), and Eurasia (3); some packaging solutions are commercially available in multiple regions. Note that the number of packaging solutions does not represent the total number of PRs because some packaging solutions were represented by multiple PRs, as explained in Section 2.2. In order from the greatest to the least number of EMP by geographic region, studies were conducted in (and therefore the solutions were relevant to) Europe (38 studies, with 9 from the UK), North America (13), Oceania (7), South America (2), and the Middle East (1); some studies were conducted in multiple countries. Studies from Asia and Africa are not represented. A limitation of this review is that it only included English-language publications, hence packaging solutions for some regions are underrepresented or unrepresented.

The geographic regions the EMPs were conducted in match the geographic regions that the identified HFW drivers and packaging solutions are relevant to. For the PRs this is not always the case. The magazine platforms that published the PRs are based in Europe (11 platforms, with 8 from the UK), North America (7), Oceania (4), Asia (2), and Eurasia (1). While the magazines generally reported on packaging solutions available in the same country in which it is based, five magazines based in Europe (2) and North America (3) reported on packaging solutions relevant to South America (11 PRs) and the Middle East (7 PRs).

There is a strong Eurocentric—particularly UK—focus for the EMP and PRs, at more than double of North America and more than five times of Oceania (the next two regions for the most publications). These regions also dominate in the same order for the greatest number of reported HFW drivers and packaging solutions; important to note as this review will be most representative of these regions. The implications of a Eurocentric focus are discussed in Section 4.4.

3.2. HFW overview from the empirical studies: what is wasted and why

Packaging designed to reduce HFW is more likely to be effective when aligned to consumer needs (Wikström et al., 2019). HFW drivers represent some of these needs, so they are presented in this section along with what foods are wasted, focusing on the most frequently mentioned as they represent key areas for HFW prevention solutions—including packaging—to target.

Fig. 2 shows HFW reasons identified from EMP, Fig. 3 shows what foods were wasted and why; with reasons for waste grouped by whether packaging contributed. For some entries (see Section 2.2), more than one reason was given for why food was wasted. The category for 'both packaging and other reasons' in Figs. 2 and 3 show that packaging reasons for food waste can act in tandem with other reasons; there is often more than one reason for why a food item is wasted and these reasons can be interconnected (Quested et al., 2013). 'General--perishable-food' was the most wasted food category, used where studies did not specify what was wasted. Similarly, 'reason not reported' is highly represented, used where studies did not specify the reason food was wasted. The prominence of these two categories demonstrates a limitation of extant studies in reporting what food was wasted in connection to why, highlighting an opportunity for future studies. It is useful to identify specific foods to target and understand the reasons why they are wasted when developing/specifying packaging solutions to reduce HFW, so the remainder of this section focuses on specific foods and reported reasons for waste.

The most frequently mentioned food categories are perishable foods: vegetables, fruit, bread/cakes, dairy, and meat. The most reported reasons for why these foods were wasted are connected to the most frequently reported reasons/drivers for HFW: 'unfinished-in-pack' (where a package of food is not used up and the remainder is discarded within the package), 'food spoiled/unsafe-to-eat', 'past date label (best-before and use-by/expiry dates or similar), 'spoiled-in-pack', and 'inappropriate pack size, too big'. This is not to say that other food categories are not highly wasted within these specific HFW drivers, but these food categories were most mentioned overall, so they are of greater relevance when identifying key foods to target HFW solutions

For packaging-only reasons for HFW, date-label-related reasons were the most reported, where the reasons refer to both best before and use-by/expiry dates. While best before dates indicate that a product can be safely consumed after the date and use-by/expiry dates indicate a

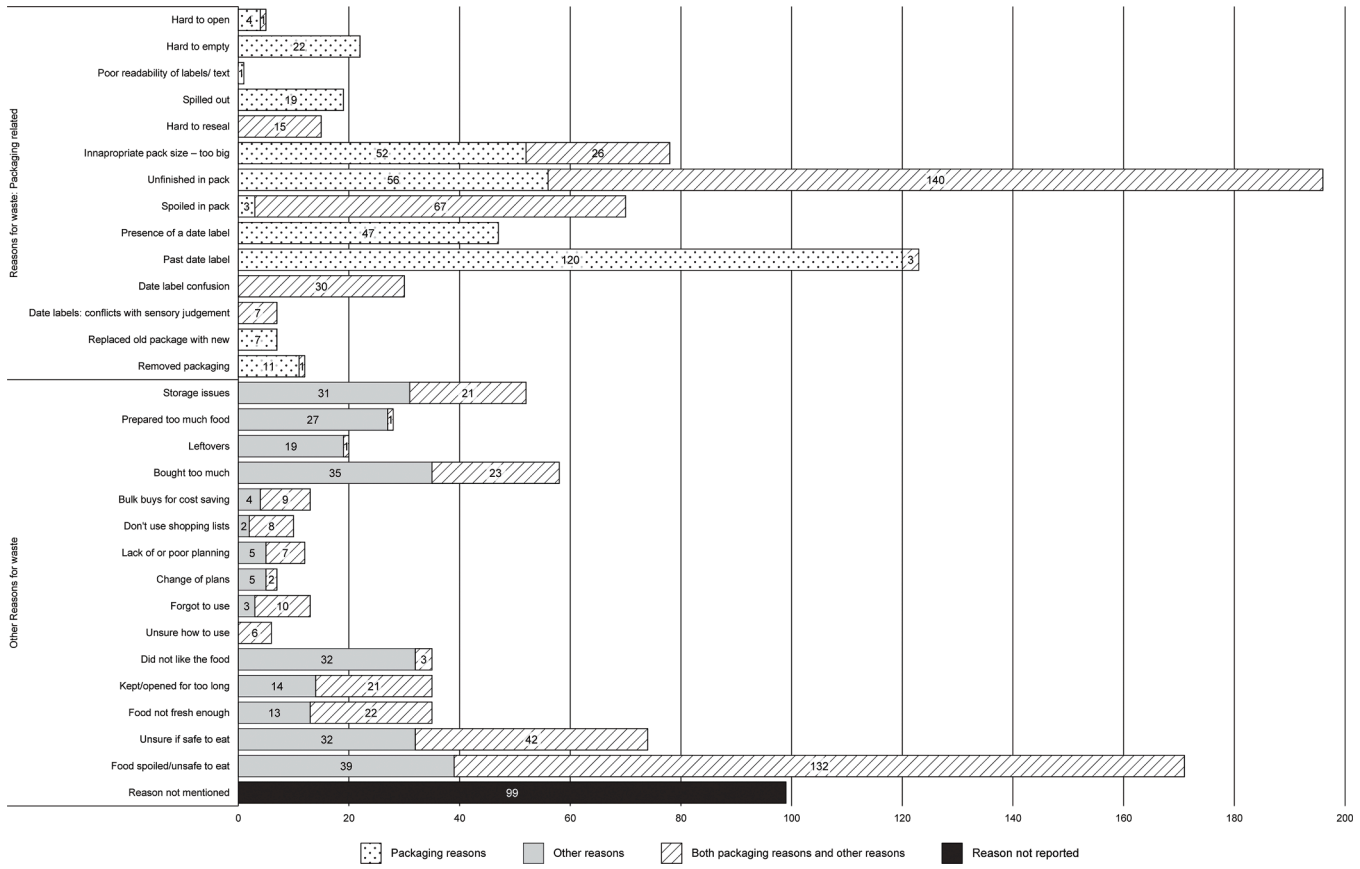


Fig. 2. Reasons for food waste by packaging and non-packaging reasons. A total of 909 entries from 60 empirical studies, where 49 studies contained reasons for food waste.

possible safety risk, the EMP showed inconsistent use and understanding of both labels by consumers. Hence, unless specified, both best before and use-by/expiry dates are relevant for all the different date-label-related HFW reasons discussed in this paper.

Food discarded due to being 'out-of-date' was most common, followed by the 'presence-of-a-date-label', 'date-label-interpretation-confusion', and date labels that 'conflict-with-sensory-judgment' (appearance/smell/taste). 'Presence-of-a-date-label' means that date labels were mentioned pertaining to FW without further elaboration of the type of date label; it is possible that food being 'out-of-date' may play a role as it is the most frequently reported date-label-related reason for waste. This driver was most reported for fresh fruits/vegetables in relation to best before dates (despite only being a quality guide), followed by dairy products due to use-by/expiry dates. Most food types were discarded due to being 'out-of-date', but the most reported were bread/cakes, pasta/rice/noodles, dairy products (including yogurt), meat/poultry. Perishable foods are therefore most affected, with the exception being pasta/rice/noodles which are assumed to be dried and thus more shelf-stable.

'Date-label-interpretation-confusion' occurs when consumers find it challenging to understand the meaning of best-before and use-by/expiry dates. This confusion is amplified by the inconsistent use of date labels across similar food categories (Ceuppens et al., 2016; Wilson et al., 2018). 'Date-label-interpretation-confusion' is related to 'conflict-with-sensory-judgment', where shelf-life information implied by the label is mismatched to consumer sensory judgments regarding food safety, leading to precautionary food discards (Brook Lyndhurst, 2008; Van Boxstael et al., 2014). Both drivers most affected fresh fruits/vegetables. Other affected food categories include bread/cakes, eggs, dairy products (including milk, yogurt, and cheese), meat/poultry, fish/-seafood, charcuterie, and salad. The influence of food safety is therefore unsurprising, as the data suggests that HFW reasons related to date labels and sensory judgment primarily affect perishable foods, posing food safety risks if eaten when spoiled.

For HFW drivers that are associated with both packaging and other reasons, the two most-mentioned are 'unfinished-in-pack' and 'food spoiled/unsafe-to-eat'. In connection to 'unfinished-in-pack', the most-mentioned foods are bread/cakes, vegetables, sauces/condiments/spreads, fruit, and dairy. For 'food spoiled/unsafe-to-eat' (referring to consumer perceptions), the most-mentioned are fruits/vegetables and dairy products. These two drivers ('unfinished-in-pack' and 'food spoiled/unsafe-to-eat') are often reported in connection to other HFW reasons; the most-mentioned include over-purchasing (including for cost savings), unsuitable (overly large) packaging sizes, inadequate freshness from a package opened for too long, spoilage, and forgetting to use the food. Bread/cakes, vegetables, and dairy discarded 'unfinished-in-pack' were also frequently reported in connection to the reason 'replaced old package with new', where consumers discard an existing (unfinished) package of food after purchasing a new package, in preference of consuming food that is fresher. There are patterns within some of these food categories. For fresh fruits/vegetables, 'unfinished-in-pack' and 'food spoiled/unsafe-to-eat' were identified twice as often as the other most common reasons. These same reasons were frequently identified for dairy products, but date labels are also a significant driver. Storage issues were frequently reported as HFW drivers for cheese and meat, especially relating to food quality. For meat, this is possibly tied to other commonly reported drivers: 'bought too much', 'past date label', 'unfinished-in-pack', and 'food spoiled/unsafe-to-eat'. Premature spoilage of fresh fruits/vegetables, cheese and meat are also reported in connection with 'removed packaging', where consumers remove the original packaging for storage. As packaging helps to provide storage conditions conducive to food product protection through reduced

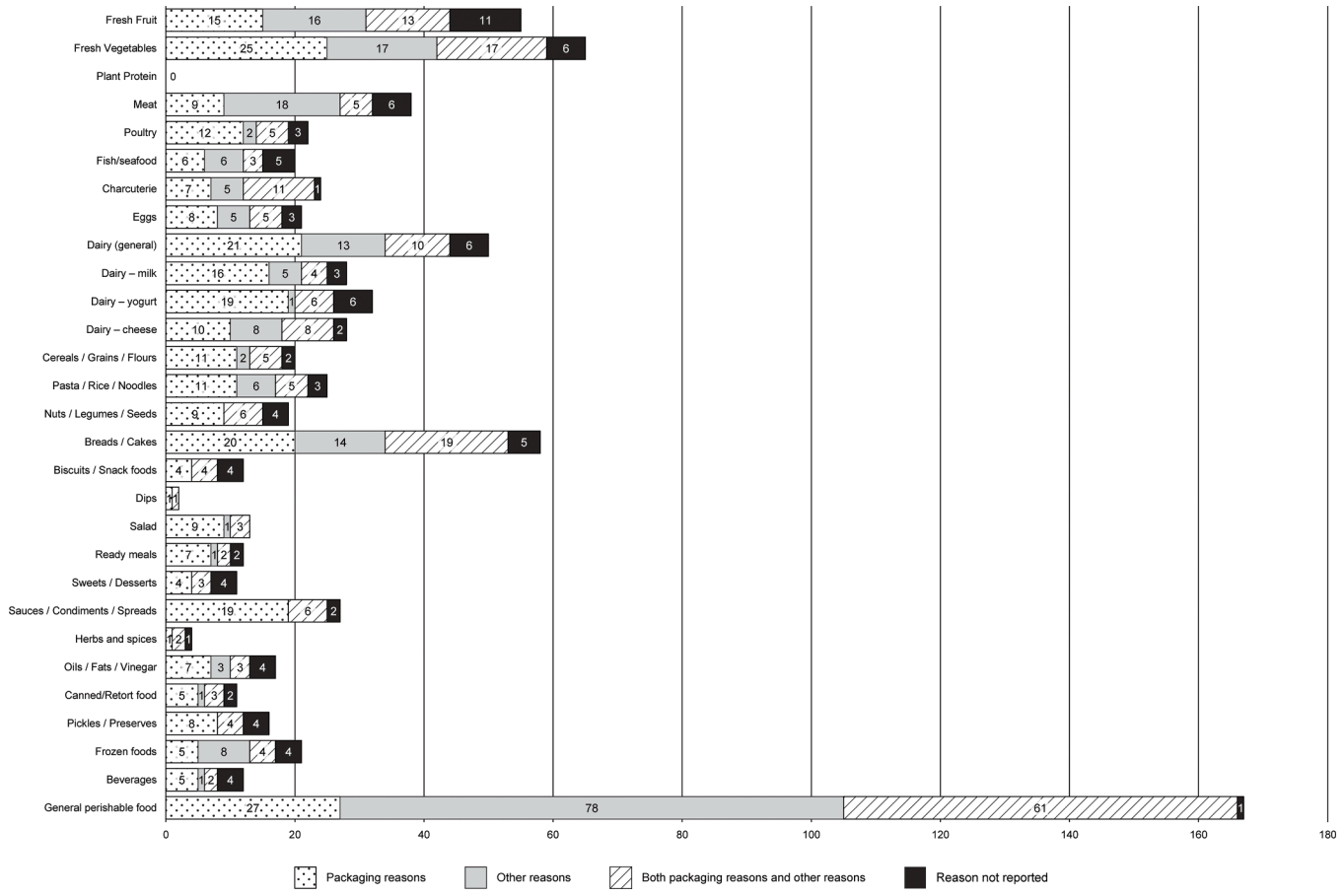


Fig. 3. Reasons for food waste by food categories. A total of 909 entries from 60 empirical studies, where 49 studies contained reasons for food waste.

exposure to elements that can accelerate spoilage (including oxygen, moisture, and pathogens) and protection from physical damage, removing packaging for food storage can contribute to food waste (Lockrey et al., 2020; Plumb et al., 2013).

3.3. Comparing packaging related HFW solutions from the empirical literature and industry PRs

3.3.1. Solutions by packaging functions

This section provides an overview of the 29 packaging functions information was gathered pertaining to HFW packaging solutions. Packaging solutions can comprise multiple packaging functions; a milk bottle has a function of physically protecting the milk and could have an additional function of resealability through a screwcap closure. This section will focus on packaging functions.

Fig. 4 shows packaging related HFW solutions from the EMP and PRs, compared by how frequently each packaging function is mentioned pertaining to the total number of studies for that publication type. It shows that the most-mentioned packaging functions differ between the EMP and PRs.

Industry PRs mentioned a greater number of packaging functions (27) compared to the EMP (22). However, when accounting for solutions within the 'other' category—only identified in the EMP—both publication types mentioned a similar number. The 'other' category includes an emphasis on consumer needs, smaller packages at the right (lower) price-point, food-safety-assessment guidance for opened packages, on-package information explaining packaging's benefits and/or FW consequences, and more protective packaging.

All but two packaging functions ('portion information' and 'other') identified from EMPs are present in the PRs. This suggests that majority of the packaging functions suggested in EMPs have precedence for commercial availability because they were also identified in PRs that promote packaging products released to market.

'Shelf-life-extension' is common to the five most-mentioned packaging functions in both publication-types. The most-mentioned packaging functions in the EMP are 'date labels' (22.7%), 'shelf-life-extension' (20.6%), 'other' (20.1%), and 'apportionment' (19.7%); in the PRs they are 'shelf-life-extension' (69.0%), 'barrier properties' (65.6%), and 'sealing properties' (55.2%).

The least-mentioned packaging functions in the EMP are 'easy-to-serve' (0.5%), 'easy-to-open' (1.0%), 'easy-to-dose' (1.0%), 'portion information' (1.0%), and 'smart packaging' (1.0%). Excluding the 'other' category, in the PRs they are 'storage information' (1.2%), 'easy-to-dose' (1.2%), 'cooking instructions' (2.1%), 'easy-to-read' (2.1%), and 'smart packaging' (2.5%). 'Easy-to-dose' refers to packaging that assists consumers to conveniently measure out the amount of food needed (Wikström et al., 2019). 'Easy-to-read' refers to on-pack information with a high degree of legibility such as adequately large text with adequate contrast to the background (Brook Lyndhurst, 2011; Langley et al., 2021).

Nearly a quarter of the packaging functions mentioned by PRs were not mentioned in EMPs: 'facilitates handling', 'sealing properties', 'tamper-proof/evident', 'integrated use', 'mechanical properties', 'barrier properties', and 'controlled atmosphere packaging'. 'Tamper-proof/evident' refers to packaging with a barrier to entry where if breached or missing, indicates the packaging may have been opened or tampered with; an intact seal at purchase helps to provide confidence to consumers that food is safe to consume.

Appendix D1 shows the number of times packaging functions were mentioned as HFW packaging solutions across both publication types,

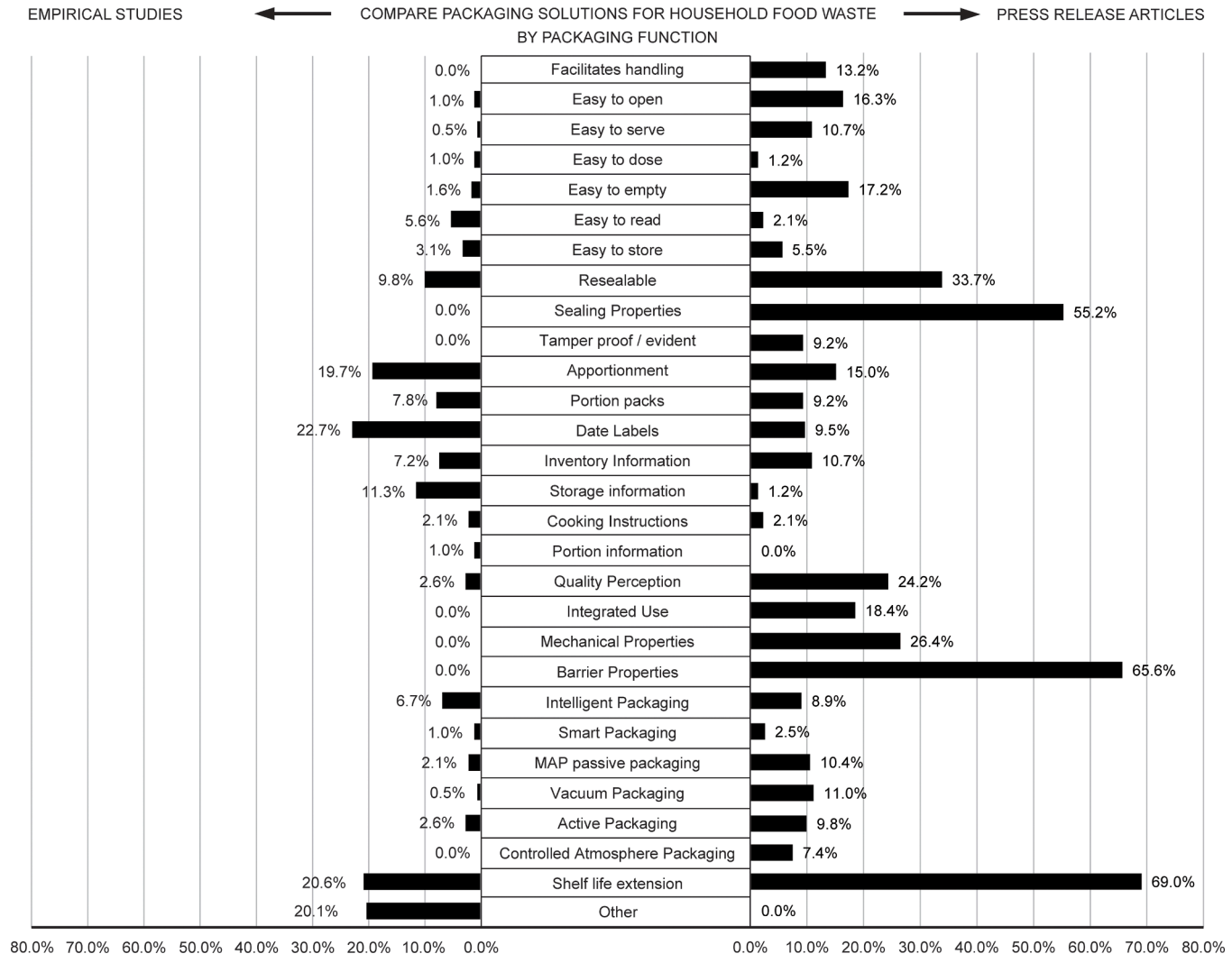


Fig. 4. A comparison of solutions for household food waste from empirical studies and press releases, listed by packaging function. The percentages listed represent the proportion out of total entries for empirical studies/press releases. A total of 306 entries for the empirical studies from 60 publications, where 48 publications contained packaging solutions. A total of 765 entries for the press releases from 412 publications.

grouped by 2-year time spans from 2006–2021. Different packaging functions were first mentioned in different years and some were increasingly mentioned, showing the progression of packaging development and trends.

Half of the packaging functions from the PRs were mentioned at an exponentially increasing rate, in particular, 'shelf-life-extension', 'barrier properties', and 'sealing properties'. This applied for fewer packaging functions from the EMPs but includes 'date labels', 'shelf-life-extension', and 'resealable'.

Some packaging functions in the PRs were first mentioned after 2006, the earliest year in this review. 'Date labels', 'easy-to-read', 'tamper-proof/evident' and 'mechanical properties' were first mentioned 2009–2011; 'easy-to-dose', 'storage information', 'cooking instructions', 'smart packaging' and 'antimicrobial packaging' was first mentioned 2012–2014.

Some packaging functions in the EMP, especially for packaging accessibility, were first mentioned years after they were first mentioned in PRs: 'easy-to-empty' (14 years after in 2020), 'easy-to-open' (7 years after in 2013), 'easy-to-serve' (7 years after in 2016) and 'easy-to-dose' (3 years after in 2015). Others include 'quality perception' and 'vacuum packaging' (both 14 years after in 2021), and 'smart packaging' (7 years after in 2020).

3.3.2. *Solutions by food categories*

This section provides an overview of the 29 food categories that HFW packaging solutions were suggested for in the publications.

Appendix D2 shows the number of times each food category was mentioned for packaging solutions identified in both publication types, grouped by 2-year time spans from 2006–2021. Packaging solutions can comprise multiple packaging functions but the number of mentions per food category was counted by packaging solution. For example, a milk bottle has a function of physically protecting the milk and could have an additional function of resealability through a screwcap closure; here milk counts as one mention.

The number of packaging solutions suggested by both publication types rose over the years, but for the EMP most solutions were for 'general perishable foods'. HFW packaging solutions by industry for staple perishable foods—including fresh fruit/vegetables, poultry/meat, dairy, and beverages—increased exponentially over the years. Solutions by EMP for these foods increased at a slower rate. Solutions for some food categories were first mentioned in both publication types in recent years including cereals/grains/flour (2014), pasta/rice/noodles (2014), and plant protein (2017).

Fig. 5 shows packaging related HFW solutions for different food categories from the EMP and PRs, compared by how frequently each food is mentioned pertaining to the total number of studies for that

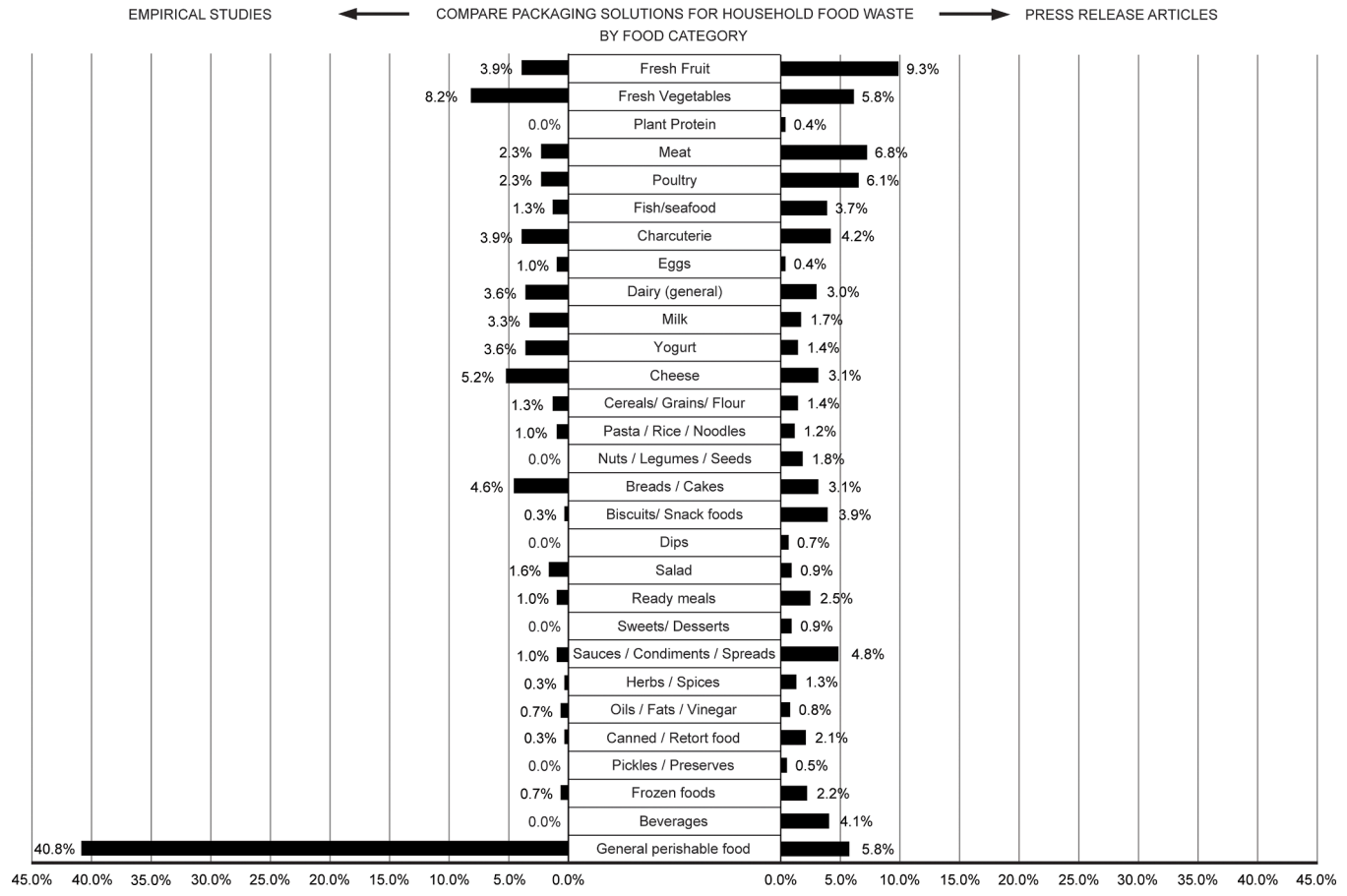


Fig. 5. A comparison of solutions for household food waste from empirical studies and press releases, listed by food category. The percentages listed represent the proportion out of total entries for the empirical studies/press releases. 306 entries total for the empirical studies from 60 publications, where 48 publications contained packaging solutions. 765 entries total for the press releases from 412 publications

publication type. Of the 29 food categories, industry mentioned 6 types more than in EMP, with HFW packaging solutions for plant protein, nuts/legumes/seeds, dips, sweets/desserts, pickles/preserves, and beverages mentioned only in PRs.

'Fresh vegetables' is common to the top-five most-mentioned food categories in both publication types (excluding general perishable food). The other most-mentioned food categories by the PRs are fresh fruit (21.8%), meat (16.0%), poultry (14.4%), and sauces/condiments/spreads (11.3%); these are less mentioned in the EMP (6.2%, 3.6%, 3.6%, and 1.5%, respectively). The other most-mentioned food categories for the EMP are cheese (8.2%), bread (7.2%), charcuterie (6.2%), dairy and yogurt (both 5.7%); charcuterie, bread, and dairy are mentioned in the PRs more frequently (9.8%, 7.4%, and 7.1%, respectively) but cheese and yogurt less frequently (7.4% and 3.4%, respectively).

The least mentioned food categories mostly differ between the EMP and PRs. For the EMP they are biscuits/snack foods (0.5%), herbs/spices (0.5%), canned/retorted food (0.5%), oils/fats/vinegar (1.0%), and frozen foods (1.0.%). For the PRs, they are plant protein (0.9%), eggs (0.9%), pickles/preserves (1.2%), dips (1.5%), and oils/fats/vinegar (1.8%).

3.4. *Whether suggested HFW packaging solutions address identified HFW drivers*

Packaging solutions from the EMP and PRs address different drivers identified in the EMP. Differences were expected due to the different focus of industry and researchers. It was surprising, however, that the HFW packaging solutions suggested by industry (through PRs) addressed a greater number of HFW drivers identified in the EMP than the EMPs themselves. That said, this can be explained by the focus of the reviewed EMPs, which was primarily to explore the drivers behind HFW (rather than suggest packaging solutions).

3.4.1. *Protecting food and extending shelf-life*

The most common HFW drivers were food becoming 'spoiled/unsafe-to-eat' or discarded 'unfinished-in-pack' due to date-labeling reasons. The most-reported packaging functions in the PRs address these issues by extending the shelf-life of food through physical protection (sealing/barrier/mechanical properties) against physical impact and elements that promote food degradation (including oxygen, moisture, and pathogens). Other packaging functions suggested in the PRs also promote shelf-life-extension through a tailored atmosphere—MAP/controlled-atmosphere/vacuum/active packaging technologies—but were less mentioned and these packaging lose their effectiveness after opening (Holdway, 2011). In fact, most were rarely mentioned in the EMPs; controlled-atmosphere-packaging was not mentioned.

3.4.2. *Managing the amount of food purchased*

Other HFW drivers related to 'unfinished-in-pack' include consumers over-purchasing food, connected to foods that come in inappropriately large pack-sizes. Overly large pack-sizes are of the top-5 most reported HFW drivers. This is addressed by the packaging functions of 'apportionment' and 'portion packs'; identified in both literature sets but more so in the EMP.

Packaging functions that assist with 'inventory information' can reduce FW by assisting consumers to keep track of what foods they have, identified in both the EMP (7.2%) and PRs (10.7%). Furthermore, the

presence of on-pack storage instructions can assist consumers to store food in a way that extends shelf-life, important when there are larger amounts of food to manage. 'Storage information' is mentioned in the EMP (11.3%), but much less so in PRs (1.2%).

3.4.3. Enabling packaging accessibility, ease of use

PRs mentioned accessibility-related packaging functions significantly more than in the EMP (see Fig. 4), both for the function type and how frequently each is mentioned. However, the EMP help to explain why packaging accessibility is important to help reduce HFW.

'Hard to open' packaging is associated with HFW because the force needed to open such packaging (such as metal cans with pull rings) by hand can result in the package tipping over or being damaged, leading to food spilling out (Caner and Pascall, 2010; Świda et al., 2019). 'Poor readability of labels/text' refers to small-sized text or text with inadequate contrast to the background it is printed on, which can render on-pack information such as date labels, food preparation and storage instructions harder for consumers to access—information that is key to helping consumers manage food and preventing waste (Brook Lyndhurst, 2011; Ford et al., 2016). As such, addressing packaging accessibility issues can help to reduce the chance of HFW. Packaging accessibility issues (hard to open/empty/reseal packaging and poor readability of labels/text) identified in the EMP were addressed by PRs through the functions of 'facilitates handling', 'easy-to-open', 'easy--to-empty', 'resealable', and 'easy-to-read'. Of these functions, 'easy--to-read' (2.1%) was least mentioned in the PRs, but the most mentioned in the EMP (5.6%). That said, all the other accessibility-related functions are infrequently mentioned in the EMP (1.6% or less) and 'facilitates handling' was not mentioned.

3.4.4. Packaging solutions for commonly wasted foods

Perishable foods were most reported as wasted and the packaging solutions suggested in both literature sets addressed this. Many packaging solutions in the EMP focused on perishable foods, so fewer were recommended for shelf-stable foods. While a similar pattern of packaging recommendations was observed in the PRs, solutions were suggested for a greater number of different foods and with a greater number of suggestions for these foods.

3.5. Material sustainability and HFW packaging solutions

In this review, 'material sustainability' refers to the direct impacts of packaging, such as the waste impact of a material when disposed (Sundqvist-Andberg and Åkerman, 2021). Material sustainability affects the ability of packaging solutions to be acted upon, so is relevant to this review.

Most of the packaging solutions identified in the PRs are made from polymer (or 'plastic') (75.2%), which includes polymer-composite materials. Other materials include fiber-pulp (12.6%), biobased materials (10.4%), metal (6.8%), glass (0.9%), and other materials (3.4%). The percentages for these materials do not add up to 100% as some packaging are made of more than one material type; 20.3% are composite materials.

For the EMP, however, nearly 80% of the HFW packaging solutions did not mention materials. Where mentioned, polymer was the most common (6.7%), followed by composite materials (4.1%), metal (2.1%), and glass (0.5%).

Most of the PRs (66.3%) did not mention packaging disposal. For those that did, 26.7% indicated recyclability, 5.2% indicated compostability, 4% indicated biodegradability. The percentages do not add up to 100% as some of the PRs indicated multiple end-of-life packaging disposal; fiber-pulp packaging is both recyclable and compostable. As for compostability, most indicated suitability for composting at an industrial facility while few mentioned home compostability.

The EMP did not mention disposal options for any of the recommended packaging solutions.

For the PRs, it was expected that the number of mentions for the material types would increase/decrease with the number of reported packaging solutions over the years (2006-2021). However, this was only true for polymer. There were three glass packaging solutions overall and metal packaging slightly decreased. From 2015, PRs for packaging solutions made from composite materials began to slightly decrease. The number of fiber-pulp packaging solutions increased but most were mentioned only from 2016, and this coincided with an uptick of packaging marketed as recyclable. PRs for packaging made from biobased materials marketed as biodegradable and compostable began to rise in the following years.

There is insufficient information on materials and end-of-life disposal options for the packaging solutions from the EMP to be able to comment on trends.

The EMP does, however, discuss consumer perceptions on packaging from a material sustainability perspective. Consumers' negative perceptions toward packaging are documented, especially concern over the polluting effects of plastic (INCPEN and WRAP, 2019; Lindh et al., 2016a; Plumb et al., 2013).

The implications of negative consumer perceptions and the effects of material sustainability on HFW packaging solutions are discussed in Section 4.4.

4. Discussion and opportunities for future research and industry practice

4.1. Awareness of packaging's role to reduce HFW

The rising number of HFW packaging solutions in both publication groups over the years (see Fig. 1 in Section 3.1.1) and the nature of the reviewed PRs suggest there is increasing awareness in the research community and industry of packaging's role to help reduce HFW. This is significant, as greater awareness is a first step towards developing and implementing packaging solutions to reduce HFW.

Most of the PRs were by food/beverage–packaging companies, promoting packaging formats that help reduce HFW by way of explaining the technical benefits of the materials used or the packaging's physical features/functions. Those PRs also raise awareness of packaging's role to reduce HFW and act as case studies on ways to design FW-prevention packaging. In isolation, however, greater awareness of packaging's potential to reduce HFW is insufficient to motivate action. Insights from an Australian study on product–packaging processes utilized by industry indicated 30% of respondents were unwilling to redesign product packaging to reduce FW, with cost being a key concern (Francis et al., 2021). Among other potential drivers of change, this highlights the importance of communicating to industry the benefits of reducing FW, as the financial benefits of action often outweigh the cost (Hanson and Mitchell, 2017).

An increasing number of HFW packaging solutions reported in PRs over the years could mean that more packaging solutions were specifically developed for HFW. It could also mean that existing solutions are increasingly recognized for their potential to reduce HFW. Either way, this is another positive step towards implementing packaging solutions to reduce HFW.

A contribution of this paper is to share the compiled information critically and clearly to help inform researcher/industry decision-making in packaging and studies; further research can explore drivers for researcher/industry behavior.

4.2. Implications of a Eurocentric focus for HFW research and packaging solutions

As shown in Section 3.1.3, most publications focus on developed nations; predominately countries in Europe, but also North America and Oceania/Australia. This means that the HFW drivers and packaging solutions reported here are most representative of these geographic

regions and should not be generalized to other regions.

The majority of the EMP and PRs relevant to Europe were for the United Kingdom (UK), partly driven by UK government–industry decisions prompting action (WRAP, 2022a). WRAP is behind over half of these EMP, an indication of their influence in shaping current research/practice. WRAP is tasked to deliver the Courtauld Commitment—a voluntary agreement for the UK food supply chain to reduce environmental impacts—and actions include packaging optimization and FW-reduction (WRAP, 2010). A connection between packaging suggestions by researchers and industry packaging developments is expected and indeed, some PRs mention WRAP/Courtauld Commitment (including Gyekye, 2012; Hills, 2009; McTigue, 2012). While WRAP is UK-focused, its work on reducing FW is inspiring action in other countries including Australia and New Zealand, where a version of WRAP's consumer behavior change campaign Love Food Hate Waste was adopted (Love Food Hate Waste New Zealand, 2019; State of NSW and EPA, 2017; Yamakawa et al., 2017). WRAP is also managing the development of voluntary agreements to reduce FW in various countries (Denmark, Indonesia, South Africa, USA, and Australia), including the Australian Food Pact which is similar to the Courtauld Commitment (Stop Food Waste Australia, 2021; WRAP, 2021). Therefore, a cross-continental collaborative approach can enable countries beyond Europe to benefit from the expertise/knowledge generated within Eurocentric—even UK-centric—FW reduction research/practice.

This review can be used as a starting point for further study that explores research and industry actions in non-anglophone areas including South America, Africa, Asia, and the Middle East—regions where there are currently few empirical studies and PRs published in English. Reviewing publications in other languages will provide information on the HFW waste drivers and packaging solutions available in these regions. This will assist to illuminate potential differences in supply chains and consumer behavior that are worth developing knowledge about in these contexts, facilitating the development/implementation of packaging solutions that reflect the different cultural/economic concerns and drivers of each region.

4.3. An opportunity to combine HFW packaging solutions from PRs and empirical studies to address a greater number of HFW drivers

This section will support researchers and the food/beverage–packaging industry to act against HFW by suggesting ways for both parties to learn from one another, collaborative opportunities, and research suggestions.

Packaging solutions from the EMP and the PRs each address different HFW drivers. Differences in academic/industry foci represent an opportunity for strengthened HFW-prevention-packaging research/implementation, especially through academic–industry collaborations. Combining solutions from both publication types may expose researchers/industry to existing solutions that they may not be aware of, increasing the chance of identifying a suitable solution to implement. This is supported by research that suggests a higher probability of positive commercial outcomes when academic-researcher–industry research collaborations leverage off complementary knowledge/resources (Marullo et al., 2021).

Most of the packaging functions/formats suggested in the EMP have precedence for commercial availability because they feature in the PRs. The PRs also communicated a greater variety of packaging solutions for a greater variety of food groups. This is positive, as it means that packaging suggestions identified in the EMP could already be making a difference to reduce HFW. However, extant EMP on HFW rarely provide evidence for the effectiveness of the solutions they recommend. Furthermore, a portion of the solutions in the PRs may no longer be on-market. Hence an opportunity for a market audit of HFW packaging solutions to see which are currently available and in which geographic regions. There is also an opportunity for researchers to collect data on how consumers use packaging to determine if existing recommendations/solutions work as intended; these data could be presented as case studies for industry to consider when implementing packaging solutions to reduce HFW, increasing the likelihood of transforming academic knowledge into industry impact.

Opportunities regarding specific food groups and packaging functions are detailed in subsequent subsections. Readers are reminded that that the reasons for HFW are complex and that multiple reasons may contribute to the waste of a single food item (Quested et al., 2013). Hence, the effectiveness of specific packaging functions suggested to help reduce the waste of specific food products may be dependent on multiple factors working in tandem. For instance, WRAP (2022b) demonstrates that the preservation qualities of packaging cannot be solely relied upon to prevent HFW as other factors play a role, including enabling consumers to purchase the amount of food that meets their needs, proper storage conditions, and effect of date labels on behavior.

4.3.1. Perishable foods

In the EMP, perishable staple foods—including fresh fruit/vegetables, bread/cakes, dairy products, meat/poultry—were most reported as wasted. It is therefore unsurprising that most of the packaging solutions in the EMP focused on these same foods. In the PRs, the number of packaging solutions for most of these foods increased exponentially at the greatest rate (see Appendix D2). This suggests that industry is addressing the short shelf-life of these foods as an issue, which is positive as solutions to reduce their waste are likely to yield significant results (for the volume of FW reduced) as they are frequently wasted.

There is an opportunity for industry to focus more on packaging solutions for other highly wasted foods, including bread/cakes and dairy products because PRs indicate that there has been less emphasis on solutions for these foods when compared to fresh fruit/vegetables and meat/poultry. A greater proportion of HFW solutions in the EMP were for bread/cakes and dairy products, so there is an opportunity for industry to note what these solutions are and implement them where appropriate. Solutions for industry to consider include on-pack storage advice and freezing advice for bread/cakes (Brook Lyndhurst, 2011; Plumb et al., 2013). Considerations for dairy products include an on-package guide to food safety with ways to judge food safety through sensory assessment and easy-to-empty packaging for viscous dairy products (cream, yogurt, etc.) to reduce the amount of food residue that remains inside (Williams et al., 2020).

Industry has suggested more packaging solutions for fish/seafood than in EMP; this is unexpected as fish/seafood is highly perishable. That said, half the amount of packaging solutions was recommended for fish/seafood by industry when compared to fresh fruit/vegetables and meat/poultry; representing an opportunity for researchers/industry to develop and implement more HFW packaging solutions.

4.3.2. Shelf-life-extension and an appropriate amount of food

EMPs provide substantial information that may be useful to industry for reducing HFW through packaging that better meets consumer needs pertaining to food quantity and shelf-life/freshness. Most of the packaging solutions in the EMP are mentioned in the PRs. However, the most-suggested solutions in the EMP (aside from shelf-life-extension) were less mentioned in the PRS, even though these addressed the most frequently reported HFW drivers. Hence opportunities for industry to develop more packaging solutions that address food apportionment and date-labeling issues.

Addressing food apportionment means providing consumers with the choice of multiple package sizes so that consumers are better able to purchase the needed amount. Overly large package sizes are a source of frustration (Ford et al., 2016; Joutsela and Korhonen, 2015) and as shown in Section 3.4.2, a significant HFW driver. Smaller package sizes should also be at a price-point that consumers are willing to pay (Lockrey et al., 2020; Williams et al., 2020), as consumers may otherwise opt for a larger package to save money—another HFW driver (Porpino et al., 2015).

Portion-packs and multi-packs, where food is divided into multiple sealed compartments, are another option to reduce HFW. These packaging formats enable consumers to keep bulk purchases fresher for longer, as one compartment can be opened for consumption while the remainder stays sealed (Scott and Butler, 2006). It is important that consumers recognize the benefits of these packaging as this would influence purchase decisions. This could be achieved through on-pack communication (Almli et al., 2018) and targeted education campaigns (Obersteiner et al., 2021).

Shelf-life-extension—the most-mentioned packaging function in the PRs—is based on the premise that giving consumers longer to consume food will reduce waste. There are, however, insufficient EMP consumer studies to support this in practice despite it being the second most-mentioned packaging function in the EMP. Hence, an opportunity for consumer testing within households on the effectiveness of packaging formats designed for shelf-life-extension—especially MAP/controlled-atmosphere/vacuum/active/intelligent packaging formats—as they are less mentioned in the PRs and underrepresented in HFW studies. Recent studies show that Italian consumers are more willing to purchase intelligent packaging than active packaging to reduce HFW (Cammarelle et al., 2021), and that MAP packaging can reduce the chance of wasted ham through a 30% extension of perceived shelf-life (Obersteiner et al., 2021). There is, however, scope for more studies. An Australian study on FW-prevention-packaging design practices supports this, showing that industry underutilizes active and intelligent packaging (Francis et al., 2021).

Shelf-life-extension is also related to date-labeling. Where safe and appropriate, extending the date can provide consumers a longer opportunity to consume food (Brook Lyndhurst, 2011). Furthermore, it is suggested that industry continue to educate consumers of the differences between best before and expiry dates and that industry is mindful to apply the appropriate type of date label on foods in a consistent manner (Brook Lyndhurst, 2011; Ceuppens et al., 2016); this would help to reduce the chance that edible food is discarded by consumers due to date label confusion and misinterpretation. Another aspect to consider is whether a date label is required; removing best before dates from fresh produce packaging is suggested by studies that show that its presence can lead to consumers discarding edible food (Brook Lyndhurst, 2011; WRAP, 2022b). The guide by WRAP et al. (2017) on industry best-practice for date labeling is a starting point to help industry navigate the nuances of date label use different food types. However, it is specific to the UK, hence an opportunity for more country-specific guides to be developed as the specific wording of date label terminologies differ across countries.

4.3.3. Storage-related solutions

Storage-related issues can drive HFW. Both the EMP and PRs have presented related solutions but with a different emphasis, bringing multiple opportunities.

Consumer confusion on how to appropriately store food can lead to waste (Brook Lyndhurst, 2011; Lockrey et al., 2020), highlighting the importance of consumer communication and education on this matter. One approach is through on-pack storage information but in the PRs, this was one of the least mentioned packaging functions/solutions (1.2%). However, a recent Australian study indicates that storage instructions are already adopted by industry to reduce HFW (Francis et al., 2021). While this is positive for action toward reducing HFW in Australia, it does not reflect industry practices in Europe, where most of the packaging solutions identified from PRs pertain to. A European supermarket audit study highlights the issue of inconsistent storage advice across similar food categories as it contributes to consumer confusion (Ceuppens et al., 2016). Hence an opportunity for industry to focus on consistent and unambiguous communication of storage advice to consumers (WRAP et al., 2017).

Storage information is within the top-5 most-mentioned packaging solutions in the EMP. Suggested packaging solutions in the EMP often respond to drivers identified from these studies, so industry is encouraged to learn more about the context of storage-related issues from these studies. This would be a starting point for developing and implementing storage related HFW packaging solutions.

There are research opportunities for how consumers use resealable packaging because fewer EMPs (9.8%) mentioned resealability than PRs (33.7%), which is in the top-5 most-mentioned solutions. EMP mostly mentioned resealability in response to food wasted due to the inability/difficulty in resealing an opened package, resulting in food dropping below a quality standard that consumers accept, including dried-out cheese and deli meat (Lockrey et al., 2020; Williams et al., 2020). Cheese and deli meats are therefore a suggested starting point for future research in regions such as Europe, North America, and Oceania/Australia where they are consumed in large amounts, especially pertaining to the effectiveness of current resealable packaging formats for these foods.

Packaging that renders food 'easy-to-store' is a function where there is an opportunity for both industry and researchers to focus more on, especially given how infrequently it is mentioned (3.1% for EMP and 5.5% for PRs). 'Easy-to-store' includes stackable packaging (Hebrok and Heidenstrøm, 2019), which assists with food management. It is related to packaging functions regarding convenience and accessibility, including 'easy-to-open', 'easy-to-serve', 'easy-to-dose', 'easy-to-empty', and 'easy-to-read'; all underrepresented in the PRs and EMP, hence an opportunity for research/development. A researcher–industry collaborative effort is suggested for the benefits of empirical data and application of the findings, for a greater chance of reducing HFW.

4.4. Balancing material sustainability and sustainability perceptions when implementing HFW packaging solutions

Material sustainability is a pertinent issue for industry as it affects the design/development, market implementation, and consumer acceptance of packaging solutions designed to reduce HFW (APCO, 2020; Lindh et al., 2016a; Otto et al., 2021). These issues are hinted at in the PRs and EMP.

Despite the importance of material sustainability to packaging design, it is unsurprising that majority of the PRs and all the EMP did not mention packaging disposal options, despite mentioning packaging materials. This is partly due to the focus of this review (packaging solutions for HFW) affecting publication selection criteria. Packaging materials are therefore more often mentioned pertaining to the functions they provide (e.g., oxygen/moisture barriers from certain polymers/plastics). That said, the broader context of sustainability in which industry operates can be gleaned from the reviewed PRs. In the past five years, a greater number of PRs reported on HFW packaging solutions that are recyclable, biodegradable, or compostable; more solutions made from fiber-pulp (recyclable) and fewer PRs for composite materials (harder to recycle). This aligns with a market shift toward a greater emphasis on material sustainability for packaging, which is expected to continue affecting what HFW packaging solutions are released to market (Smithers, 2021).

This market shift is partially due to packaging targets and laws (introduced in different countries including Australia and France) that govern what materials are used in packaging and how they can be disposed of (APCO, 2020; EU FUSIONS, 2015). In Australia, the 2025 packaging target encourages industry to reduce the use of unnecessary plastic, increase the use of recycled materials, and ensure all packaging is either reusable, recyclable, or compostable (APCO, 2020). This packaging target is before the 2030 target of halving FW (SDG 12.3), showing that industry must balance competing priorities when designing food packaging. This challenge of balancing material sustainability with FW is mentioned in some of the PRs (PN Staff, 2020; Poole, 2020; Qureshi, 2020), and is supported by a study of packaging design practices by the Australian food/beverage–packaging industry (Ryder et al., 2021). To assist industry with this challenge, the

sustainable packaging guidelines in Australia contain a section on reducing product/FW (APCO, 2019), addressing the risk of increased FW when packaging is indiscriminately reduced or removed to meet material sustainability targets.

Industry is encouraged to consider both FW and material sustainability when deciding whether to remove or reduce packaging to meet material sustainability targets. Life-cycle analysis studies show that in situations where reduced/removed packaging results in increased FW, the environmental impact of the FW can be greater than using packaging to prevent FW, demonstrating that reducing/removing packaging is not always the most environmentally beneficial option (Abejón et al., 2020; Lockrey et al., 2019; Miller, 2020). While studies evaluating the potential impact of plastic-free supermarket aisles for fresh fruits/vegetables showed decreased shelf-life for fresh fruits/vegetables and an increased chance of FW (Allen et al., 2019; White and Stanmore, 2018), they also show that the benefit of packaging for fresh fruit/vegetables depends on variety and type of packaging. Hence, a case-by-case basis is warranted when determining whether to sell loose. A in-home storage simulation study by WRAP (2022b) recommends that retailers sell fresh fruits/vegetables loose, where the effects of packaging to extend in-home shelf-life (and therefore reduce HFW) are considered insignificant when compared to other factors that influence HFW (including appropriate storage temperatures, ability to purchase the needed amount, and the effect of date labels on consumer behavior). A way forward is built-in leeway within packaging targets and laws for judicious use of packaging that considers HFW and material sustainability for individual food products (APCO, 2019; WRAP, 2022b). France banned plastic packaging for many fresh fruit/vegetables in 2022 as part of an anti-waste law that moves toward phasing out single-use plastic by 2040, yet the country is also committed to a national pact to halve FW by 2025, so there are some exemptions to the ban for foods at risk of deterioration if sold in bulk (EU FUSIONS, 2015; Packaging Europe, 2021). Industry faces many challenges when designing and implementing packaging to help reduce HFW, and part of the solution is understanding and communicating these challenges. There is therefore an opportunity for case studies to be released on how material sustainability and FW have been addressed during package design; this would assist industry knowledge on what to consider, for a better chance of designing packaging that balances both.

Consumer perceptions of packaging sustainability play a role in whether packaging is deemed necessary or wasteful, affecting consumer acceptance of packaging (Lockrey et al., 2020; Otto et al., 2021; Plumb et al., 2013). While packaging's role in sustainable development through its ability to reduce FW is recognized in the EMP (Verghese et al., 2015; Wikström et al., 2018), it appears that consumer understanding of this aspect is limited, so consumers see packaging as wasteful (Lindh et al., 2016a). Consumers' negative perceptions toward packaging affects industry willingness to implement packaging solutions to reduce FW (Ryder et al., 2021). Further work is therefore needed to educate consumers on packaging's role to reduce FW (Lockrey et al., 2020), as this will help to increase consumer acceptance of (and therefore willingness to purchase food in) packaging designed to help reduce FW. As packaging is the main interface between industry and consumers where marketing messages can influence consumer decision-making at the point of purchase, industry can consider using on-pack messaging to communicate to consumers the benefits of packaging (Almli et al., 2018; Rundh, 2005). The more consumers accept (and purchase) packaging designed to reduce FW and recognize its role in sustainable development, the greater the incentive for industry to implement it; important for packaging to make a difference in reducing FW.

Moving forward, industry is encouraged to remember that while both packaging and FW negatively affect the environment, appropriate packaging systems that prevent FW can result in a net environmental benefit (Heller et al., 2018; Svanes et al., 2018). Sustainability is viewed by parts of the Australian food/beverage–packaging industry as a 'Save Food Packaging' function due to packaging's role in delivering sustainability benefits through reduced FW (Francis et al., 2021). It would be beneficial if the food/beverage–packaging industry in other countries adopt this view because this would encourage a holistic method of designing sustainable packaging that takes into account material impacts, FW impacts, and packaging functions that suit consumer needs (Grönman et al., 2013), resulting in food packaging that meets material sustainability targets while helping to minimize HFW.

5. Conclusion

HFW is a significant problem with many potential solutions. This study focused on compiling, comparing, assessing, and summarizing recommendations for packaging solution implementation, guided by the 'act' stage of the 'target-measure-act' approach for reducing FW where researchers and the food/beverage–packaging industry play a role. There is a lack of EMP studies that show what industry has done so far, making it a challenge to contextualize extant packaging related EMP in relation to industry action. Thus, this comparative review sought to contribute related insights.

The results were encouraging due to significant growth in the number of HFW packaging solutions recorded in the EMP and PRs over the years. Most of the solutions suggested by researchers have precedence for commercial availability as they were mentioned in the PRs; a positive sign for HFW reduction if these solutions are effective and accessible to consumers/still on-market, but more research is needed to confirm this. While the PRs indicate that industry has developed a plethora of solutions, industry has focused least on the packaging functions that researchers have emphasized the most. This presents a significant opportunity for industry, as these functions suggested by researchers address the most-reported HFW drivers (date labels, inappropriate pack sizes, 'unfinished-in-pack'). Recommendations pertaining to specific packaging functions (including date labels, apportionment, easy-to-empty, on-pack communication, storage instructions) and key food groups with opportunities to develop more packaging solutions (including bread/cakes, dairy products, fish/seafood) are provided, and it is hoped that industry and researchers will consider these. Readers are reminded that the results presented in this study focus on English-speaking countries and are predominantly Eurocentric.

Industry faces many challenges when designing/developing and implementing packaging solutions. This includes, but is not limited to, the competing priorities of balancing FW reduction with material sustainability. There are many ways to address this but researcher–industry collaboration is a way forward. If academic research into HFW-prevention-packaging is to contribute to practice through improved packaging that accounts for societal contexts and industry challenges, there is benefit in encouraging knowledge-sharing between academia/industry to actively seek insights from research findings generated in each other's contexts. Considering the different focus of researchers and industry when recommending solutions, when combined, the unique contributions and skills of both are likely to result in more effective implementation of packaging solutions to reduce HFW.

Researchers and industry are therefore encouraged to communicate and collaborate on future research/practice, to develop and implement packaging solutions that will enable people to reduce HFW. This literature review has demonstrated the value of looking across, by indicating the types of empirical data that can inform product development within industry.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Supplementary materials

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