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Abstract

This study complements a previous study that combined household survey data with weights of curbside separated organics in the residential sector (Parizeau et al., 2015). Our findings reinforce the need for the collection of detailed observational data in household food waste audits. We revisited some households from the original study and a new set of households in order to conduct compositional audits on all three streams of waste, and to combine these results with survey data. In the compositional audits, we observed an average food waste per capita of 1.64 kg per week, and avoidable food waste per capita of 1.05 kg per week. Overall, 64% of wasted food was avoidable. The highest proportions of total and avoidable food waste came from fruits and vegetables (63%; 59%), followed by bread products (14%; 22%). Combining the compositional audits with survey data, we confirmed some of the behavioural and attitudinal patterns assessed in our previous study, including that household composition, food awareness, waste awareness, and convenience lifestyles may impact household food waste generation rates. Individual household audits provide greater insight into food waste generation than do curbside weights.

Keywords

Compositional audits, household food waste, Canada, avoidable food waste, observational data, variability

1. Introduction

Household food waste is a significant source of economic, nutritional, and environmental cost (von Massow et al, 2019). Despite increased attention to food waste generation in policy circles and advocacy campaigns, there is still relatively little observational data on household

food waste generation and its drivers around the world. In this paper, we report on a follow-up study to Parizeau et al. (2015), wherein we combined household survey results with curbside weights for three streams of waste (organics, recyclables, and residual garbage). In the present study, our objective was to return to a subset of households in the initial curbside study in Guelph, Ontario as well as an additional set of households to conduct compositional audits, which included a detailed analysis of food waste according to food groups and avoidability. A primary aim of this study was to understand what compositional audits could contribute relative to other observational methods of assessing household food waste.

The direct observation of household food waste via compositional audit makes an important contribution to discussions of food waste generation. The combination of detailed audit data with household survey data allows for a novel analysis of the social and familial dynamics that can impact food wasting. As noted by Xue et al. (2017), only 20% of published food waste studies reported observational research findings; this category included diary and self-report methods, which have been found to be unreliable. A number of studies have documented the substantial underreporting of food waste generation behaviours when using self-report methods (Delley and Brunner, 2018; Giordano et al., 2018; Giordano et al., 2019; van Dooren et al., 2019; van Herpen et al., 2019; Quested et al., 2020; van der Werf et al., 2020). Elimelech et al. (2019) conclude that while "subjective self-assessments" are less costly, they are also not accurate: in their study, people both over- and under-estimated their food waste generation. These studies highlight the importance of direct observational data for assessing household food generation rates, such as can be obtained through composition audits.

Table 1 summarizes published research on the household food waste generation rates as observed in composition audits from different locales. We have included research that reports on

per capita rates of food waste generation rather than the whole household's rate of food waste generation, as household sizes can vary greatly. This table indicates that per capita household food waste generation rates are lower in Global South countries (e.g. South Africa and China), moderate in some European nations (e.g. Austria, the Netherlands, Finland, Denmark, Norway) and Israel, and higher in Hungary and the United Kingdom. The proportion of food waste that was deemed avoidable[1] varied among these studies, although many reported that approximately 50-60% of food waste was avoidable. Research from the United Kingdom reported a much higher avoidability rate of 81%.

[Insert Table 1]

Table 1: Household food waste generation rates observed in waste composition audits

In Parizeau et al. (2015), we estimated a weekly per capita household food waste generation rate of 4.2 kg per capita (or 218.4 kg per capita annually) in Guelph, Ontario. However, this was an estimate based on curbside weights of source separated organics, which can include non-food organic materials such as lawn waste and compostable paper products. Furthermore, this method did not allow us to observe food waste disposed of in the garbage and recycling streams, and it also did not allow us to observe food waste placed in the sewage system (e.g. van Dooren et al. 2019 estimate that an additional 57.3 L of liquid waste are disposed of per capita annually; see also Reynolds et al., 2014). We concluded that more extensive composition audits were needed in order to directly observe per capita residential food waste generation rates in a Canadian municipality. These audits also offered the opportunity to observe ratios of

[1] Avoidable food waste is considered "food and drink thrown away that was, at some point prior to disposal, edible" (WRAP 2009, p.4).

unavoidable and avoidable food waste in the household food waste stream, and to observe food waste generation rates across food groups.

Most published household food waste composition audits do not report on sub-categories of food waste according to food groups. A Canadian study (van der Werf et al., 2020) reported that avoidable household food waste was comprised of 32% fruits and vegetables, 23% bread and baked goods and cereals, 15% other foods, 14% meat and fish, and 10% dairy, and 6% dried foods (including cereals). In the Netherlands, van Dooren et al. (2019) observed the following proportions of avoidable food waste in their composition audits: 32% fruits and vegetables (including potatoes), 26% breads, pastry, and cake, 19% dairy, 8% meat and fish, 4% rice and pasta, 4% sauces and fats, with the remainder divided among small categories of other foods, soups, sweets, leftovers, etc. While there are differences between these two studies, they both indicate that produce is the most wasted food group, followed by bread products. Studying the composition of food waste provides valuable information for designing interventions to prevent future waste.

2. Material and methods

This series of studies was conducted in partnership with the City of Guelph's Solid Waste Resources department. Parizeau et al. (2015) reported on 2013 data from household survey results combined with curbside weights of three streams of waste; the organics stream waste was used as a proxy for total household food waste. In the Summer of 2014, we returned to a subset of 61 households from the 2013 curbside study who had also completed surveys to complete compositional audits. We also conducted follow-up surveys with all of the audited households to ensure that the same residents lived there, and to assess if there had been any changes to

92 household composition since the surveys were conducted in the previous year. Only households
93 with the same residents were included in the study, allowing us to appropriately combine the
94 previous year's survey results with the compositional audit results. We repeated this process in
95 the Summer of 2015, auditing 54 households that had participated in a separate study using
96 curbside weight and had completed surveys, conducting follow-up surveys to ensure we were
97 observing the same residents. In total, our compositional audit sample included 115 households
98 between the data collected in Summer 2014 and Summer 2015.
99 The surveys were administered door-to-door, collecting information about socio-
100 demographics, food-related behaviours, and environmental attitudes and beliefs. For the
101 compositional audits, we collected all three streams of waste (organics, recycling, and garbage)
102 for 2 weeks in the summers of 2014 and 2015 audits on the normal waste collection day.
103 Organics are collected every week in Guelph, and garbage and recycling are collected every
104 other week. The City composts the organic waste it collects, sorts and markets its recycling, and
105 landfills the garbage. We looked through all three streams for both avoidable and unavoidable
106 food waste, documenting where the food was found and whether it was categorized as avoidable,
107 possibly avoidable, or unavoidable. The avoidable and possibly avoidable streams were
108 combined for the analysis described below. The compositional audits followed the methodology
109 described in WRAP (2013), with small adaptations to the categorizations. In particular, we
110 grouped foods according to their primary constituent components (such as including cakes and
111 muffins with bread products, when they would have been classified as "cake and desserts" using
112 the WRAP categories). Our compositional categories included fruit and vegetables; bread and
113 cereals; milk cheese, and eggs; meat and fish; fats and sugars; and other. The "other" category
114 was used for items like coffee grounds and tea bags, as well as unidentifiable foods. Composite

meals were sorted out as best as possible according to their primary ingredient. We also documented the amount of non-food organic waste in all three streams, the amount of food waste found in the recycling and garbage streams, and the amount of contamination (i.e. garbage or recycling) found in the organics stream. We used SPSS software for our bivariate and correlational statistical analyses, and a significance threshold of $p \leq 0.05$.

There were some limitations to our method, including our inability to observe liquid food waste disposed through the sewer system, food fed to pets, or food diverted to at-home composting systems. Food waste is seasonal, and our observations in the summertime are likely not representative of year-round food waste generation rates. This study also focused on single-family homes due to the logistics of collections and the ability to identify which waste came from which household. Our estimates are therefore likely more representative of middle-income households with more members than the average multi-residential household. There are limitations to the comparability between this composition audit and Parizeau et al. (2015): this study revisited some of the households reported on in the earlier study, but also includes additional households of similar type.

3. Results and discussion

3.1 Household characteristics and audited waste amounts

In this analysis of a subset of households from our curbside audit studies, we observed an average of 3.3 people per household, and an average of 0.9 children per household. These figures are in line with those reported in the larger curbside study (Parizeau et al., 2015), where we observed an average of 3.3 people per household, with an average of 1 child. As detailed in Table 2, the composition audits yielded an average weekly rate of total food waste generation per capita of 1.64 kg, which is an annual equivalent of 85.28 kg (average weekly weight times 52).

This amount is substantially less than the weekly per capita total food waste generation rate of 4.2 kg reported in Parizeau et al. (2015), revealing the methodological limitations of using organics curbside waste weight as a proxy for total food waste. In the current study, 37% of the organics we audited were non-food organics in the composition audits. Anecdotally, non-organic food waste amounts varied substantially across our curbside and compositional audits. We occasionally observed households setting out multiple bags of kitty litter (accepted in the organics stream locally) or yard waste, including heavy brush. The organic waste stream itself varies greatly from week-to-week, especially as seasonal fruits (such as watermelon and un-shucked corn) become locally available. These factors can substantially and inconsistently impact the weight of the entire organics stream, and support the need for detailed composition audits undertaken for several weeks.

Compiling household-scale composition audits from 9 Canadian municipalities, van der Werf et al. (2018) reported an annual household total food waste generation rate of 2.40 kg per week, or 124.80 kg per year. At the household scale, we have observed more total food waste (4.83 kg per week, or 251.16 kg annual equivalent) in Guelph. We cannot know whether household sizes were comparable across these locales, and suspect that the households were larger among the single-family houses we audited compared to broader municipal audits. It is also possible that residents of our study locale generate more organic waste than other locales. It is possible that households waste more food when they believe it will be composted due to access to a source separated organics stream. The per capita total food waste amounts that we observed in the composition audit (1.64 kg per week, or 85.28 kg per year) are almost exactly the amount that the Commission for Environmental Cooperation (2017) estimated for per capita

residential food waste in 2012 (85.09 kg). This variability highlights the need for locally based audits to support local policy.

3.2 Waste composition

We observed that 64% of all food waste was avoidable / edible, with a weekly per capita average of 1.05 kg of avoidable food waste and an annual equivalent of 54.60 kg. The weights are in line with the amounts of avoidable food waste reported in Nordic countries and Israel as summarized in Table 1 (Edjabou et al., 2016; Hanssen et al., 2016; Elimelech et al., 2018), and the proportion of avoidable food waste is higher than in all locales except for the United Kingdom (WRAP, 2008). The proportion of avoidable food waste observed in this composition audit is similar to the 68% of avoidable food waste that our research group observed in a self-selected sample in the same locale (von Massow et al., 2019).

[Insert Table 2]

Table 2: Summary statistics from food waste composition audits

Table 2 also documents contamination across the three streams. We observed a weekly average of 0.45 kg per capita of food waste sorted incorrectly into the garbage or recycling streams, and also observed an average of 0.07 kg per person of contamination of garbage or recycling materials in the organics stream. The variability evident in the standard deviations and the levels of contamination in the non-organic streams highlight the importance of auditing all streams of waste for individual households (where municipalities have implemented source separation) in order to locate and document food waste wherever it was disposed.

Figure 1 depicts the breakdown of total food waste according to food groups, and Figure 2 shows avoidable food waste according to food groups, based on the compositional audit data.

In both cases, fruit and vegetables made up the majority of waste, indicating that fruit and vegetables drive both unavoidable food waste (e.g. pits and peels), as well as avoidable food waste, likely due to their relatively short shelf-life. Breads and cereals are the next largest category of both avoidable and unavoidable waste: all of this waste was considered avoidable (or possible avoidable) in our auditing protocol. Meat and fish was the next largest category of both unavoidable and avoidable food waste, followed by the other category, milk, cheese and eggs, and fats and sugars. This pattern is consistent with the findings of van der Werf et al. (2020) and van Dooren et al. (2019), as discussed above.

[Insert Figure 1]

Figure 1: Proportion of total food waste according to food groups

[Insert Figure 2]

Figure 2: Proportion of avoidable food waste according to food groups

Figure 3 shows the proportions of avoidable versus unavoidable food waste observed across all households according to food waste. This graph shows the predominance of fruit and vegetable waste in households in terms of both unavoidable and avoidable food wastes.

[Insert Figure 3]

Figure 3: Proportions of avoidable and unavoidable food waste observed across the composition audits according to food groups

3.3 Drivers of household food waste

In Parizeau et al. (2015), we compared household survey responses to the relative amounts of organic waste generated by households. We proposed four sets of relationships based on that analysis: family size and large households (larger families and households generated more organic waste, but less per capita), food awareness (there were some indications that those exhibiting more attentive or intensive food practices generated less organic waste), waste awareness (those more conscious of waste issues generated less organic waste), and convenience lifestyles. We noted two patterns of convenience-related waste generation. First, household spending on non-grocery food – including restaurants, cafeterias, and fast food – was associated with both higher amounts of organic waste generation and more money spent on groceries. We hypothesized that busy households bought their groceries and then left them to spoil as the week became busy and they turned to restaurants and fast food to supply their meals, thus driving up both weekly food costs and organic waste. Second, households that relied on pre-packaged foods as a convenience strategy (rather than eating out) generated less organic waste. We hypothesized that households relying on pre-packaged food as a grocery strategy generated less unavoidable food waste that would be associated with food preparation, thus leading to a lighter organic waste stream. We returned to the survey data from the households included in our composition audits to retest these relationships, given that the composition audits provide a more accurate assessment of food waste amounts within the organics stream.

The compositional audit data confirmed the family and household size observations from Parizeau et al. (2015): households with children and those with more than two people produced less total food waste per capita (Wilcoxon Ranksum: $p = 0.003$; $p = 0.018$), as well as less avoidable food waste per capita (Wilcoxon Ranksum: $p = 0.036$; $p = 0.004$). This relationship has been observed in other studies of household food waste, including audit-based and self-report

studies (do Carmo Stangherlin and de Barcellos, 2018; Schanes et al., 2018; Quested et al., 2013).

With respect to food awareness, the composition audit data revealed that those who reported more frequently making impulse purchases when food shopping produced more total food waste per capita (Wilcoxon Ranksum: $p = 0.000$), more avoidable food waste per capita (Wilcoxon Ranksum: $p = 0.000$), and more avoidable fruit and vegetable waste per capita (Wilcoxon Ranksum: $p = 0.007$). In contrast, those who said they more regularly shopped for food according to a budget generated less avoidable food waste per capita (Wilcoxon Ranksum: $p = 0.029$).

With respect to waste awareness, those who said that reducing food waste is primarily the responsibility of individuals (rather than stores or government, for example) generated less total food waste per capita (Wilcoxon Ranksum: $p = 0.006$), less avoidable food waste per capita (Wilcoxon Ranksum: $p = 0.002$), and less avoidable fruit and vegetable waste per capita (Wilcoxon Ranksum: $p = 0.008$). These findings suggest that believing food waste reduction is within a household's locus of control could lead to concordant behaviours (see also van der Werf et al. 2019). In Parizeau et al. (2015), we hypothesized that households who reported that they disposed of spoiled food may have been more likely to place this type of food waste in the garbage stream. We were not able to verify the hypothesized relationships in the composition audit, but did observe that those households reporting that they decided to throw away food after smelling (Kruskal-Wallis: $p = 0.001$) or tasting it (Kruskal-Wallis: $p = 0.018$) were more likely to have disposed of food waste in the garbage or recycling streams. This finding suggests that a more visceral experience of disgust associated with waste decision pathways may prevent proper sorting of organic waste into the source-separated organics stream (for more on the visceral

253 nature of food waste see Fraser and Parizeau, 2018; Waitt and Phillips, 2015). We regularly
254 observed that food found in the garbage and recycling streams was in its original disposable or
255 recyclable packaging. A visceral disgust might prevent someone from engaging with food
256 enough to remove it from its packaging before disposal.

257 With respect to the convenience lifestyle findings, the composition audit data confirms
258 that amount of money spent on grocery food waste positively correlated with the amount of
259 money spent on non-grocery food (Pearson correlation coefficient: 0.378, $p = 0.000$). The
260 amount of money spent on non-grocery food alone was not significantly correlated with
261 avoidable food waste, but total food waste was positively correlated with the amount of money
262 spent on all food (Pearson correlation coefficient: 0.195, $p = 0.037$), and total avoidable food
263 waste was positively correlated with amount of money spent on groceries (Pearson correlation
264 coefficient: 0.245, $p = 0.009$). The hypothesized convenience pattern in Parizeau et al. 2015 (i.e.
265 purchasing groceries and then buying unplanned take-out or restaurant meals, leading to wasted
266 food) fits within the relationships that we observed in the composition audits. However, we
267 would expect to observe that the amount of money spent on all food would be positively
268 correlated with avoidable food waste, and not just total food waste in this case. A larger sample
269 size may allow for more power in assessing this subset of the waste stream. When we analyzed
270 the amount of unavoidable waste generated in households according to their reliance on pre-
271 packaged foods, we did not find a significant relationship. However, we note that very few
272 households participating in the composition audit study reported that they "often" or "always"
273 relied on pre-packaged foods ($n = 8/115$), which likely limited our ability to assess this
274 hypothesis properly.
275

4. Conclusions

These results indicate that weighing the mixed organics stream of residential waste is not a good proxy for food waste amounts. However, the proportional differences between the full organics stream and food waste amounts appear somewhat consistent given the consistent survey relationships observed in both this data set and Parizeau et al (2015).

We observed that among a sub-set of detached homes in Guelph, ON, average food waste per capita was 1.64 kg per week, and avoidable food waste per capita was 1.05 kg per week. Overall, 64% of wasted food was avoidable. We also observed food waste according to food groups, and the highest proportions of total and avoidable food waste came from fruits and vegetables, followed by bread products. These results were comparable to those reported from some other high-income contexts.

We re-assessed the patterns of social behaviours and attitudes that we reported in Parizeau et al. (2015), and found comparable findings to suggest that household composition, food awareness, waste awareness, and convenience lifestyles can impact household food waste generation. We conclude that observational data provides an important foundation for food waste policy and programming, and suggest that researchers continue to refine the methods that we use to assess household food waste generation.

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401 Table 1: Household food waste generation rates observed in waste composition audits

	Annual food waste per capita	Proportion that is avoidable or possibly avoidable	Source
Denmark	48 kg avoidable	56%	Edjabou et al., 2016
Norway	79 kg total / 46 kg avoidable	59%	Hanssen et al., 2016
Finland	23 kg avoidable	--[2]	Silvennoinen et al., 2014
Sweden	--	35%	Bernstad and Andersson, 2015
Netherlands	30.4 kg avoidable	53%	van Dooren et al., 2019
UK	70 kg avoidable	81%	WRAP, 2008
Hungary	68 kg total / 33 kg avoidable	49%	Szabó-Bódi et al., 2018
Austria	33 kg total / 19 kg avoidable	56%	Lebersorger and Schneider, 2011
Israel	95 kg total / 50 kg avoidable	54%	Elimelech et al., 2018
China	16 kg total	--	Song et al., 2015
South Africa	8-12 kg total	--	Oelofse et al., 2018

402

403 Table 2: Summary statistics from food waste composition audits

	Weekly average	Standard deviation	Annual equivalent
Total food waste per capita	1.64 kg	2.22 kg	85.28 kg
Avoidable food waste per capita	1.05 kg	1.69 kg	54.60 kg
Total unavoidable food waste per capita	0.59 kg	0.96 kg	30.68 kg
Total food waste in garbage / recycling streams per capita	0.45 kg	0.70 kg	23.40 kg
Total green bin contamination per capita	0.07 kg	0.18 kg	3.64 kg

404

[2] "—" denotes unavailable data.

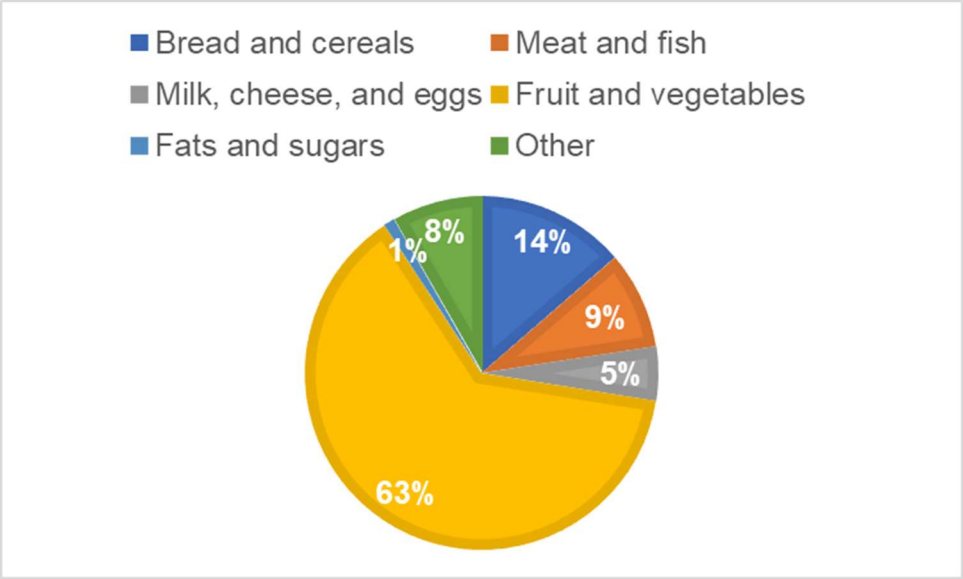

Figure 1: Proportion of total food waste according to food groups

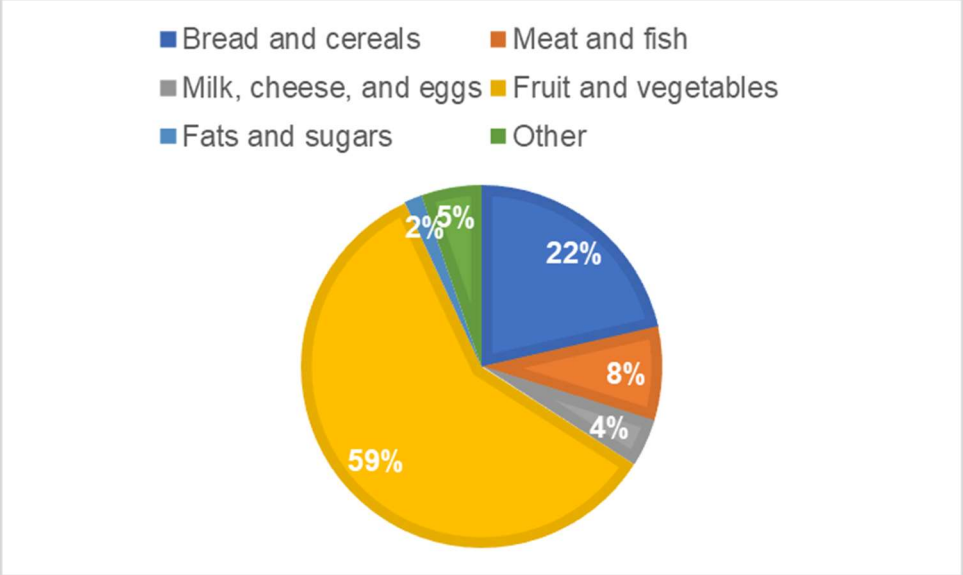

Figure 2: Proportion of avoidable food waste according to food groups

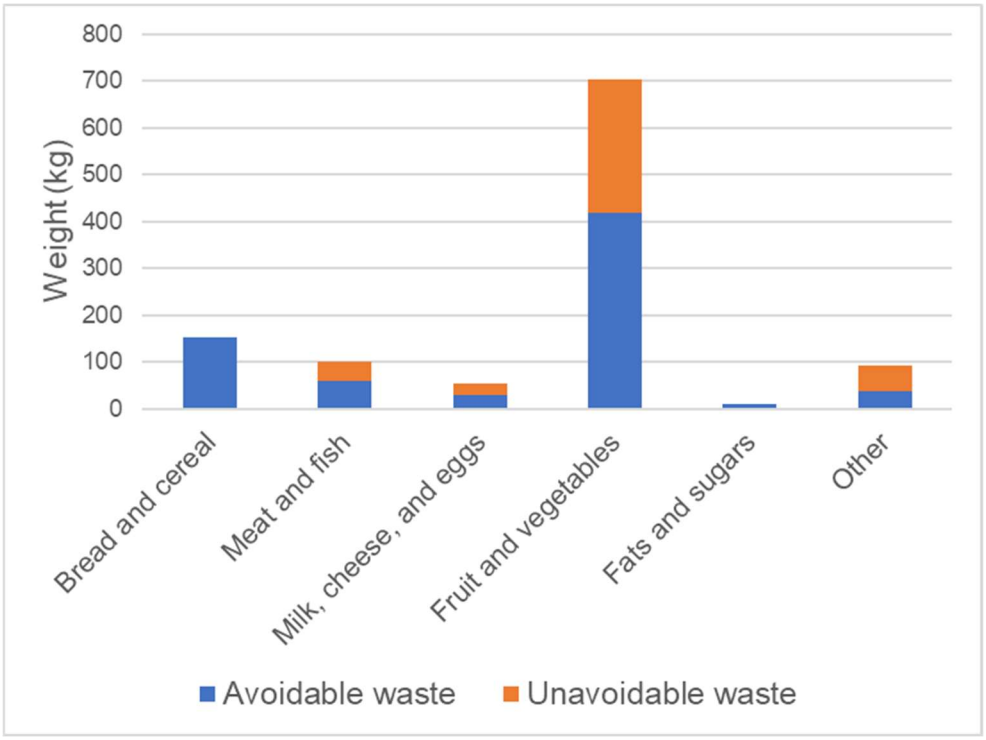

Figure 3: Proportions of avoidable and unavoidable food waste observed across the composition audits according to food groups