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Research Paper

Tackling the challenges of food waste diary studies — Testing strategies with Finnish data

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ABSTRACT

This study reports food waste diary results in Finland from 2019 (296 households) and 2022 (372 households) using an online food waste diary Kotihukka. According to the results, Finnish households waste 15.5–16.9 kg (SD 16.7–17.5 kg) of edible food per person per year. The results are an underestimate, but diary method is still a suitable method for collecting detailed and household specific food waste data and monitoring the relative difference in waste volumes. Furthermore, to evaluate the results, it is important to concentrate on 1) sample requirements for repeated measures, 2) needed resources, and 3) methodological restrictions. First, food waste diary studies often lack evidence-based discussion on the adequacy of data to monitor the direction of food waste. This study demonstrated that the sample sizes and length of the observation period (14 days) would be sufficient to detect a population-level decrease of 20–25 % in the amount of food waste during the next decade. Secondly, as bigger sample sizes require more resources, the necessity of kitchen scales was systematically studied for the first time. This study found evidence that households can report food waste as reliably without the assistance of kitchen scales as with kitchen scales, and therefore it is possible to cut costs and improve scalability without causing measurement bias. Third, since often most motivated participants attend the diary studies, this study also provides strong evidence that a self-selection bias can be reduced with monetary compensation: the household dropout rate decreased from 29 % to 7 %.

1. Introduction

Though there is pressure to produce more food due to global population growth, it is estimated that roughly a third of food is lost in the food chain (UN, 2024). While food production affects the environment (Rockström et al., 2009), wasting food results is an unnecessary burden on the environment (Scherhaufer et al., 2018). Food waste reduction is high on the political agenda. Indeed, the United Nations (UN) targets the halving of food waste at retail and consumer levels and the reduction of overall food losses in the entire food chain (UN, 2016), while the European Commission has also launched an action plan to reduce food waste by 30 % by 2030 (European Commission, 2023).

In developed countries, most food waste occurs at the end of the food chain, especially in households (Bräutigam et al., 2014; Parfitt et al., 2010; Principato et al., 2021; Stenmarck et al., 2016; Eurostat, 2023). Additionally, since the number of invested resources increases towards the end of the food value chain, it is particularly efficacious to reduce food waste at the end of the food chain, hence in households (Timmermans et al., 2014).

1.1. Food waste quantification methods at the household level

Table 1 shows the main differences between food waste quantification methods at the household level. Some methods require more active household participation, and these methods include surveys, diaries, and kitchen caddies (self-collecting household waste) (van Herpen et al., 2019; Merian et al., 2024). In contrast, waste compositional analysis (waste bag sorting after bags leave the household) and bin cameras do not require active participation from households (Sjölund et al., 2025; Withanage et al., 2021).

Waste compositional analysis, bin cameras, and kitchen caddies are used for monitoring food waste, whereas food waste diaries are used for multiple purposes (Table 1). Diaries support especially the collection of detailed data from each participating households, where the aim is to increase the understanding of food waste in connection to the household type and behaviour (Merian et al., 2024). Furthermore, household

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specific data is needed to study the possible root causes of food waste (Aschemann-Witzel et al., 2021; Withanage et al., 2021) and to identify hot spots for targeting reduction measures (Hebrok and Boks, 2017).

Diaries give a more comprehensive picture of waste composition because they are not restricted to whether waste ends up in a waste bin or other location such as a sewer or compost (Withanage et al., 2021) (Table 1). As a downside, diaries are widely criticised for underreporting due to behaviour change (van Herpen et al., 2019; Quested et al., 2020; Schoeller et al., 2013; Withanage et al., 2021). Household awareness of the study objective seems to be a key factor of underreporting. For instance, according to the study by Merian et al. (2024), the time and effort used to self-report household food waste did not impact the results, but those households who were aware of the study objective reported less food waste.

Diaries can be relatively affordable (Merian et al., 2024) (Table 1), whereas kitchen caddies and bin cameras are the most resource intensive. Whilst the sample sizes of waste compositional analysis are larger, their data can be still skewed because waste compositional analysis is limited to individual or at the most a few waste disposal facilities serving near-by limited areas. Moreover, waste compositional analysis often takes place in waste sorting facilities where food waste has remained in waste bags for several days, which leads to sieving, where smaller material is not detected in waste sorting; degrading, where food is no longer recognisable; and evaporating, where water evaporates especially from fruits and vegetables, resulting in weight changes (Quested et al., 2020).

1.2. Challenges of food waste diary studies

Quested et al. (2020) list the main four challenges of waste diary studies that cause underreporting: 1) behavioural reactivity, 2) misreporting, 3) measurement bias, and 4) self-selection bias. In behaviour reactivity, the diary respondent intentionally changes their behaviour because they want to minimize the burden of reporting. In contrast, in misreporting, the respondent forgets to report all waste, while in measurement bias, the respondent reports the wrong waste amount because of challenges in estimating waste. In the self-selection bias, the respondents do not represent the rest of the population because only the most motivated participants attend the study (Quested et al., 2020).

Moreover, food waste diary studies often fail to provide an understanding of how different methodological choices impacted the results. For instance, Eičaitė and Baležentis (2024) reviewed European food waste diary studies where the results ranged from 18.2 kg per person per year (kg/p/year) in Switzerland (Ammann et al., 2021) to 74.5 kg/p/year in Lithuania (Eičaitė & Baležentis, 2024). However, since there were differences in the execution of the diary studies, it is not possible to compare the results. For example, the high waste figure of the Lithuanian study (Eičaitė & Baležentis 2024), could be partly explained by the fact that the households were visited before and after the diary study, and each household was also contacted by phone during the study.

1.3. Opportunities of food waste diary studies

The usual strategy to minimize behaviour reactivity is to simply ask the participants to behave as usual (Koivupuro et al., 2012; Herzberg et al., 2020; Withanage et al., 2021). Additionally, some methods, such as photo-diaries could reduce the threshold to report food waste (Roe et al., 2020), whereas home visits by the research team could increase the household engagement-level (Eičaitė & Baležentis, 2024). Underreporting can be minimized also with a careful study design by identifying strategies that help the participants to avoid errors, remind them to keep waste records, and motivate different types of households to participate in the study.

Nevertheless, the present study also acknowledges that it is difficult to completely avoid behaviour change in diary studies. In fact, some level of underreporting should be acceptable, given that underreporting is constant and does not affect the overall trend of food waste volumes. Moreover, the methodological choices of diary studies need to remain constant to monitor change in the volume of waste between repeated measurements. Consequently, if these conditions apply, the present study argues that diary studies can be used to monitor relative change in waste volumes.

1.4. The study's objectives and novelty

An online diary was used because diary studies have the potential to attain sufficiently large and representative sample sizes (Withanage et al., 2021), and to collect detailed household level data on the amount of edible food waste (food that could have been eaten at one point in its lifecycle) (Table 1). However, because diary studies suffer from underreporting and they can be resource intensive (Table 1), the aim was to test ideas that have potential to improve the diary study as a method. Consequently, three hypotheses (H1–H3) were derived for the present

Table 1
Comparing food waste quantification methodologies (modified from Merian et al., 2024), WCA = waste compositional analysis.

	WCA	Bin camera	Kitchen caddy	Diary	Survey
Household involvement, awareness[b]	Very low/none	Low	Medium-high	High	High
Location of measurement	Waste sorting facility	Household	Research facility	Household	Household
Purpose	Monitoring food waste	Monitoring food waste	Monitoring food waste	Monitoring food waste Explanatory research Alternative waste routes	Limited food waste monitoring Limited explanatory research Household background information
Strengths	Accurate measures on solid food waste	Accurate measures on solid food waste	Relatively accurate measures on solid food waste	Detailed information on every food item wasted	Affordable Easy to combine with other methods
Weaknesses	Resource intensive Excludes alternative waste routes Sieving, degrading, evaporation No link to household	Resource intensive Excludes alternative waste routes	Resource intensive Excludes alternative waste routes Sieving, degrading, evaporation Underreporting if aware	Underreporting Can be resource intensive	Based on household recall: significant underreporting
Sample	Restricted to certain areas	Low sample size Longitudinal Self-selection bias	Low sample size Self-selection bias	Relatively representative Self-selection bias	Relatively representative Self-selection bias

[b] Indicating the level of household involvement and awareness of the study objective.

study.

The first aim was to improve the sample representativeness and reduce self-selection bias. Since waste recordings take time and effort, there is a danger that only the most motivated participate and finish the study successfully. Although many food waste diary studies use monetary compensation (e.g. Merian et al., 2024), there is little evidence on its actual impact on the sample. Therefore, the first hypothesis (H1) was:

H1: Monetary compensation is needed to motivate households to engage in food waste reporting and to reduce possible self-selection bias.

Secondly, self-reporting often reduces the transparency of reporting. Therefore, due to a lack of transparency, there is a risk of not noticing if households miss-report or change their behaviour to minimize the burden of reporting (behaviour reactivity). Hence, there is a need for practices that both increase the transparency of reporting and remind households of the study. Since constant reminders could lead to behaviour adaptation (Merian et al., 2024), the aim was to keep the reminders to the minimum. Therefore, the second hypothesis (H2) was:

H2: Obligatory daily entries make sure that households produce a daily routine in using the online diary, and hence improve the transparency of reporting, and consequently reduce the risk of behaviour change and possible miss-reporting.

Thirdly, the aim of the present study was to test if kitchen scales could be abandoned so that in future the sample size could be scaled up and costs cut. Here, the target was to find out if it is possible to guide households in other ways to help them in waste recordings. Although there is little evidence on the impact of kitchen scales to results, Roe et al. (2020) found evidence that while kitchen scales did not completely remove the possibility of human error (some households reported their waste using wrong units (kg instead of g)), kitchen scales let to fewer errors in comparison to visual aids. Therefore, the aim was to make sure that abandoning kitchen scales does not lead to measurement bias. Hence, the third hypothesis (H3) was:

H3: Food waste amounts, and possible failures in measurement do not differ between households that use kitchen scales and households that do not use scales.

Moreover, to support food waste monitoring, there is a need to produce a time series that reliably gives the direction of the volume of food waste. However, the literature lacks a discussion of the representativeness and quality of the time series data needed to verify the direction of food waste levels in households (Xue et al., 2017). A time series requires both good quality data and methods that enable growing the sample size (H1-H3). Additionally, there is a need for estimating how large the sample size should be and how long the observation period should last so that the targeted reduction could be observed with sufficient statistical power. Therefore, the research objective (RO1) was also to:

RO1: Estimate the necessary sample size depending on the length of the observation period (3–14 days) for observing a given level of change in the volume of waste between repeated measurements.

2. Materials and methods

The data presented here are based on two online diary studies conducted in Finland in November-December 2019 and May 2022. The studies were conducted 2.5 years apart to detect possible changes between repeated measures. In previous studies, the only clear seasonal trend in waste levels has been autumn with a significant peak of apple waste (Silvennoinen et al., 2014; Silvennoinen & Nisonen, 2020). Hence, autumn as well as seasonal holidays were excluded from the possible study periods.

2.1. Recruitment process

In the 2019, the survey was sent to 4,000 respondents through a survey poll (Appendix A), and altogether 1,151 respondents answered the online survey. Next, the survey respondents were also asked whether they were willing to participate in the online food waste diary study. In the request, they were told that there would be a draw for a tablet computer among other smaller prizes for the participants. Initially, 417 households agreed to participate in the study, but in the end 296 households completed the study.

In the 2022 study, unlike in the 2019 study, the respondents were recruited directly from the poll (Appendix A). The respondents were told that the survey was about food waste recording. Additionally, as an incentive, all participating households were rewarded with a gift card for a grocery store (worth €30). In addition, half of the respondents also received kitchen scales (worth €20). The invitation was sent to 3,339 households before the targeted 400 respondents agreed to participate in the study, and 374 completed the study.

2.2. Representativeness of samples

The number of respondents to the online diary studies numbered 296 (2019 study) and 374 (2022) (Table 2), whereas, at the time of the studies, there were around 5.5 million residents and 2.8 million households in Finland (Statistics Finland, 2023). Furthermore, when comparing the sociodemographic factors of the food waste diary studies to the national averages, the biggest difference was in the household sizes: single households were underrepresented in both samples (Table 2). The average household size was 2.3 in the 2019 sample and 2.1 in the 2022 sample, whereas the national average was 1.9 in 2022 (Statistics Finland, 2023). Moreover, women and Uusimaa-residents were overrepresented in both samples (Table 2).

2.3. Kotihukka online food waste diary

Designed by researchers at National Resources Institute Finland (Luke) and Mediasignal Communications, the Kotihukka-diary[1] is a web

Table 2
Number of participants and the sociodemographic factors of diary respondents compared to national demographics.

	Diary 2019	Diary 2022	All Finnish households in 2022 (Statistics Finland, 2023)
Number of households, n	296	374	2,816,206
Gender (respondent/ reference person), %			
Female	57	63	51
Male	43	37	49
Age (respondent/ reference person), %			
15–34	34	20	28
35–54	40	38	29
55–64	12	19	15
65 +	14	23	27
Living area (household), %			
Uusimaa	35	41	31
Southern Finland (excl. Uusimaa)	19	23	21
Western Finland	25	19	25
Northern and Eastern Finland	21	17	23
Household size (household), %			
1 person	28	33	46
2 persons	39	43	32
3 persons	14	12	10
4 + persons	19	12	12

[1] Kotihukka is the brand-name of the online food waste diary owned by Natural Resources Institute Finland. Kotihukka comes from the Finnish words *koti* (home) and *hukka* (waste).

application which is accessible via smart phones, tablets, and computers (Fig. 1). The participants were instructed to keep a record of each time edible food (excluding inedible food parts) was wasted by any member of the household (see further information in Appendix A).

In 2019, all participating households reported their waste amounts to Kotihukka without using kitchen scales, whereas in 2022, half of the participating households (189) had kitchen scales to measure food waste, while half (183) did not a have a scale. Those households that received kitchen scales were not allowed to base their reporting on estimates but were required to report their waste amounts by only using kitchen scales. In the 2022 study, the households were divided into the two groups (scales and no scales) randomly, and the socio-demographic features of both groups were comparable.

Those households that did not have kitchen scales (296 households in 2019 and 183 in 2022), were asked to report the amount using units from a list. These units included grams, pieces, decilitres, plate (big or small), and spoon. To estimate the amount of food left on a plate, the respondents were given visual aids to choose from (Fig. 2).

Conversion factors were used to convert all food waste entries into grams (Appendix B), which were based on the Finnish Institute for Health and Welfare database (Fineli, 2020; Sääksjärvi & Reinvuo, 2004). Food waste calculation models for both study periods are presented in Appendix C.

2.4. Hypothesis testing and sample evaluation

The expenses, and completion and attrition rates of both diary studies are presented in Table 3. To test the hypotheses H1–H3, both data and methods between the 2019 and 2022 studies were compared (Table 3). The threshold for statistical significance was set at $p = 0.05$. First, the strategy to attract and motivate respondents was a treatment between the two data sets (H1). Here, the aim was to study the dropout rates (share of respondents who agreed to participate in the study but did not register to Kotihukka), to see how engaged the households were in both groups. The difference in the dropout rates was calculated using Fisher's exact test, as this can be used to test differences in rates without any distribution assumptions, based on a 2×2 contingency table with the sampling years as columns and the number of enrolled participants who did and did not finish the study as rows.

Secondly, the obligation to report every day was also a treatment between the two data sets (H2) (Table 3). While in both studies the aim was to always report food waste, in the 2022 study, households also reported no-waste. The aim of this was to study if the obligation to report also no-waste would impact the number of food waste reporting entries and the proportion of days with reported food waste. Also, to remove the impact of the measurement method from the results, only those households that reported food waste without kitchen scales were considered. Due to the extreme skewness of the household food waste distribution, the statistical significance of the difference in the total food waste amount was tested with the nonparametric bootstrap (Efron, 1994). No assumptions need to be made about the shape of the distributions. Though differences in the number of entries could be tested in the aggregate by also using, for example, a binomial test, the bootstrapping approach is more robust against outliers. In all, a total of 100,000 bootstrap samples were used.

Third, a kitchen scale, or the lack of it, was considered a treatment between the respondents. Here, the aim was to test whether in the 2022 study households with kitchen scales differ in their waste amount, number of entries, and/or number of reported days containing food waste in comparison to households who did not use kitchen scales (H3). Again, due to its flexibility and non-normality of the response variables, the statistical significance of the differences was tested with the nonparametric bootstrap.

Finally, regarding the research objective (RO1), data from the two studies were used to obtain reliable estimates for a sample size necessary for observing targeted reductions in the food waste amount. A parametric form for the distribution of food waste was estimated using graphical investigations and the results were confirmed with the Kolmogorov–Smirnov test. Power calculations were done by simulating dataset pairs with given differences in means for a range from $N = 10$ to 3000. Furthermore, the effect of shortening the observation period to 3, 5, 7, or 10 days on the required sample size was estimated by repeating the analysis after truncating the data by cutting the necessary number of observation days from the end. In addition, checks for the number of entries between the first and second week and weekdays and weekends were performed for the whole sample with a standard binomial test. These tests should be regarded as explorative and were not part of the predetermined hypotheses.

All statistical analyses were carried out with the R statistical software (R Core Team, 2022), with some visualisations implemented through the use of the ggplot2 package (Wickham, 2016).

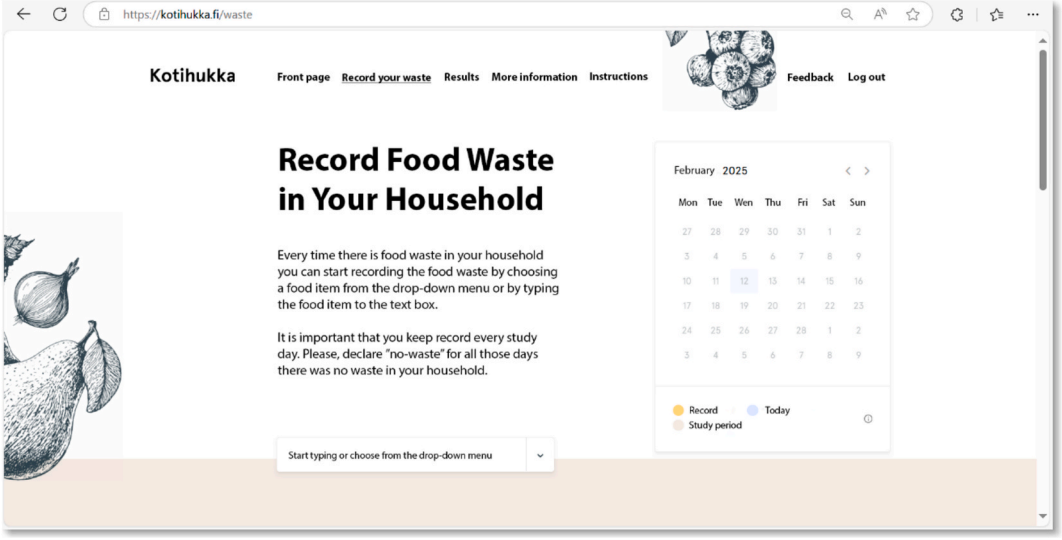

Fig. 1. Kotihukka online diary, front page.

Fig. 2. Visual aids to choose how much food was left on a plate, Kotihukka-diary.

Table 3
Number of households, monetary expenses, completion and attrition rates, and tested hypotheses. KS=kitchen scale

	Diary 2019	Diary 2022
Number of households, n	296	374
Price per respondent: recruitment, survey[c], Kotihukka development & maintenance, €	49	26 (without KS) 26 (with KS)
Price per respondent: respondent motivation, kitchen scales (incl. handing, shipping), €	2	32 (without KS) 61 (with KS)
Price per respondent: total, €	51	58 (without KS) 87 (with KS)
Completion rate, %	71	93
Attrition rate, %	7	11
Respondent motivation (H1)	Price draws	30 € gift card (+ KS)
Obligatory to report every study day (H2)	No	Yes
Household uses kitchen scale, n (H3)		
Yes	0	189
No	296	183

[c] Only in the 2019 study.

3. Results

3.1. Kotihukka-diary feedback

The Kotihukka-diary received good feedback from its users. According to a feedback survey in 2019, the respondents considered the diary intuitive and easy to use. Among 227 respondents, 79 % considered the diary to be easy or very easy to use, and 99 % considered it at least relatively easy to use (on a 6-step scale: 'very easy' to 'very difficult'). Additionally, in the open feedback, none of the respondents complained about not having kitchen scales to hand when reporting food waste amounts. In 2022, though there was no feedback survey, households were asked to report if they faced any challenges. None of the households reported problems with Kotihukka-diary.

3.2. Attrition and dropout rates

In 2019, 417 households agreed to participate in the diary study and use the Kotihukka-diary, but only 296 households successfully registered to Kotihukka and completed the study. Hence, the dropout rate was 29 %. Additionally, since the invitation to the respond survey was sent to 4,000 households, the attrition rate was 7 % (households that successfully completed the study divided by invitations sent).

In the 2022 study, the attrition rate was 11 % and 400 households agreed to participate in the study. In the end, 374 registered to Kotihukka and completed the study, and hence the dropout rate was only 7 %. The difference in the dropout rates between 2019 and 2022 was highly statistically significant ($p < 0.0001$) thus supporting the first hypothesis (H1).

3.3. Food waste entries

In the 2019 study, the 296 households recorded an average 0.59 entries per household per day (Fig. 3) (average 174 entries/all households/day, Appendix D1). During the 14 days, the average household recorded food waste on 5.0 days and made 8.2 entries. Furthermore, the number of entries showed no decline towards the end of the study period (Fig. 3). Entries in the first 7 days represented 52 % of all entries, and the difference in the number of entries between the first and latter 7 days was not statistically significant ($p = 0.08$) based on a two-tailed binomial test. Moreover, there was no difference ($p = 0.41$, binomial test) in the number of entries between weekdays and weekends (23.-24.11 and 30.11.-1.12.).

In the 2022 study, during the official food waste recording period (14 days: 16.5.-29.5.2022), households with scales recorded 0.66 food waste entries per household per day, while households without scales recorded 0.57 entries per household per day (Fig. 3) (average 459 entries/all households/day, Appendix D2). However, the difference was not statistically significant ($p = 0.15$) based on the nonparametric bootstrap. During the official food waste recording period, households with scales reported food waste on 5.5 days on average and households without scales on 5.0 days, but again no statistically significant differences were found in the number of days with reported food waste ($p = 0.20$).

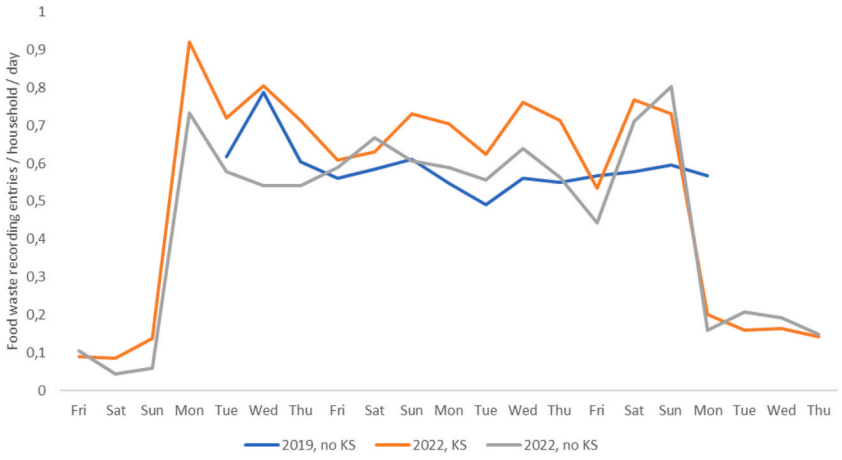

Fig. 3. Number of food waste recording entries per study day. 2019: 296 households, 19.11–2.12.2019. 2022: 189 households with scales and 183 households without scales, 13.5. – 2.6.2022 (official study period 16.5. – 29.5.2022). KS = kitchen scale.

In the 2022 study, during the official food waste recording period, households kept a record on 13.6 days of the 14 days (13.7 with scales and 13.3 without scale). Entries in the first 7 days represented 50 % of all entries, and there was no difference in the number of entries between the first and latter 7 days ($p = 0.96$). Moreover, there were no difference ($p = 0.23$) in the number of entries between weekdays and weekends (21.–22.5 and 28.5.-29.5.). Regarding the second hypothesis (H2), the number of food waste reporting entries ($p = 0.24$) and the proportion of days with reported food waste ($p = 0.19$) did not differ between 2019 and those households without scales in 2022, thus no support for H2 was found.

3.4. Food waste quantification

This study estimates that in 2019, Finnish households produced on average 16.9 kg (95 % C.I. [14.3, 19.7] kg) of edible food waste per person annually (kg/p/year), with a standard deviation of 17.5 kg. In 2022, Finnish households produced on average 15.5 kg/p/year (95 % C.I. [13.6, 17.6] kg) of edible food waste per person annually, with a standard deviation of 16.7 kg. Without adjusting for sample demographics (Appendix C), the raw sample averages were 15.3 kg/p in 2019 and 15.4 kg/p in 2022. Weighting by household size had a significant effect on the 2019 dataset, which therefore explains the big shift between the adjusted and unadjusted waste average. Based on graphical investigations of the data, this appears to be because in the 2019 dataset, the underrepresented one-person households produced on average more food waste on a per-person basis than multi-person households. In the 2022 data, the underrepresentation was not as severe, and more importantly food waste did not substantively differ between households of different sizes. Additionally, weighting for geographic area, gender of the respondent or age had only marginal effects in both datasets, each changing the average only by 1.4 % (0.2 kg) or less.

In the 2022 sample, households with scales recorded food waste corresponding to an annual rate of 15.4 kg/p/year (SD 16.7 kg), while the corresponding number for households without scales was 15.3 kg/p/year (SD 16.6 kg). Within the 2022 sample, the difference of 0.2 kg (95 % C.I. [−3.3, 3.6] kg) was not statistically significant ($p = 0.93$). Additionally, since there was no statistically significant difference in the number of entries and number of reported days containing food waste between the two groups, all these findings support H3.

3.5. Sample requirements for food waste monitoring

Based on graphical investigations, the food waste amount per person per year follows a Gamma distribution (Appendix E1), which was confirmed with the Kolmogorov-Smirnov test for both the 2022 data ($p = 0.60$) and the 2019 data ($p = 0.15$). The scale parameter estimate was 0.85 for the 2022 data and 0.76 for the 2019, hence the distribution is close to the special case of exponential distribution (scale = 1, mean and standard deviation are the same), though there was slightly more variation. It should be noted that a Gamma distributed variable should be strictly positive, but any zeros can be interpreted as arbitrarily small numbers (e.g. 0.001 g). The statistical power was calculated by simulating Gamma-distributed datasets with a scale parameter of 0.8 where the first data set had a fixed rate of 1 and the second dataset corresponded to a situation where the food waste amount had decreased by − 10 % to − 70 %. Sample sizes (assuming same n for both datasets) of n = 50–1000 were considered, and the difference was tested by using Gamma-regression with $p = 0.05$ set as the limit for statistical significance. The results are presented in Fig. 4.

With the widely used requirement of 80 % statistical power, a sample size of about 160 is needed to observe a change of 30 % in the mean (Fig. 4). With a sample size of 300, a difference of about 25 % could be observed, while with a sample size of 390, a decrease of 20 % can be seen. A decrease of 15 % could be observed with n = 750. However, even with a sample size of 1,000, differences of 10 % cannot be reliably observed. If the length of the observation period was limited to 3, 5, 7, or 10 days, the necessary sample size for observing a 30 % difference would grow to N = 350, 260, 230, or 210, respectively. In general, for a 3-day period the sample size needs to be increased by roughly 120 %, by 60 % for a 5-day period, by 40 % for a 7-day period, and by 30 % for a 10-day period.

Moreover, while this study estimated that the level of food waste was 16.9 kg/p in 2019 and 15.5 kg/p in 2022, the difference is not statistically significant ($p = 0.44$). However, it should be noted that the 8 % decrease is what one would expect to see in 2.5 years if a 30 % reduction in food waste was obtained by 2030 assuming a linear decrease (see Appendix E2). It should be noted that the analysis regarding the total waste levels does not take into consideration changes in waste composition.

Altogether, the results show that there is pressure to increase sample sizes. In fact, one way to increase the statistical power could be to study the same households longitudinally as this would remove much of the random variation if household behaviour were constant over time. As

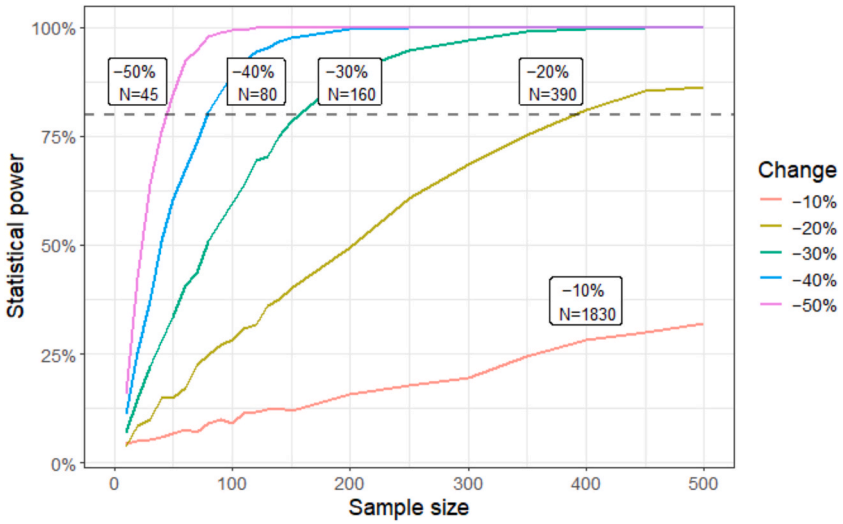

Fig. 4. Sample size and statistical power. 2,000 simulations were carried out for each sample size and difference in means (change). The textboxes give N needed to reach a statistical power of 80%.

the 2019 and 2022 studies were carried out by the same organization, it was possible to identify 17 respondents who happened to be in both studies. Between 2019 and 2022, the total food waste amount was found to be moderately correlated ($r_{pearson} = 0.53$, $r_{spearman} = 0.66$) (see Appendix E3). Of these 17 respondents, only 7 had lower FW levels in 2022 than in 2019, while 10 households reported higher values.

4. Discussion

4.1. Research objective and hypothesis

The aim of the Kotihukka-diary was to simplify the waste recordings so that the study could be repeated more frequently, and the sample size could be increased. The results demonstrate that while a decrease of 30 % could be observed with a sample size of about n = 160 within ten years, observing the half-way point of a 15 % decrease would require sample sizes of n = 750 (RO1). Hence, there is a significant pressure to increase sample sizes and the length of the observation period. The sample sizes reported here are consistent with the ones suggested by Shu et al. (2021), as they reported n = 180 per group to be necessary to observe effective sizes of 25 % in intervention studies.

Strategies that secure a good number of respondents and improve the representativeness of the data are desirable. Regarding the first hypothesis (H1), the participatory reward seems to be an essential part of the motivation since it reduces the dropout rate. However, it should be noted that while the present study the dropout rate decreased by 22 percentage points, the monetary cost was also 30 euros more per respondent (Table 3).

The option to send kitchen scales to all participating households would complicate and limit the study's scalability. Abandoning kitchen scales reduced the costs 29 euros per respondent (Table 3), but did not impact the results (H3). This finding is interesting because there is a lack of similar studies that have systematically studied the impact of kitchen scales on the reported food waste amount. In their study, Roe et al. (2020) discovered that respondents made more mistakes when using visual aids in comparison to kitchen scales. However, it is hard to compare the results because the used visual aids were different to this study and the evidence was based on a 24-household sample (Roe et al., 2020).

Regarding the second hypothesis (H2), there was no clear evidence to support that a daily requirement to report (waste or no waste) would improve the household engagement to the study. This result could be explained by the fact that the study period is relatively short, and the recruited respondents were motivated to participate in the study. In particular, the high dropout rate in 2019 could indicate that the remaining households were more engaged to the study. Moreover, because the Kotihukka-diary received good user feedback, its use was probably not a huge burden for the participating households. Consequently, in future, "no waste"-entries are still advisable to validate the results because this allows one to know exactly on how many days the households participate in the study.

4.2. Comparing results with other food waste studies

The previous Finnish diary study from 2010 estimated 22.7 kg of edible food waste per person per year (without adjusting) (Koivupuro et al., 2012). The 2010 study excluded liquid waste (except milk), and therefore the comparative waste amounts of the present study range between 12.2 and 13.6 kg/p/year. Moreover, while in the 2010 study, households recorded 1.05 waste entries a day on average (Koivupuro et al., 2012; Silvennoinen et al., 2014), the number of entries ranged between 0.59 and 0.66 in the Kotihukka-diary studies. Altogether, when comparing the 2010 Finnish diary study and the Kotihukka-diary studies, the methods are somewhat similar (Appendix F). However, it is not possible to pinpoint the reason for roughly a 10 kg/p/year lower waste amount and the drop in the number of food waste entries. At least waste compositional analyses do not show a decline in food waste during the past 10 years (Silvennoinen & Nisonen, 2020). The difference could be partly explained by the lower threshold to report food waste using pen and paper (the 2010 study used paper diary). However, there is mixed evidence to support this theory (Johnson et al., 2018; Siou et al., 2017).

In Finland, waste compositional analyses have ranged between 22 and 25 kg of edible food waste per person in 2012–2019 (Silvennoinen & Nisonen, 2020). While the results are not comparable, it is worth noting that the results of the Kotihukka-diary studies are roughly 30–40 % lower than the Finnish waste compositional analysis. Similarly Quested et al. (2020) compared diary studies and waste compositional analysis studies and food waste diary studies resulted in 18 to 70 % lower edible food waste estimates than waste compositional analysis studies.

In 2024, Eičaitė and Baležentis reviewed European food waste diary studies, and the median of the reviewed eleven diary studies was 28.6 kg/p/year. Hence, comparing to the median of the diary studies (Eičaitė & Baležentis, 2024), the results of this study, 16.9 and 15.5 kg/p/year, are low figures, which could indicate that Finnish households produce less food waste than households in Europe on average. It should be however noted that the methodological decisions of the reviewed eleven studies varied. Methodological decisions impact the results (van Herpen et al., 2019; Merian et al., 2024; Withanage et al., 2021), and therefore the results of the eleven studies are not comparable.

4.3. Limitations of the study and future research

This study was conducted in Finland, and hence the findings should be tested also in other contexts. In particular, the finding to abandon kitchen scales could be culturally dependent. Additionally, the suitable monetary compensation (€30 in this study) is context dependent.

According to this study, while monetary intensive (H1) and requirement to report daily (H2) are advised to reduce any self-selection bias and to monitor possible misreporting, behaviour reactivity impacted the results of the study. In fact, behaviour reactivity is an embedded flaw with diary studies (van Herpen et al., 2019; Schoeller et al., 2013; Quested et al., 2020; Withanage et al., 2021), and the starting point of the present study was the acknowledgement that it is probably impossible to completely avoid behaviour reactivity in diary studies.

Although it was not studied here, one way to reduce behaviour reactivity is to reduce respondent awareness (Merian et al., 2024). However, methodologies that reduce household awareness are resource intensive, because they are either based on waste compositional analysis (Merian et al., 2024), or automatized technology (Sjölund et al., 2025) (Table 1). Photo recognition could potentially provide an alternative to reduce household awareness of food waste when they report their results, because in comparison to food waste diaries, photos require less effort (Roe et al., 2020), which reduces the household time to reflect on their food waste. There is also evidence that photo recognition leads to fewer errors in comparison to food waste diaries (Roe et al., 2020). Additionally, while the analysis-phase of photo recognition is now claimed to be time-consuming (van Herpen et al., 2019; Roe et al, 2020), AI-based photo recognition could save time substantially in the future.

This study indicates that the requirement for sample sizes could be reduced if the same households were compared (Appendix E3). Moreover, this study reveals that the study length impacts the sample size requirement. Hence, the findings support longitudinal studies. However, longitudinal studies are problematic because there is a risk that continuing an observation affects household behaviour. On the other hand, methodologies such as bin cameras could solve this problem, because they reduce the household awareness of the study and are therefore more suitable for longitudinal studies (Sjölund et al., 2025). Moreover, the high initial investment to bin cameras is justified when the equipment is used for a longer period (Sjölund et al., 2025).

There are also opportunities with combining methodologies. While a

combination of different methodologies raises the possibility of misinterpretations (van Herpen et al., 2019; Dooren et al., 2019; Quested et al., 2020), bin-cameras or kitchen caddies could be used to obtain an estimate on the level of underreporting of food waste diaries (Merian et al., 2024; Sjölund et al., 2025). Moreover, results from waste compositional analysis could be used to see if the long-term trends point to the same direction as food waste diary studies. Furthermore, while a food waste survey is not a reliable method of monitoring household food waste (van Herpen et al., 2019; Sjölund et al., 2025), it provides background information on households, and therefore surveys are often combined with diaries.

The literature shows that the causes for food waste are complex, and there is a need for further research to identify different household types to target food waste reduction measures (Aschemann-Witzel et al., 2021; Hebrok and Boks, 2017). Food waste diaries, in combination with surveys, can be used to support targeted reduction measures. Moreover, food waste diaries could be used for other purposes such as teaching households about their food waste amounts and supporting households with their waste reduction targets (e.g. Roe et al., 2022). Additionally, since the Kotihukka-diary can be used without the assistance of kitchen scales, it is possible to extend its use outside the realm of home food consumption.

5. Conclusion

EU has set a binding target to reduce food waste by 30 % by 2030 (European Commission, 2023), and therefore EU member states should provide evidence that the long-term food waste amount trend is on a downward scale. Food waste diaries are criticised for underreporting, and this study also reports 30–40 % lower food waste figures than studies based on waste compositional analysis. Since diary studies have many other benefits over alternative methods (Table 1), they remain one of the main methodologies to monitor and understand household food waste. For example, in comparison to waste compositional analysis, diaries can be used to monitor liquid food waste. Altogether, while it is important to reduce underreporting, this study argues that a certain level of underreporting could be acceptable with food waste diaries. This could be when 1) the focus is on relative change in waste volumes, and 2) the error caused by underreporting is constant over time and thus does not affect the overall trend of waste volumes.

This study demonstrates the importance of statistical evidence for repeated measures. The study's sample sizes (n = 296) and (n = 372) and the length of the observation period (14 days) will be sufficient to detect a population-level decrease of 20–25 % in the food waste amount during the next decade. Therefore, this study shows that to detect changes in food waste levels, it is important to pay attention to sample sizes and to the length of the observation period. To cut expenses and improve the scalability of diary studies, the present study found evidence that households can successfully report food waste without the assistance of kitchen scales.

CRediT authorship contribution statement

Hanna Hartikainen: Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Data curation, Conceptualization. **Joel Kostensalo:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis. **Inkeri Riipi:** Writing – review & editing, Writing – original draft, Methodology, Data curation.

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.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2025.114844.

Data availability

The data that has been used is confidential.

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