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Comparing wasted apples and oranges: An assessment of methods to measure household food waste

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ABSTRACT

Food waste has become a global concern in recent years, especially the household food waste that is generated in the developed world. Multiple methods to measure household food waste have been proposed, but little is known about their validity. Five methods are selected and investigated empirically: survey questions about general food waste over a non-specified period of time, diaries, photo coding, kitchen caddies, and pre-announced survey questions regarding a specific time period. In an experiment, respondents were asked to assess their food waste using some or all of these methods depending on condition. Overall, the general survey questions appear to be less valid, as these lead to large underestimation of the level of food waste, low variance in reported food waste across households compared to the other methods, and low correlations with other measures. The other four methods are relatively highly correlated. A survey about food waste in the past week appears to be a useful method for large-scale measurements to differentiate households according to the amount of food waste each produces, although it should be noted that this method underestimates the amount of food waste. Kitchen caddies and photo coding seem to be valid methods and, for small samples, provide alternatives to food diaries, which have been more commonly used.

1. Introduction

Over the past years, food waste has become both a political priority and a topic of increasing research interest. A large amount of agricultural land is required to produce food that is never eaten, whilst the processes required to grow, rear, process, transport, package, store and prepare this food require energy and water, and lead to the emission of greenhouse gases. In developed countries, food wasted in the home is the single largest source (FAO, 2011; Stenmarck et al., 2016). In response to increasing awareness of the food waste issue, the number of studies that examine food waste has increased sharply over the past years (Porpino, 2016).

Given its significance, a good understanding of the drivers of household food waste and of the effectiveness of interventions, is needed. To gain such understanding, food waste needs to be characterized and quantified in a reliable and valid way. Additionally, the relative importance of different product categories and states (unused, partly used, leftovers) needs to be understood. Yet, a recent review of literature on food waste has revealed that only a small fraction of publications has used primary data collection to assess food waste, whereas many studies rely on potentially outdated or less accurate secondary data sources (Xue et al., 2017). Likewise, Porpino (2016), in his description of avenues for future research on household food waste behaviour, mentions the current lack of methods to quantify household food waste as a shortcoming of previous studies, and suggests that standardized methods to estimate consumer food waste are needed.

The present study focuses on developing practical methods for the measurement of household food waste that can be applied in large-scale empirical studies and can provide insights in different states of household food waste (e.g., food going off before it is used, partly used products, meal scraps). Food waste can result from a multitude of different behaviours during the purchase, storage, preparation and consumption of food (Quested et al., 2013; Block et al., 2016; Roodhuyzen et al., 2017). Distinguishing between different states of food waste might provide an indication of the types of behaviours that are involved (WRAP, 2014). Moreover, a good measurement of household food waste can identify the social, economic, and environmental factors that determine the amount of

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food waste, can help find the 'hotspots' where interventions should be prioritized, and thus be instrumental in reducing household food waste (Hebrok & Boks, 2017; Xue et al., 2017). In the present study, promising methods to measure food waste at the household level are identified and compared empirically. The overall aim of the study is thus to validate practical methods for measuring amounts of avoidable household food waste, by testing the convergent validity between various methods.

A clear definition of household food waste is required before any attempt to measure it can be undertaken. Divergent definitions of food waste, however, have been used in prior studies (Chaboud and Daviron, 2017; Roodhuyzen et al., 2017). In the current study, food waste is defined as food intended and appropriate for human consumption within the household, that is nonetheless not consumed by humans but instead discarded (cf. Katajajuuri et al., 2014; Stefan et al., 2013; Stancu et al., 2016). This excludes unavoidable food waste, such as bones or peels that are not edible. Discarding can take many forms, for instance putting food waste in the bin, feeding it to household pets, and home-composting. Moreover, in line with prior research, the focus is on the edible fraction, excluding the inedible fraction (e.g., egg shells, bones) from the definition and measurement of household food waste.

2. Food waste measurement

Prior studies have assessed household food waste in various ways. Table 1 provides an overview of these studies, categorized according to the types of measurements of food waste. Included studies have assessed in-home food waste at the household level, using primary data collection. This excludes studies assessing food waste at the neighbourhood level, using desk research, focusing on out-of-home food waste, and/or assessing overall waste rather than food waste specifically. Moreover, studies in which food waste assessment is used as an intervention strategy (i.e., people are asked to keep track of food waste as part of the intervention to increase awareness and motivation to change behaviour) have been excluded, because we aim for methods that have a small impact on the behaviour itself. When a study includes multiple methods (e.g., both a diary and waste-composition analysis), it is recorded in both categories.

To outline the advantages and disadvantages of the different waste measurement methods, we focus on the following criteria: (1) degree to which estimates of food waste can be biased, (2) effort required of respondents, (3) effort and costs for the researcher, and (4) ability of the method to provide information about different states of food waste. Biased estimates of food waste can occur due to various reasons such as deliberate underreporting (e.g., due to social desirability), problems in estimating or articulating a given amount, or influences of the measurement method itself on food waste. When respondents have to spend more effort in reporting food waste, this can have adverse consequences for the drop-out rate, self-selection bias, and data accuracy (due to fatigue). The effort and costs required of the researcher involve resources needed for waste handling, coding, analysis, materials and equipment. The ability of a method to handle large samples of respondents is a direct function of the effort and costs for the researcher. The ability to distinguish between different states of food waste is relevant for gaining insight on the kind of interventions that might be necessary to reduce food waste.

2.1. Diary

Diaries in which respondents report the type and amount of food that they waste over a period of several days are commonly used to report food waste. Respondents can be asked to measure the weight of discarded food in grams (Katajajuuri et al., 2014; Langley et al., 2010; Williams et al., 2012) or to describe the amount of waste in units of their own choosing (e.g. 2 slices of toast, 3 apples, a handful of grated cheese; WRAP, 2008). They may also report additional information about the waste acts, such as the state of the food waste. Measurement in weight puts a high reporting burden on the respondent, who needs to weigh the food waste. In contrast, measurement in a mixture of units can temper this respondent effort somewhat, but puts a relatively high burden on the researcher, who needs to transform these to a standardized unit of measurement before any comparisons can be made.

Regardless of how food waste is reported, respondent effort for the diary method is relatively high. Langley et al. (2010) describe the task of keeping a food-waste diary as considerable, and report a tapering of enthusiasm of respondents over the period in which the diary was kept (one week). Sharp et al. (2010) also mention the required close interaction with the household representative as a disadvantage. The effort required of respondents implies not only difficulties in recruitment and high dropout rates, but also the potential risk of self-selection and poor data quality (Sharp et al., 2010). Furthermore, the diary method itself can lead to changes in waste behaviour (Langley et al., 2010), as it can be a motivator for behaviour change and a visible reminder (Sharp et al., 2010) and it has been shown to underestimate food waste as compared to a waste-composition analysis by as much as 40 percent (Høj, 2011).

2.2. Self-report in survey/interview

Self-reports in which respondents are asked to answer questions on their level of food waste without using a diary, have been applied in both surveys and in-depth interviews. Measures such as absolute or frequency measures, visually-based measures, and proportional waste measures have been employed. Absolute measures require respondents to directly self-report on the amount of food waste in their home, without the aid of a diary or other instrument. Although sometimes people have been asked to directly indicate the amount of food waste in grams (Ghinea & Ghiuta, 2018; Schmidt & Matthies, 2018), mostly this is considered too difficult for people. Because people have difficulty answering such a question in the amount of grams that they waste, broad categories ranging from definitely wasting to no wasting (Gül et al, 2003), as well as frequency measures, asking people to report how often food is wasted (Parizeau et al., 2015; Setti et al., 2016; Young et al., 2017) have been used. In another approach, Martindale (2014) has used oval shapes to aid respondents in reporting amounts. Proportional or relative measures of food waste have appeared as well, in which respondents report the percentage of proportion of food items brought into the household that goes to waste (Aschemann-Witzel et al., 2017; Graham-Rowe et al., 2015; Secondi et al., 2015; Stancu et al, 2016; Stefan et al., 2013).

In surveys it is not always straightforward to ensure that questions are clear and unambiguous, especially for a topic such as food waste. Another disadvantage is that the measurement draws upon people's memory, which can be faulty. Because food-wasting is not top-of-mind for most people and results from multiple routinized behaviours, underreporting is highly likely (Hebrok & Boks, 2017). Pre-announcing a survey may diminish this effect, but does not necessarily eliminate it. Moreover, respondents may be inclined to give socially desirable answers. Advantages of survey measures are that these can be collected at relatively low budgetary cost for the researcher, typically require little effort of respondents, and that questions on the state of the wasted food can be incorporated.

Table 1
Food waste measurement methods used in prior research.

Reference	Sample	Measurement
Food waste diary		
Adelson et al. (1963)	Several studies in small groups of households, USA	Inventory of food in the home for 7 categories. Record of weights of additional food brought into the household and discarded food
IGD (2007)	1036 questionnaires and 8 interviews, UK	Diary for one week and observation of food stocks
WRAP (2008)	284 completed diaries, UK	Weight and cost of wasted food in total, by type of food, by state of preparation, foods whole or unopened, foods still in date
Langley et al. (2010)	13 households, UK	Diary for 7 days. List of food categories, waste routes, and lifecycle stages. Packaging type, origin, weight, % consumed, visible dates, cost
WRAP (2009)	319 respondents, UK	Diary for 7 days. Type, amount (weight or volume), and reason for disposal
WRAP (2011)	Pilot: 8 interviews. Focus groups: 48 consumers, UK	Short diary in pilot. Two week diary about bread and bakery waste for focus group participants
Williams et al. (2012)	61 households, Sweden	Diary for 7 days (mostly weight, but sometimes approximate amounts); reason for waste noted
Koivupuro et al. (2012)	380 respondents, Finland	Methods described in more detail in Silvennoinen et al
WRAP (2013a)	1192 households, UK	Various measures, including kitchen diary
Katajajuuri et al. (2014)	380 households, Finland	Diary for two week (electronic kitchen scales); type of food disposed of and reason for disposal
Silvennoinen et al. (2014)	380 respondents, Finland	Diary for two weeks (written entries); weighted food waste and liquid milk waste
Verghese et al. (2014)	23 households, Australia	Diary for 7 days; on what is cooked and what is not eaten, combined with photographs of stored food that has 'gone off'
Richter and Bokelmann (2017)	25 households, Germany	Diary for 7 days; food storage, purchase, and waste behaviours. For waste, type of food and cause are noted; quantity not recorded
Self-report; absolute/frequency		
Gül et al. (2003)	391 households, Turkey	Approach to bread waste, on a 5-point scale from definitely wasting to definitely no wasting
WRAP (2011)	492 respondents, UK	Self-reported bread waste, in slices in a typical week, on a 6-point scale from no waste to 15 + slices. Number of items typically thrown out for rolls, pittas, wraps, crumpets, and croissants
Parizeau et al. (2015)	61 households, Canada	Frequency of food waste for trim, spoiled food, food we didn't like, food at best before date, overprepared food, on a 4-point scale from regularly to never
Setti et al. (2016)	1403 respondents, Italy	Frequency of food waste, monthly. On a scale of never, sometimes, often. Five product categories
Tucker and Farrelly (2016)	147 respondents, New Zealand	Estimates of average household food waste in a week. Described in bucket equivalents
Visschers et al. (2016)	796 respondents, Switzerland	For 11 food groups, the frequency of disposal and the amount disposed. Amount in portions, with one portion defined as one handful
Janssen et al. (2017)	506 households, the Netherlands	Frequency of waste, on a 7-point scale ranging from $\geq$ 2–3 time per week to never. Combined with a proportional measure in an index
Ponis et al. (2017)	500 households, Greece	Volume of food waste, in total and for 6 types of food, 7-point scale from not at all to extremely much
Russell et al. (2017)	172 respondents, UK	Frequency of food waste, on a 5-point scale from never to most mealtimes. Quantity of food waste by selecting items what were thrown out in the past week
Young et al.(2017)	2018 respondents, UK	Frequency of waste, on a scale from never to most mealtimes. Types of food wasted from 9 categories
Diaz-Ruiz et al. (2018)	418 respondents, Spain	Amount of food thrown away in a recent week; 7-point scale from nothing to a lot. Asked for: amount thrown away because it has expired, it has passed the best before date, it has been damaged or moulded, leftovers not used for another meal, cooked more than needed, stored but finally not eaten
Falasconi et al. (2019)	1201 respondents, Italy	Estimation of the quantity of household food waste, on a 10-point scale from nothing to a lot
Ghinea and Ghiuta (2018)	100 respondents, Romania	Estimated amount of weekly food waste, in grams
Mattar et al. (2018)	1264 households, Lebanon	Frequency of "eating everything prepared" as proxy, recoded to 0 (sometimes at most) and 1 (frequently/regularly)
Schmidt and Matthies (2018)	402 respondents, Germany	Frequency of discarding in the past two weeks, for meat, dairy, and bakery products, on a 15-point scale from no times to more than 14 times, with never as additional option. Amount usually discarded for the same products, on 10-point scale from up to 200 g to more than 2.0 kg, with never discarding as additional option. Both questions are asked separately for prepared and unprepared food. Indices are taken by calculating the products between frequency and amount, and summing these per food group
Young et al. (2018)	61 respondents, UK	Number of product categories for which waste occurred in the past week, from a list of nine categories
Self-report; visual tools		
Brook Lyndhurst (2010)	20 respondents, UK	Photographs of various amounts of waste for apples, bread, mixed food; used to estimate amount of waste
Martindale (2014)	83 households	Quantities of food waste by indicating how much of a meal is wasted, using oval shapes
Self-report; proportional to what is brought into the household		
Stefan et al. (2013); also taken up by Romani et al., 2018	244 respondents, Romania	Amount thrown away as proportion of what is bought in a regular week, in general and for 5 product categories. Answer categories: not at all, less than a tenth, more than a tenth but less than a quarter, more than a quarter but less than half, and more than half
Abeliotis et al. (2014)	231 respondents, Greece	Question "How much of the total food items do you throw away into the bin?", answer categories: significant amounts, quite a bit, small amount, hardly any, none
Secondi et al. (2015)	Over 26,000 individuals, multiple EU countries	Percentage of food that each individual buys which goes to waste, by distinguishing six categories ranging from "none" to "more than 50%". Flash Eurobarometer survey

(*continued on next page*)

Table 1 (*continued*)

Reference	Sample	Measurement
Graham-Rowe et al. (2015)	204 individuals, UK	Self-reported waste in fruit and vegetables. Question: "Please estimate what percentage of your household's total fruit/vegetables got thrown away in the last seven days." Possible responses ranged from 0% (1) to 100% (11) with ten percent increments
Stancu et al. (2016)	1062 respondents, Denmark	Items worded as "how much . . . is thrown away in your household of what you buy and/or grown, in a regular week", for five categories. Scale: hardly any, less than a tenth (less than 10%), more than a tenth but less than a quarter (between 10% and 25%), more than a quarter but less than a half (between 25% and 50%), more than a half (more than 50%)
McCarthy and Liu (2017)	346 respondents, Australia	Question: "how much of the food and drink that you buy do you throw away in a regular week". Eight answer options, ranging from 'not at al' to 'low' (being less than 5%) and 'high' (being greater than 30%
Janssen et al. (2017)	506 households, the Netherlands	Amount usually disposed, on a scale of (almost) all bought, half of the purchase, a quarter of the purchase, 2–3 tablespoons, practically nothing. Combined with a frequency measure in an index
Aschemann-Witzel et al. (2017)	848 respondents, Denmark	Question: "If you would try to estimate your own household, how much of the following food that you buy or cook ends up being thrown away at home?". In percentage, for five categories
Waste-composition analysis		
Dennison et al. (1996)	867 households, Ireland	Waste collected and hand-sorted into 12 main categories and 36 categories in total. Waste fractions were weighed. Over a 5-week period
WRAP (2008)	2138 households, UK	Waste from residual, source-separated organics and separate food-waste collections from a one or two week period (depending on collection frequency). Hand-sorted into 14 food categories, and sub-divided into 152 food types
WRAP (2013a)	1800 households, UK	Waste from residual, source-separated organics and separate food-waste collections from a one or two week period (depending on collection frequency). Hand-sorted into 14 food categories, and sub-divided into 152 food types
Parizeau et al. (2015)	68 households, Canada	Weighing of source-separated organics, recyclables, and residual garbage placed at the curb. Sampled on two subsequent garbage collection days
Self-collection of household waste		
Wenlock et al. (1980)	672 households, UK	Households collected all food wasted in their homes during 1 week
Gutiérrez-Barba & Ortega-Rubio (2013)	41 families, Mexico	Households turned in a day's waste to collectors, weekly, for a full year. Weighing of waste
Ramukhwatho et al. (2017)	210 households, South Africa	Households provided food waste on a weekly basis, during three weeks. Weighing of waste
Elimelech et al. (2018)	192 households, Israel	Collection of waste in coded garbage bags, from resident's doorstep, on a daily basis for one week. Waste is sorted and weighed
Photographs and in-home observation		
Farr-Wharton et al. (2012)	7 households, Australia	Respondents either took a photograph or wrote down expired products that were thrown away each week
Farr-Wharton et al., (2014)	Interviews with 12 respondents and observations in 6 households, Australia	In-home observation and photographs of inside of fridges, weekly visits over a 4-week period
Porpino et al. (2015)	14 households, Brazil	In-home observations and photographs

2.3. Waste-composition analysis

In waste-composition analysis, food waste of households is collected, physically separated, weighed and categorized. This method can be applied to kerbside collection, and can be collected without changing respondents' behaviour and without effort from respondents. Waste-composition analysis can be done using various approaches. Dahlén and Lagerkvist (2008) provide an overview of twenty known methods, and indicate various sources of error. In addition, Lebersorger and Schneider (2011) provide an in-depth discussion of the methodology for determining food waste in waste-composition studies.

Overall, compared to other methods, waste-composition analysis requires specific knowledge, is costly and time-consuming for the researcher, and it is difficult to distinguish between food being thrown out before use, partly used, or as leftovers. Moreover, waste-composition analysis focuses on the waste put out for collection, which implies that the researcher is unable to observe food waste that was disposed of by other means (e.g., sink waste disposal units, home composting, animal feed) (Parizeau et al., 2015). Yet, waste-composition analysis does not rely on self-reporting, and is thus not dependent upon respondents' memory or subject to social desirability.

2.4. Self-collection: Kitchen caddies

A few studies have asked people to collect and turn in their food waste separately (Wenlock et al., 1980; Gutiérrez-Barba & Ortega-Rubio, 2013; Elimelech et al., 2018). This can be done by having people fill caddies, bins, or other containers with their food waste, which is collected at regular times. This provides an overall measurement of the grams of food waste. Effort for researchers can be substantial, as on-site visits to people's homes may be required. Effort for respondents is relatively low, as it only requires them to dispose of the food waste in the provided caddies rather than the regular waste bin. Yet, the habitual nature of throwing food waste in the regular bin and concerns over social desirability might lead to underreporting. Insights into the states of wasted food could be obtained by providing respondents with separate caddies for each of the states.

2.5. Photographs and in-home observation

In a few studies, consumers have been asked to photograph the food they dispose of (Farr-Wharton et al., 2012). The widespread use of cameras in mobile phones makes this a relatively low-effort procedure for respondents. Yet, because the coding of these

photographs is time-consuming, this method can lead to high costs of data handling and applicability to large samples may be difficult. Because this method has not been used often, little is known about potential biases, both due to underreporting and due to incorrect coding.

The development of new technologies increases the possibilities for in-home observations. This holds potential for improving the accuracy of measurements while lowering the burden for respondents. For instance, trashcan cameras have been used as an influencing tool (Comber & Thieme, 2013), but could also be applied to measure food waste. Potential issues are the cost involved, the reliance on new, not yet fully tested, technology, privacy concerns for participants, and the required work in keeping track of and interpreting the data.

3. Study: Comparison of food waste measurement methods

This study assesses the validity of methods of food waste measurement by applying all or a subset of methods to the same instances of household food waste and calculating the extent to which the measures give similar estimates of the average amount of food waste and are correlated across households (convergent validity). In selecting the methods to examine, we contacted and received feedback of experts on food waste measurement. Experts were identified based on suggestions for external experts provided by members of the REFRESH consortium (eu-refresh.org) and based on a list of authors of papers included in the literature review. A total of 27 potential experts were contacted, of whom 13 participated. Experts received an invitation and questionnaire by e-mail, gave an initial response by e-mail, and participated in a telephone interview. They were initially provided with a description of different methods: (1) food waste diary, (2) survey with relative proportion, frequency, amount estimation, photographs, and visual scales as examples, (3) in-home observation, (4) waste compositional analysis, (5) kitchen caddies. They evaluated these on accuracy, effort for participants and researchers, and main advantages and concerns. In addition, they were asked to indicate whether any methods were missing (none were identified).

Experts indicated advantages and limitations for all methods. The methods that they deemed most suitable for large samples were diaries, surveys, and waste compositional analysis. Interest was also expressed in kitchen caddies, for which the experts had less experience. They agreed that in-home observation is especially time-consuming and effortful, and not suitable for large samples, which is why we excluded it from our study.

Based on the literature overview and the input of the experts, we chose to include the food-waste diary, survey, photograph coding, and kitchen caddies. These are methods that can be applied in quantitative data collections, have been used in prior studies, and can provide information about different states of food waste. Waste composition analysis was not included due to cost and logistical issues, but the kitchen caddies provide a different method based on collecting and weighing the food that is wasted.

A pilot study with 30 participants, recruited from the social network of the researchers, was carried out for the chosen methods, in order to optimize the operationalization of the materials and instructions, as well as the practical logistics involved. Results showed high variance in food waste across days (ranging from 0 to 580 g on a single waste act, that is, a waste of a specific kind of food at one particular moment) and across households (ranging from 0 to 2162 g in a week). Given the high variance across days, assessing food waste for several days appears needed to get a good estimate of the amount of food waste at the individual-household level. Given the high variance across households, a study that compares different methods would need to either have a large sample for between-subject measurement or to use various methods on the same sample. In the main study, we opted for the latter.

3.1. Study design

Given that the measurements could influence each other, and that both kitchen caddies and photographic coding present logistical challenges, only a subset of participants was subjected to all methods. The problem of disruption due to other measurements is probably highest for survey questions. Noting waste acts in a diary or taking pictures is likely to heighten the awareness to food waste and influence survey questions. Therefore, general survey measures of food waste (not related to the week in which the study took place) were asked at the beginning of the study, to eliminate this influence. Furthermore, we included a group in the design in which participants answered only self-reported survey questions in one week, and reported food waste in both diary and survey for a second week, as well as a group who reported on both diary and survey in both weeks. The differences in reported food waste and correlation between the weeks were compared across both groups, to assess if the diary influenced the survey. The considerations detailed above led to the study design presented in Table 2. Participants in the second group were informed that they would be asked to report on food waste after the first week.

3.2. Participants

Participants were 143 members of a consumer panel of Wageningen Food and Biobased Research. Panel members were recruited in the past by mailings, flyers, newspaper advertisements or introduced by other panel members. Members aged between 18 and 80 years were invited for this study by e-mail. Participants were predominantly female (79.7%, which is considerably higher than the 50.4% females in the Dutch population in 2016, www.cbs.nl) with an average age of 50.1 years (range between 20 and 79 years). Households generally consisted of one (21.7%) or two

Table 2
Study design.

	Group 1 (n = 48)	Group 2 (n = 48)	Group 3 (n = 47)
Initial measurement	Survey: general food waste assessment [measures 1–5]	Survey: general food waste assessment [measures 1–5]	Survey: general food waste assessment [measures 1–5]
Measurement in week 1	Diary [measure 7]	None	Diary [measure 7], kitchen caddy [measure 9], and photographs [measure 8]
Measurement end week 1	Survey: food waste in the past week [measure 6]	Survey: food waste in the past week [measure 6]	Survey: food waste in the past week [measure 6]
Measurement in week 2	Diary [measure 7]	Diary [measure 7]	Diary [measure 7], kitchen caddy [measure 9], and photographs [measure 8]
Measurement end week 2	Survey: food waste in the past week [measure 6]	Survey: food waste in the past week [measure 6]	Survey: food waste in the past week [measure 6]

Note: Measurement numbers refer to Table 3.

(65.0%) adults, with some households of three (8.4%) or four (4.9%) adults (18+). Of all households, 35.7% contained one or more children (<18 years). The percentage of single-person households in the sample (17.5%) was similar to that in the population (17.1%), but females are overrepresented there as well. The average household size was 2.62 persons, which is somewhat larger than the average household size of 2.17 in the Dutch population in 2016 (www.cbs.nl).

Panel members filled in a screening questionnaire including questions on gender, date of birth, and household composition. Additionally, they were asked how often on average food products are thrown out in the household (nine point scale ranging from "daily" to "(almost) never"). Panel members who indicated that (avoidable) food waste occurs (almost) never in their household were excluded from participation, to increase the likelihood that food waste occurs and would be reported during the study period. In this way, we aimed to avoid including households with little or no food waste, as this could potentially inflate measures of convergent validity as self-reported zero food waste would be repeated across measurements, and could confuse participants who would report little or no waste across multiple measurements. Panel members who were employed in the food sector or by the university carrying out the study were also excluded. When assigning participants to the groups, age, family composition, and frequency of self-reported food waste were similarly distributed across the groups.

3.3. Procedure

Participants obtained instructions by regular mail, including examples of how to fill in the diary and how to take photographs. Hardcopy diary pages were provided, as well as a return envelope. If participants had questions they could contact one of the researchers by e-mail or telephone. Participants were e-mailed a reminder at the start of the study, and participants in the third group additionally received reminders regarding the collection of the rubbish bags. All participants signed a consent form.

At the start of the study, participants received a description of what was considered as food waste. The word "waste" was avoided to prevent its negative connotation from triggering social desirable responses. Instead, instructions stated that the study concerned food products that have been bought with the intention to be eaten, but which were not eaten after all. It was explicitly mentioned that this occurs in every household from time to time, and that it does not matter whether the food is disposed in the bin, composted, or fed to animals. Moreover, it was clarified that the study only concerns those parts of food products that are edible or were at one point edible, and that inedible bones, peels, pits, etc. are excluded, whereas food that has gone bad is included. Finally, it was mentioned that only food in the household is included, and not food consumed out-of-home.

At the end of the study, participants answered questions on the experienced difficulty with the study, whether their awareness of food waste changed due to the study, perceived accuracy with which the food waste in their household was reported, and whether other household members collaborated in the study. Participants received 40 Euro for their participation and the study obtained ethical approval from the Social Sciences Ethics Committee of Wageningen University.

Across the methods, the same waste states and product categories were used, as indicated in the Appendix. In the survey, the food categories were further divided into 22 subcategories (e.g., fresh and non-fresh vegetables; non-alcoholic and alcoholic drinks). This was done to increase the chance that participants would remember and report specific food waste. The subcategories were constructed such that the combination of two or three of these would lead to the above-mentioned ten general food categories used throughout the study. Before analyses, the amounts in the subcategories of the same general category were summed together.

3.4. Measurements

General food waste assessment. Four different survey measurements of general food waste were included in the initial online survey (measures 1–4 in Table 3). Specifically, participants provided the frequency with which products from 22 categories were consumed in the household, on a scale labelled daily/multiple times per week/once per week/multiple times per month/once per month/multiple times per year/(almost) never (recoded into number of approximate days per year: 365, 156, 52, 24, 12, 6, and 0, respectively). Next, participants reported on the general food waste in their household, absolutely (ordinal scale), as a relative amount (cf. WRAP, 2013a), as an overall percentage of bought foods (cf. Stefan et al. 2013), and as the frequency of food waste (ordinal scale, cf. Parizeau et al., 2015; see Table 3 for question wording). For each of the product categories that they indicated were consumed in their household, participants subsequently answered questions on the proportion of the amount bought that was typically discarded, as a measure of food waste in each of the categories. Participants also indicated in which state(s) most of the product category was discarded. As an additional measure of food waste, we calculated a weighted index of the reported discarded proportions based on the reported consumption amounts (in line with Janssen et al., 2017; measure 5 in Table 3).

Weekly survey. Participants indicated in an online survey which of 22 categories food was discarded in the past week, and for each ticked category, the amount wasted and the waste state(s). Amounts were reported in relevant units for the product category (e.g., spoons of vegetables, pieces of fruit, portions of meat), using six answer categories. Based on online information, the average weight of these units was estimated (e.g., 100 g for a piece of fruit, 50 g for a spoonful of pasta, 250 g for a portion of meat), and reported units were transformed into grams (measure 6 in Table 3).

Diary. In the diary (measure 7 in Table 3), participants recorded the weight for each waste instance (in grams), state, product category, and if the waste was thrown in the bin (yes/no). The bin was either their own food waste bin (first and second group) or the caddy provided for the study (third group). If waste was not thrown in the bin, participants were asked to write down in their own words what other method of disposal was used. Each page of the diary contained the date and lines in which participants could fill out their waste of that day. Participants used an average of 1.60 lines per day, with number of lines used per day ranging between 0 and 18.

Photographs. To ensure that the photographs could be interpreted easily, detailed instructions were provided and participants were asked to photograph all food waste on a place mat that was provided. Photos were sent to the researchers and coded for weight, state, and product category by trained coders (measure 8 in Table 3). The checked pattern on the place mat (each 2 cm wide) allowed coders to have a clear and easy indication of size.

Kitchen caddies. The kitchen caddies consisted of two bins, each with two compartments, which were labelled with a waste state. Participants used waste bags containing the same labels. Researchers picked up the bags every two or three days and weighed the waste. Weight measures were summed to weekly measures, per state (measure 9 in Table 3).

Combination of kitchen caddy and diary. In the diaries, participants indicated whether waste was discarded in the bin or not. Based on this, a combined measure of caddy plus diary was com-

Table 3
Overview of food waste measures.

Measure	Method	Description	Measurement approach	Answer scale
1. Absolute waste, general	Survey	General waste assessment, absolute	How much uneaten food, overall, would you say you generally end up throwing away of the food that is bought in your household?	Quite a lot / a reasonable amount / a small amount / hardly any / none (analysed as ordinal scale)
2. Relative waste, general	Survey	General waste assessment, relative	What percentage of the food that is bought in your household is discarded?	none / 5% or less / 6% to 15% / 16% to 30% / 31% to 50% / more than 50% (coded using the midpoint of the answer categories as scores)
3. Frequency, general	Survey	Frequency of wasting food in general	How often is food discarded in your household?	Regularly / sometimes / infrequently / never (analysed as ordinal scale)
4. Relative waste, unweighted	Survey	Waste assessment, per category, relative	What proportion of {product category} is discarded of what is available in your household?	Nothing or does not apply / Almost nothing / about a tenth / about a quarter / about half / more than half (coded as 0 / 0.05 / 0.10 / 0.25 / 0.50 / 0.75); measure is averaged across the categories
5. Relative waste, weighted	Computed	Measure 4 weighted with consumption	Reported waste proportion weighted with reported consumption (recoded into days per year)	Resulting ratio scale ranges from 0 to 274; measure is averaged across categories
6. Weekly survey	Survey	Food waste in past week	How much {food category} was discarded in your household in the past week	Scales based on units that are appropriate for the category (recoded into grams per week)
7. Diary	Diary	Self-reported amount	Weight reported in diary	Grams (per waste act)
8. Photos	Photos	Content-analysis of photos	Weight assessment based on photos	Grams (per waste act)
9. Caddies	Kitchen caddies	Weighed amount of rubbish bags	Weight of food waste in kitchen caddies	Grams (every couple of days; aggregated to grams per week)
10. Caddies plus diary	Computed	Weighted waste plus waste not in the bin (from diary)	Weight from kitchen caddies and reported weight not placed in the bin	Grams (per week)

puted, in which the weighed waste from the kitchen caddies and the reported waste that was not discarded in the bin, based on the diaries, were added together (measure 10 in Table 3). This computed measure represents an approach in which consumers keep track of waste not put in the bin, and this is added to kitchen caddy measurements.

Evaluation of the study. At the end of the study, participants answered questions about the tasks they performed, on unnumbered slider scales ranging from completely disagree to completely agree. Answers were recorded on a 0–100 scale. Questions concerned the effort required in the study (4 items: it was easy to perform the study (recoded); the study was rather difficult to do; the study took a lot of time; the study took a lot of effort; $\alpha = 0.81$), clarity of instructions (1 item: the instructions were clear), doubt (1 item: I often doubted what to do when participating in the study), the effect of the study on awareness of food waste (3 items: I became more aware of food waste due to the study; I think that I changed my behaviour in the past two weeks due to the study; I intend to pay more attention to food waste in the future; $\alpha = 0.73$), and inaccuracy of reporting (3 items: possibly food was thrown out in my household without it being reported; I sometimes felt tempted not to report food waste in the study; the food waste in my household has been very carefully reported (recoded); $\alpha = 0.55$; analysing individual items separately leads to comparable results as analysing the scale). In households with more than one occupant, three additional questions were asked (I know exactly what other household members threw out in the past two weeks; my household members have cooperated well for this study; my household members have carefully noted their food waste).

4. Results

4.1. Evaluation of the study

Participants in the third group, who provided input for all measurements, found the study more effortful ($M = 29.87$, $SD = 19.29$) than participants in the other two groups ($M = 21.57$, $SD = 17.61$ in the first group and $M = 15.81$, $SD = 15.92$ in the second group; $F(2, 141) = 7.52$, $p = .001$; pairwise differences (LSD) significant at $p < .05$). The first and second group did not significantly differ on perceived effort ($p = .11$). For all other study evaluation measures, no significant differences between groups emerged ($Fs < 0.7$; $ps > .4$). Across all groups, participants found the instructions clear ($M = 86.45$, $SD = 18.64$) and had little doubt about what to do during the study ($M = 25.76$, $SD = 26.20$). They also indicated that they perceived little inaccuracy in their reporting of food waste ($M = 12.64$, $SD = 13.97$), and that they knew the food waste that was discarded by household members ($M = 83.80$, $SD = 20.58$). They reported that their household members had cooperated well ($M = 88.78$, $SD = 15.98$) and had carefully noted what they threw out ($M = 81.87$, $SD = 25.51$). Moreover, participants indicated that the study made them somewhat aware of food waste ($M = 54.93$, $SD = 22.73$).

4.2. Amount of food waste (total, per category, and per state)

As shown in Table 4, columns 4 and 5, the average amount of food waste in grams per week per household ranged between 614 and 1220 g, according to the different measurements. For the diary method, information was available on the amount that was thrown in the bin versus disposed elsewhere. The most frequent methods of disposing waste in the latter case (as % of instances) were that food was given to animals (43.3%), poured down the drain (31.4%), or composed (22.1%). The amount of food that was disposed outside of the bin per week was substantial (262 g on average per household) and differed widely across participants (ranging between 0 and 4013 g). A large proportion of the households only reported food waste going into the bin (45.9%), and only 11 households (4.7%) reported not throwing any of their food waste in the bin.

All measures were lower than the food waste reported in a previous study, using waste composition analysis in 11 neighbourhoods in different cities throughout the Netherlands (van Westerhoven, 2013; 34.6 kg/person/year, which amounts to

Table 4
Food waste according to the different measures.

Measure	*n*	Mean/Median	Mean week 1	Mean week 2	Minimum	Maximum
1. Absolute waste, general	143	Small amount			0	3
2. Relative waste, general (0–75%)	143	6.48 (5.66)			0	22
3. Frequency, general	143	Sometimes			0	3
4. Relative waste, unweighted (0-0.75 scale)	143	0.04 (0.02)			0	0.18
5. Relative waste, weighted (0–4.5 scale)	143	7.14 (4.63)			0.12	31.15
6. Weekly survey (grams per week)	284	639 (573)	614 (579)	662 (568)	0	4170
7. Diary (grams per week)	233	1122 (1086)	1076 (904)	1154 (1196)	14	7213
8. Photos (grams per week)	88	933 (788)	972 (865)	893 (708)	40	4070
9. Caddies (grams per week)	92	1042 (811)	1056 (763)	1029 (865)	0	3216
10. Caddies plus diary (grams per week)	90	1208 (868)	1197 (799)	1220 (941)	36	3980

Note. Median provided for measures 1 and 3. For other measures, means are provided with standard deviations in brackets. The columns labelled "mean week 1" and "mean week 2" provide the grams per household per week. Measures 1 to 5 are not asked per week. Number of participants differs across measures because not all participants were exposed to all measures (see Table 2 for details), and because not all participants reported on every measure they were asked to use. Measures 1 to 5 were answered by all participants ($n = 143$). Measure 6 was measured twice by all participants, and contained two missing values. Measure 7 was measured twice by 95 participants and once by 48 participants, and contained five missing values. Measures 8 and 9 were measured twice by 47 participants, and contained six and two missing values, respectively.

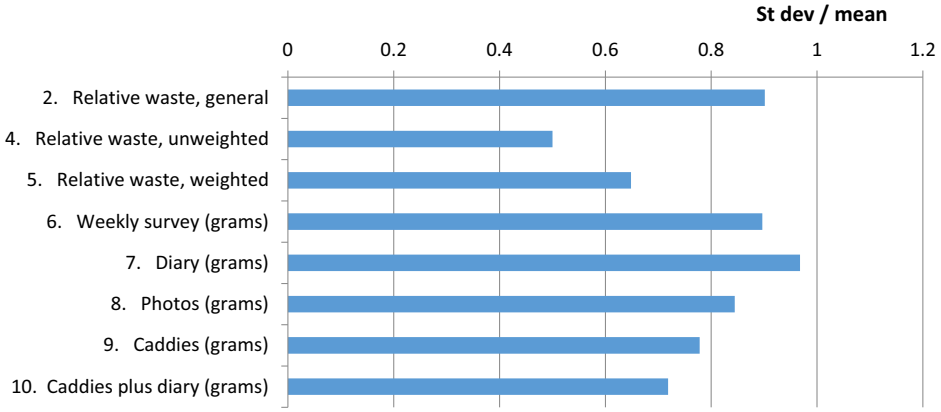
665 g/week/person or 1450 g/week/household). This is in line with prior research, which has shown that the amount of food waste recorded in diaries is smaller than the amount measured in waste-composition analysis (Høj, 2011; WRAP, 2013b). This indicates that all measures in our study may be underreporting the amount of food waste, an issue that we will come back on in the discussion.

For 85 occasions, food waste estimates in grams were available from the weekly survey, diary, photos, caddies, as well as the caddy plus diary measure (measurements provided by the 47 participants in group 3, see Table 2). A repeated measures ANOVA, using measurement as within-subject factor, showed differences between the estimates ($F(4, 336) = 30.93$, $p < .001$). The highest amount of food waste (1188 g for these 85 occasions) was estimated using the combination of caddies and diaries, and posthoc analyses (LSD) showed that this was significantly higher than the other measurements ($p < .001$). The lowest amount of food waste was estimated using the weekly survey (577 g for these 85 occasions), and this was significantly lower than the other measurements ($p < .001$). This is evidence that the weekly survey substantially underreports. The diary (1055 g), photos (954 g), and caddies (1039 g) generated intermediate estimates of food waste that did not significantly differ from each other (estimates based on the 85 occasions in which all measures were provided).

This consistency in measures was also evident when assessing photos and diary entries. Photos and diary entries could be linked based on household number, date, category, and amount, leading to 1010 identified waste acts. There were 129 waste acts (12.8%) with a diary entry but no photo, and only 7 waste acts (0.7%) with a photo but no diary entry, indicating that the diaries were more complete. For matching records, a strong correlation of $r = 0.73$ was found (after excluding one coding mistake), with no evidence of systematic under- or overestimation (paired-sample t-test: $t(775) = -0.15$, $p = .885$). This indicates that researchers estimating the amount of food waste in the photos were relatively accurate.

To assess the extent to which the measures are able to distinguish between households with higher versus lower levels of food waste, we calculated coefficients of variation for the interval scaled measures (see Fig. 1). These showed that the relative waste measurements (measures 4 and 5) showed remarkably little variability across participants. This low variability is not only due to the different scale on which they were measured, since, compared to the other measures, the shrinkage in the standard deviations is larger than in the means. The other measures showed more variability, and thus may be better able to meaningfully distinguish between households. For the ordinal measures, for which the coefficient of variation is not appropriate, we examined the frequency tables and interquartile ranges. This showed that there was very little variability in the answers that respondents gave on these measures (i.e., interquartile ranges of one category only).

Relatively high amounts of food waste (in terms of weight) occurred for vegetables, fruit, and bread. Relatively low amounts occurred for confectionary / snacks and meat and fish. This order of food categories was mostly consistent across the methods of

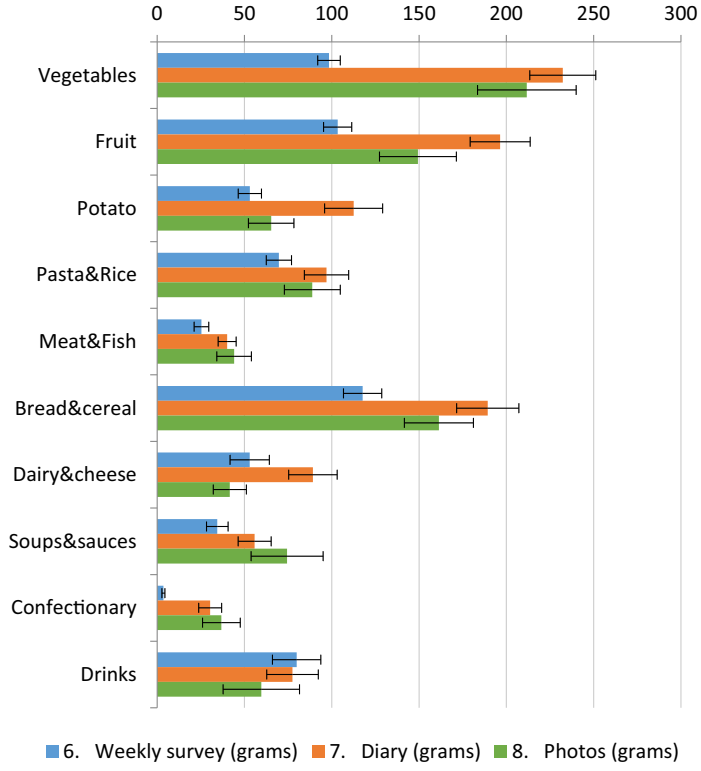


Note. Coefficient of variation (standard deviation divided by mean), as an indication of the relative variability of the scale.

Fig. 1. Ability of methods to show variation in household food waste levels.

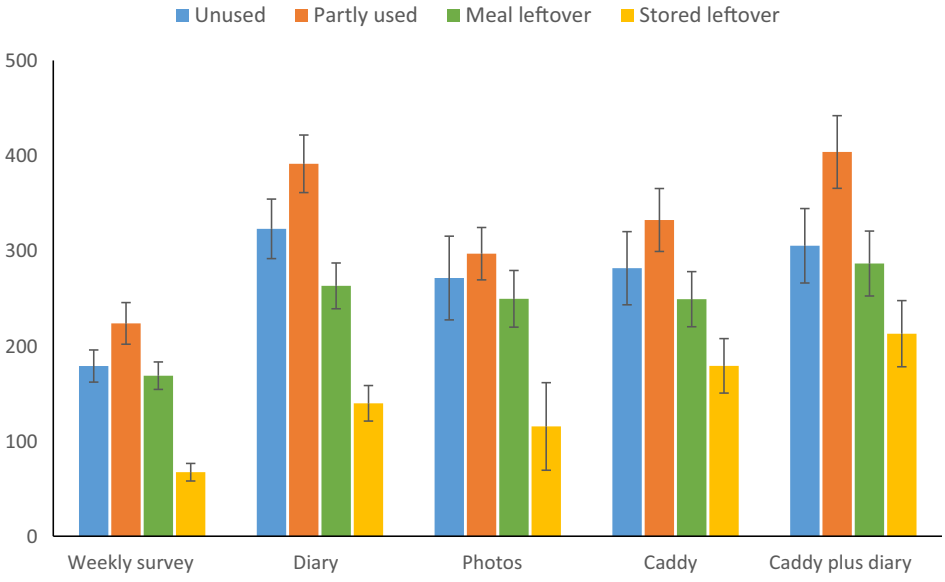
weekly survey, diaries, and photos, and similar to prior research (van Westerhoven, 2013). Fig. 2 shows that underreporting in the weekly survey was relatively large for vegetables and fruit, but not for drinks. The waste assessment using survey measures based on the proportion of food that is discarded in general (measures 4 and 5) showed somewhat different patterns, with higher proportions of potato, pasta/rice, meat, and confectionary reported and lower proportions of fruit and bread.

Fig. 3 shows the reported food waste per state (unused, partly used, meal leftover, or stored leftover). As can be seen, the highest



Note. Error bars represent standard errors (SE) of the mean. Measurement numbers correspond to measures described in Table 3. Measures 1-3 and 9-10 were not reported per food category; measures 4 and 5 were not reported in grams.

Fig. 2. Grams of food waste per category: weekly survey, diary, and photos.



Note. Error bars represent standard errors (SE) of the mean.

Fig. 3. Reported food waste in each of the states, per measurement method.

amounts of food waste occurred for partly used products, whereas the lowest amounts were for stored leftovers. This pattern was consistent across methods.

4.3. Correlations between the measurement methods

Correlations between measurement methods were calculated on the basis of weekly food waste amounts in grams, and are indicated in Table 5. As can be seen, the general waste assessment measures (absolute amount, relative amount, and frequency of food waste) were correlated moderately to high among themselves (correlations between 0.54 and 0.72), but correlated rather poorly to the waste measurement methods that estimated grams (correlations between 0.18 and 0.50).

The three methods of diary, photographs, and kitchen caddies correlated relatively well to each other. The highest correlation was between caddy and diary ($r = 0.86$). The combined measure of caddy plus diary correlated highly with its two components (as would be expected), and also with the photos ($r = 0.80$). Interestingly, the weekly survey was also highly correlated to the diary ($r = 0.71$). As this measure is relatively easy to collect, the weekly survey may be useful in distinguishing between households generating high and low amounts of food waste.

4.4. Correlations and differences between the two weeks

As indicated in Table 4, the average amounts of food waste were similar for the first and second week. Paired sample *t*-tests for each of the methods confirmed that the average amounts did not significantly differ between the first and second week ($ts < |1.1|$, $ps > .29$). For the weekly survey and the diary, we also examined whether the amounts differed between the first and second weeks in each of the groups, using a repeated measures ANOVA. The diary did not show significant effects, but for the survey we found a significant interaction between week and group ($F(2, 138) = 4.17$, $p = .017$). Follow-up paired comparisons showed that in the second group there was a significant difference in reported food waste across both weeks ($p = .004$), with more food waste reported in the second week when participants used both the diary and the survey (768 g) than in the first week when participants used only the survey (519 g). In the other two groups, no significant differences were present between both weeks. This indicates that the survey by itself may underestimate food waste compared to a survey in combination with a diary. To assess this further, we examined the correlations between both weeks (see Table 6).

As participants in the second group did not keep a diary in the first week, we were interested to see if the correlation between the two week-based survey measures would be lower in this group than in the other two groups. A test for differences between independent correlations, based on Fisher's transformation, showed that the difference in correlation between the first group ($r = 0.59$) and the second group ($r = 0.52$) was not significant ($z = 0.47$, $p = .638$). The correlation of the third group ($r = 0.28$) was marginally significantly lower than that of the first group ($z = 1.83$, $p = .067$), but not compared to the second group ($z = 1.35$, $p = .174$). We thus found no evidence that keeping the

Table 5
Correlations between the food waste measurement methods.

	1	2	3	4	5	6	7	8	9
1. Absolute waste, general									
2. Relative waste, unweighted, general	0.56 (n = 143)								
3. Frequency, general	0.72 (n = 143)	0.54 (n = 143)							
4. Relative waste, unweighted	0.44 (n = 143)	0.55 (n = 143)	0.46 (n = 143)						
5. Relative weight, weighted	0.44 (n = 143)	0.55 (n = 143)	0.47 (n = 143)	0.91 (n = 143)					
6. Weekly survey	0.32 (n = 141)	0.28 (n = 141)	0.39 (n = 141)	0.50 (n = 141)	0.50 (n = 141)				
7. Diary	0.35 (n = 94)	0.50 (n = 94)	0.42 (n = 94)	0.59 (n = 94)	0.60 (n = 94)	0.71 (n = 231)			
8. Photos	0.36 (n = 45)	0.41 (n = 45)	0.18 (ns) (n = 45)	0.65 (n = 45)	0.62 (n = 45)	0.62 (n = 86)	0.79 (n = 88)		
9. Caddies	0.36 (n = 46)	0.27 (ns) (n = 46)	0.20 (ns) (n = 46)	0.42 (n = 46)	0.39 (n = 46)	0.51 (n = 90)	0.86 (n = 90)	0.73 (n = 87)	
10. Caddies plus diary	0.37 (n = 45)	0.33 (n = 45)	0.22 (ns) (n = 45)	0.55 (n = 45)	0.51 (n = 45)	0.62 (n = 88)	0.94 (n = 90)	0.80 (n = 87)	0.95 (n = 90)

Note: Spearman's rankorder correlation (ρ) reported for correlations involving measures 1 and/or 3. Pearson correlation (r) otherwise. Correlations are significant at the $\alpha = 0.05$ level unless indicated as not significant (ns). Survey measures on general waste assessment are correlated with the first week measures of other methods.

Table 6
Correlations between food waste measures in Week 1 and Week 2.

Method	Total food waste	Unused	Partly used	Meal leftover	Stored leftover
Weekly survey	0.46	0.23	0.41	0.61	0.27
Group 1	0.59				
Group 2	0.52				
Group 3	0.28				
Diary	0.78	0.42	0.50	0.66	0.44
Group 1	0.82				
Group 3	0.70				
Photos[1]	0.71	0.10	0.42	0.43	NA[2]
Caddies[1]	0.80	0.67	0.54	0.22	0.53
Caddies plus diary[1]	0.77	0.67	0.43	0.32	0.34

[1] Only measured in group 3.
[2] This state was rarely coded, so the number of observations was very low.

diary had influenced the correlation between the survey measures. The results on between-week differences in the average amounts of food waste reported in each group and the differences in the correlations imply that, although the survey by itself may lead to an underestimation compared to using both survey and diary, this seems to be a systematic bias, which does not lower the correlation between the measurements.

Overall, correlations between both weeks were average to high, with an exception for the survey in the third group. A potential reason could be participant fatigue (leading to less reported food waste in the second week), but the overall amount of food waste reported did not reflect this. Given that other measures in the third group were more strongly correlated across the weeks, overall, results appeared to indicate that measurement of the overall amount of food waste in one week might suffice as an indication of household food waste.

In addition to the overall correlation, Table 6 also provides correlations for the states. The coding of photos provided difficulty in attribution to states, with especially the state of "meal leftover" being chosen rarely only. As shown in the table, correlations per state were lower than the overall correlations, possibly due weekly fluctuations in waste and measurement errors that are not correlated across states. Paired sample *t*-tests showed that average food waste in Week 1 did not significantly differ from food waste in Week 2 for any of the measurements per state.

5. General discussion

In-home food waste at the household level can be measured in multiple ways. In this study, the methods of food waste diaries, survey-based scales, kitchen caddies, photos, and the combination of caddies and diaries have been compared, both based on existing literature and through an empirical data collection. Although general survey questions related to how much a household wastes or how often food is discarded have been used frequently in prior studies (e.g., Gül et al., 2003; Parizeau et al., 2015; Setti et al., 2016; Young et al., 2017; Russell et al., 2017), these have received criticism as well (Hebrok & Boks, 2017). In line with this, our results indicate low variance in reported waste across households for these general survey questions and weak correlations of such measures with other waste measurement methods. For these reasons, such general survey questions do not appear very useful in providing insights into food waste amounts.

This does not imply that all survey-based measures share these limitations. Survey questions about the amount of food wasted in the past week correlate strongly with other measures, but also show underreporting compared to these. In the current study, for the weekly survey, participants were alerted in advance that they would be asked questions on food waste, so that they could anticipate this measurement and keep track of food waste. Additionally, participants recorded their amount of food waste per product category and in units appropriate for that category. We recommend that future studies into food waste include both advance notice and measurement in easy-to-comprehend units. Although this measure results in underreporting of food waste compared to other measures, the strong correlation with these other measures indicates that useful insights into household differences (relative amounts of food waste) can still be obtained. For studies that aim to describe the absolute amount of food waste correctly, the underreporting remains an issue.

A method that has been used often in prior research is the food waste diary (e.g., Langley et al., 2010; Williams et al., 2012; Katajajuuri et al., 2014; Richter & Bokelmann, 2017). In contrast, kitchen caddies have been used rarely (our literature review uncovered four prior studies using kitchen caddies or a similar method using self-collection of household waste; Wenlock et al., 1980; Gutiérrez-Barba & Ortega-Rubio, 2013; Ramukhwatho et al., 2017; Elimelech et al., 2018). Systematic photograph coding to measure household food waste has not yet been applied in prior studies, as far as we know. Our results indicate that kitchen caddies and photographs, despite their lack of use in prior research, may be useful methods to consider nonetheless. The diary, kitchen caddy, and photograph coding measures correlate strongly. The comparison of photograph coding with the waste reported in diaries has confirmed that photo coding can give an accurate indication of food waste. Both kitchen caddies and photograph coding are more suitable for small samples, given the high level of researcher effort currently required.

For the caddies, a concern was the amount of food waste not disposed of in the caddies (liquids, home composting, feeding to animals). This relates back to similar concerns voiced about waste-composition analysis (Parizeau et al., 2015). From our study, the impact of these alternative disposal methods appears low. Even though households differed considerably in how much of the food waste is thrown in the caddies, the measure correlates strongly with the diary entries. Future research could combine caddies with diaries, to include a measurement of waste streams not going into the bin, but our results indicate that this additional effort may not be needed if the aim of the study is to obtain an estimate of the *relative* amount of total food waste in a household.

A limitation of household food waste measurement in general is that there is no "golden standard" to compare the measurement methods against. All measurement methods may be subject to biases. Prior research has compared the amount of food waste recorded in diaries with waste-composition analysis for the same waste stream (Høj, 2011; WRAP, 2013b). In these studies, the households participating in the diary-based research and the waste-composition analysis were not the same, although both aimed to be representative of households in the UK. Both studies found that the amount of food waste reported in diaries is substantially lower than the amount resulting from the waste-composition analysis (waste in the diaries was approximately 60% of that in the waste-composition analysis). Yet, from these studies it is unclear whether this is the result of underestimation in the diaries due to underreporting, or correct estimation of lower waste amounts because participating households actually had less food waste than non-participating households (e.g., self-selection bias whereby households with lower waste levels are more likely to complete the diaries, or modification of behaviour during the research period). This limitation of different samples does not hold for the present paper, as the same participants reported food waste using diaries and kitchen caddies. The results indicate that the food waste recorded in diaries may be an underestimation of the actual food waste. Given that in our results a combination of caddies and diary leads to higher estimated amounts than diaries alone, and that amounts are smaller than those reported in waste-composition analysis (van Westerhoven, 2013), this is a distinct possibility.

Food waste varies considerably between different households and days within the study. Still, there appears to be a relatively high degree of correlation between the measured amounts of total food waste for the two weeks, although correlations are less strong when food waste is split into states. Moreover, a previous study using waste-composition analysis to assess total food waste from two (non-consecutive) weeks for a sample of households (WRAP, 2013c) reported lower levels of week-to-week correlation ($r = 0.56$). This suggests that measurement of food waste for a single week may be sufficient to provide information on an individual household's total food waste in certain circumstances, but for high levels of accuracy, longer periods may be required. As the week-to-week differences are more pronounced for subsets of the total

amount of food waste (e.g., states, food categories), to understand these subsets either longer study periods or large sample sizes are required.

5.1. Limitations and future research

Underestimation as such does not necessarily invalidate research findings for studies assessing whether interventions affect food waste, or for studies investigating the effects of household characteristics on food waste, assuming that underestimation is relatively constant across participants and over the course of measurement. Both these assumptions need future research attention. Further research is required to see if the level of underreporting for each measure is stable during the course of interventions aimed at reducing levels of food waste or whether the intervention influences the degree of underreporting. This would need to be investigated for a range of different types of interventions (e.g., communication-based campaigns versus changes to the way food is sold aiming at reducing over-purchasing). As the present study focused on validating the measurements themselves without assessing interventions, the measures are currently not validated for use in monitoring the effect of a food-waste-prevention intervention and further research is required.

A specific limitation in the current study is that it focused on differences between highly divergent methods, while different operationalisations of these methods may affect results as well. Most notably, we have shown that weekly survey measures outperform the general survey measures. Yet, our operationalisations of these methods differ in (a) whether measurement was done on a subjective scale or with units appropriate for the product category, (b) whether the method was pre-announced to participants or not, and (c) whether total food waste was assessed or waste per category. Future research should assess the extent to which each of these individual factors is crucial to the performance of the measurement instrument.

A final point of consideration is the representativeness of the sample. Percentage of single person households was similar to that in the population, but average household size was slightly larger and women were overrepresented in the sample. As we focused on food waste at the household (as opposed to individual) level, the overrepresentation of women in our sample does not pose a big concern. The somewhat higher household size in our sample compared to the population indicates that food waste may be slightly overestimated in the study, but this should not affect the correlations between the measurements.

5.2. Conclusion

In conclusion, due to the relatively high correlations between the five measures for household food waste that were examined (general survey questions, diaries, photo coding, kitchen caddies, and weekly survey), most of these are appropriate measurement tools for household food waste in certain situations with the exception of the general survey questions. The general survey questions ask participants to estimate absolute food waste, relative food waste, or frequency of food wasting. These questions lead to a large underestimation of the level of food waste, and correlate relatively low with other household food waste measurements. It is thus not advisable to use surveys deploying 'general' questions for self-reporting food waste (i.e., those questions asking about either the amount, frequency, or proportion of food waste, but not related to the past week). An alternative measurement is the weekly survey, in which participants indicate which food was wasted in the past week and in which amounts. Although this measurement underestimates the amount of food waste, it correlates higher with other food waste measurements. When researchers would like to understand the relative amount of food waste from a large number of households, this pre-announced survey about food waste in the past week could be used. Diaries are suitable as well, but require more effort from respondents than the weekly survey. For smaller samples, kitchen caddies and photo coding also become viable alternatives. These latter methods require more researcher effort. For future research, measurement performance over time, in the context of testing effects of interventions, is vital.

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Appendix A. Waste states and food categories

The following states and product categories were distinguished.
States:

Completely unused food: Food that has not been used at all (e.g., unopened packages, mouldy apples, dried up leeks).
Partly used food: Food that is disposed of when it is partly used (e.g., crusts of bread, half a pack of sandwich meat, half an onion or part of a courgette that is not used to make a dish).
Meal leftovers: Food that remains on the plate or in the pan after the meal (e.g., leftover potato, rice, mashed dish etc., leftover bread from a lunch package that comes back into the home).
Leftovers after storage: Leftover food that is thrown out after having been stored (e.g., leftovers that have been kept after a meal in the refrigerator but have not been eaten after all).

In the survey, examples specific to the product categories were given to clarify the states.
Food categories:

1. Vegetables (fresh / pot / tin / freezer)
2. Fruit (fresh / pot / tin / freezer)
3. Potato and potato products (fries, precooked small potatoes, etc.)
4. Pasta and rice (including wraps, couscous, etc.)
5. Meat, meat substitutes, and fish
6. Bread, sandwich filling (sandwich meat, sweet sandwich filling, slices of cheese, etc.), and breakfast cereals (muesli, granola, porridge, etc.)
7. Dairy products (yoghurt, custard, etc.), cheese, and eggs
8. Soups and sauces (ketchup, mayonnaise, cocktail sauce, etc.)
9. Confectionery (pieces of candy, chocolate bars, etc.), biscuits, snacks, crisps, and nuts
10. Drinks (milk, juices, carbonated drinks, alcoholic drinks; NOT including water/tea/coffee/syrup).

Appendix B. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.wasman.2019.03.013.

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