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Research article

Consider a broccoli stalk: How the concept of edibility influences quantification of household food waste

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ABSTRACT

Food waste measurement and policy often seek to differentiate between edible food and associated inedible parts, acknowledging different underlying causes for discard and different preferred solutions for waste management. Given the varying views of edibility within and across cultures, there is no widely agreed upon or universal categorization. To understand how edibility influences the outcome of food waste quantification, we applied four different categorizations to 489 household kitchen diaries from Denver, CO and New York City, NY. We also compared them to how respondents self-characterized edibility. We found that the percentage of total food discarded considered edible ranged from 52% to 71% and that the top ten lists of most discarded edible foods changed based on the categorization used. We found that edibility does matter when studying household food waste in terms of defining the extent of the problem, identifying hot spots for intervention, and tracking progress over time. Additionally, we found that respondents' perceptions of edibility varied and were not aligned with any of the four categorizations. Our findings suggest that how edibility is defined should be rigorously and transparently considered and that the varied perceptions of edibility may influence what and how interventions to reduce wasted food are designed, targeted, and evaluated.

1. Introduction

Do you eat the broccoli stalk? Do you peel your potatoes? Do you eat the chicken skin? Or, do you consider these items inedible? While the concept of edibility is seemingly straight-forward, what is considered edible varies between individuals and cultures (Gillick and Quested, 2018; Hanson et al., s.a.; Papargyropoulou et al., 2014). More importantly, as we argue in this paper, the categorization of edibility has a significant impact on the quantification of wasted food and the targeting of interventions to prevent it.

In the past decade, the public and the scientific community have come to recognize the substantial environmental, social, and economic costs of food waste and its link to food security. In 2011, it was estimated that one-third of edible food produced globally went uneaten (Gustavsson et al., 2011) and numerous national and subnational estimates support that large amounts of food are discarded along the food supply chain (Xue et al., 2017). In addition to the impacts of food disposal, the lifecycle impacts of producing food that goes uneaten are large (Food and Agriculture Organization (FAO), 2013). In the United States alone, it was estimated that growing food wasted by consumers used 7% of annual cropland acreage and was associated with other wasted resources such as irrigation water and pesticides (Conrad et al., 2018). Reducing food waste can mitigate climate change and increase the amount of food "available" for human consumption (Conrad et al., 2018; Food and Agriculture Organization (FAO), 2013; Spiker et al., 2017).

Given the size of the problem and the societal benefits in addressing it, there are an increasing number of studies to better quantify food loss and waste (FLW) and to identify the causes and determinants of food waste at various levels of the supply chain (Xue et al., 2017). With this, there has been a proliferation of guidance to help standardize accounting and reporting of FLW in order to increase transparency in methods and improve comparability between studies. In 2016, an international group of experts published the Food Loss and Waste Accounting and Reporting Standard (Hanson et al., s.a.) and two European-based projects, FUSIONS and REFRESH, also put out quantification guidance (Östergren et al., 2014; Quested, 2019; Tostivint et al., 2016). However, as highlighted in recent literature, challenges remain in quantifying food waste. There is a lack of comparability between studies due to differences in quantification boundaries, such as whether inedible parts are included and how edibility is categorized (Bellemare et al., 2017; Xue

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et al., 2017); a high reliance on secondary data indicating large uncertainties in estimates (Xue et al., 2017); and a lack of quantification of the impacts of interventions, especially of long-term effects (Reynolds et al., 2019). Of these, understanding edibility and its impact on food waste is of key importance.

Historically, FLW management has focused on diverting materials from landfills to alternate waste management destinations negating the need to understand edibility. However, in recent years, the focus of policies and programs has shifted to maximize the amount of food that is consumed, whether diverted from disposal or not (Papargyropoulou et al., 2014). Thus, food waste prevention efforts have shifted to target "edible"/"avoidable" foods (Hanson et al., s.a.; Papargyropoulou et al., 2014) and research has worked to elucidate the different mechanisms that drive the discard of edible food items.

Despite the focus on distinguishing between edible and associated inedible parts, there is not a universal or widely-agreed upon categorization of which parts of food are considered edible and which are associated inedible parts (Gillick and Quested, 2018). Using ingestibility or digestibility as the criteria for categorizing edibility is not feasible because essentially all food materials can be made into something that is digestible with enough processing or technological innovation (Gillick and Quested, 2018). Moreover, perceptions of edibility are based on a set of sociocultural, structural, technological, and other factors that vary within and across geographic borders and cultures (Nicholes et al., 2019). For instance, citrus rinds are safe to eat and eaten by some (e.g. preserved lemons), but many people consider them inedible.

There are few studies that explore how different categorizations of edibility influence food waste quantification. This gap led us to interrogate the potential impact of different categorizations of edibility on household food waste measurement outcomes and discuss how these might influence policy and interventions related to reducing FLW. To do this, we analyzed multiple categorizations of edibility and quantitatively applied them to approximately 500 weeklong kitchen diaries. Comparing the results, we contend that the categorization of edibility impacts household food waste quantification and is important for describing the extent of the food waste problem, identifying areas for targeted interventions, and tracking progress towards goals aimed at reducing wasted food.

2. Materials and methods

This study uses the following terminology and boundaries related to FLW and edibility to ensure consistency and transparency and better allow for comparison between studies. "Wasted food," or the "edible" portion of food waste is the main focus of this paper. For the purposes of this paper, we define "edibility" in terms of whether the food part *could* have been eaten, even if it was moldy or rotten when it was discarded. A similar, but distinct concept related to food donation is "rescuability," in which food must be safe and healthy to eat when it would otherwise be discarded. In addition to the above terminology, we consider food reaching any discard destination (i.e. not eaten by humans) to be a part of FLW.

To illustrate the impact of varying characterizations of edibility by researchers and consumers, we compared multiple categorizations of edibility to understand: 1) the maximum difference between two categorizations of edibility, by comparing one categorization that includes the most parts as edible and another that characterizes the least number of parts as inedible; 2) the difference between two widely-used categorizations from the U.S. and U.K.; and 3) how the identification of edibility by participants in a kitchen diary study compared to the other four categorizations. We did this by exploring the variable impact of these categorizations on real-world household measurement data (weeklong kitchen diaries in Denver and New York City).

2.1. Determining food items to be analyzed

To facilitate comparisons between the four categorizations, we generated a list of specific food items commonly discarded in US households. The food items included in this list were determined by the foods reported in kitchen diaries from 545 households in Denver and New York City collected during late 2016 and early 2017 as part of a study by the Natural Resources Defense Council (NRDC). Participants recorded a food description, mass (in ounces), state of food (e.g. inedible parts, cooked, whole), loss reason, and discard destination for all food and beverages they discarded for one week. More information on the study can be found in the original NRDC study reports and technical appendices (Hoover and Moreno, 2017a, 2017b). Using NRDC's raw kitchen diary data, 56 households were excluded from the analysis due to missing data or clear errors in measurements.

Each of the 13,962 kitchen diary entries was given a standardized food name based on the description provided by the respondent, such as "apple." After creation of a list of food items, which can be found in appendix II of the supplementary materials, all items without inedible parts were removed from the list. Cooked items such as lasagna and burritos, as well as beverages, were removed from the list as they were assumed to always be edible. The resulting list of food types with potentially inedible parts was used as the basis to compare the four categorizations of edibility.

2.2. Creating and applying categorizations of edibility

To aid in the comparisons, we created two categorizations, "restrictive" and "inclusive," to represent the "spectrum" of edibility. The *restrictive* categorization includes the most parts as inedible and the *inclusive* categorization includes the fewest parts as inedible. For example, the restrictive categorization of an apple considers all parts but the flesh to be inedible. The inclusive categorization considers the apple's peel, core, and flesh to all be edible, while the seeds and stem are considered associated inedible parts. When creating the two categorizations, items were considered "always inedible" if they were largely considered unsafe to eat (e.g. rhubarb leaves) or are generally considered inedible without prominent examples of edible uses in the United States (e.g. egg shells and bones). Even if they could be argued to be inedible, we considered items to be "potentially edible" if they are safe to eat and there are established examples of their use among some consumers. For instance, smooth melon rinds, like watermelons, are considered potentially edible because they are generally considered safe to eat and pickling watermelon rinds is a practice employed by some households in the U.S. The inclusive categorization was created to include all potentially edible items as edible given the tremendous variation in what is considered edible in our culturally diverse society. Categorizations used by the United States Department of Agriculture (USDA) in their National Nutrient Database for Standard Reference (NNDSR) and the UK Waste and Resources Action Programme (WRAP) were chosen as the two widely used categorizations (Gillick and Quested, 2018; United States Department of Agriculture, 2018). A summary of all categorizations can be found in Table 1.

In order to compare the various categorizations, all food items were characterized by part. For example, an apple was split into stem, seeds, core, peel, and flesh. We then determined whether each food part was considered edible or inedible under each categorization. The description of the food parts considered inedible under USDA and WRAP categorizations often differed from each other, requiring assumptions to standardize them with our categorizations (see all categorizations and assumptions by food type in Appendix I provided in supplementary materials). We identified trends by qualitatively comparing which items were considered edible and inedible under each of the categorizations: inclusive, restrictive, USDA, and WRAP.

Table 1
Summary of categorizations used for comparisons.

Categorization Name	Categorization Description	Notes
Inclusive	Considers the *most* number of food parts as edible. Together with the "restrictive" categorization, represents the spectrum of edibility.	Categorization developed by authors
Restrictive	Considers the *least* number of food parts as edible. Together with the "inclusive" categorization, represents the spectrum of edibility.	Categorization developed by authors
USDA	The USDA's National Nutrient Database for Standard Reference (NNDSR) provides information on nutritional content of almost 8000 individual food items. Provides description and quantitative estimate for portion of food items considered "refuse" (United States Department of Agriculture, 2018).	Sometimes the refuse percentage is broken down by food part while for other items it is provided as an aggregate percentage
WRAP	Based on the 2018 update of WRAP's categorization of commonly wasted food items into food and associated inedible parts (Gillick and Quested, 2018).	No estimations provided.
Respondent-Chosen	In the kitchen diaries, respondents were asked to indicate the state of the food item (inedible parts, prepared, cooked, or whole) and why the food was discarded (including an option for inedible parts). If food was indicated to be an inedible part, it was considered inedible for this categorization.	Only included in comparisons using kitchen diary data. A small number of items were not considered edible if the respondents indicated the state was "inedible parts" but the reason for loss was "moldy/spoiled."

2.3. Quantitative comparison of estimations

To convert total mass of an item into edible and inedible parts under each categorization, we created conversion factors for each food item. Measurement was undertaken to create conversion factors for the 69 most discarded items of mixed edibility, while assumptions were made for non-measured items using proxies from study measurement and/or data from the USDA NNDSR (more detailed information on study measurement and assumptions for non-measured items in Appendix II of the supplementary materials). For example, as shown in Fig. 1, we estimated the proportions for each part of an apple as follows: stem (<1%), seeds (<1%), core (8%), peel (10%), and flesh (80%) based on study measurement. Proportions were then combined for each categorization to provide a conversion factor for the proportion considered *inedible* under that categorization. A summary table comparing all categorizations and estimations can be found in Appendix I in supplementary materials.

In order to analyze differences by categorizations, the maximum range of inedibility for each measured food item was determined by comparing the difference in estimations for the inclusive and the restrictive categorizations. We also explored the differences in estimations between the widely used categorizations, USDA and WRAP. Trends were found by correlating differences in inedibility estimates with characteristics of the food items, including variation in size (coefficient of variation of the initial mass of measured food items), variation in purchasing options (dichotomous variable indicating whether items have major differences in how they are purchased, such as carrots being purchased with and without tops), and food type (e.g. fruit, vegetable, meat, fish, and other). When correlating the differences with food characteristics, we used two-tailed t-tests for exploring purchasing differences, ANOVA for correlating with food types, and simple linear regression for correlating size. The outcome variable for the tests was the difference in proportions considered inedible between categorizations and all statistical tests used a 95% significance level.

2.4. Application of categorizations to real-world data

In order to determine the impact of each categorization on real world data, we applied the estimations to the 489 weeklong kitchen diaries, splitting the mass of food items into edible and associated inedible parts. Each entry of potential or mixed edibility in the kitchen diary was coded to indicate which food parts were included in each entry (e.g. core/stem/seed was coded for entries where those parts of the apple were indicated as present). We created a conversion factor for each of these codes for each categorization using study measurement to determine the proportion of inedible parts. For instance, under the WRAP, USDA, and restrictive categorizations, the core, stem, and seed of apples are all considered inedible, thus a conversion factor of 1 (or 100%) is assigned to entries coded core/stem/seed. For the inclusive categorization, the

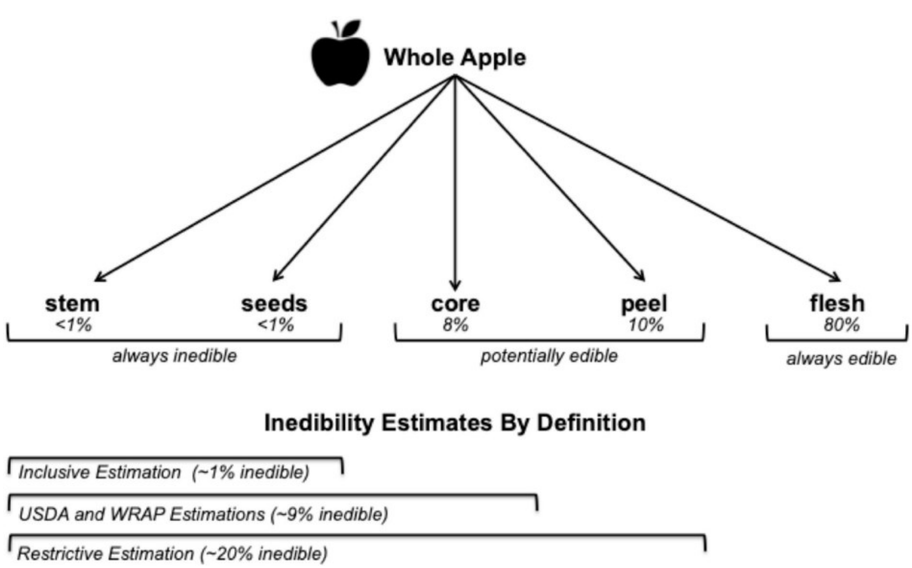

Fig. 1. Example of study measurement results and application to categorizations to generate estimations. Percentages may not add to 100% due to rounding.

core is considered edible, thus a conversion factor of 0.10 (or 10%) is assigned under that categorization for seeds and stem only.

After all of the conversion factors were applied, total food waste generation (pounds) was divided into edible and inedible components. A ratio of edible to inedible parts was created for each individual household and as an aggregate for all households. These were compared for each categorization and compared to respondent-indicated inedibility.

Considering only the edible portions of discarded food in aggregate (by mass) for each categorization, we identified the following hot spots: 1) top 10 most wasted food items by food type; 2) breakdown by loss reasons as stated by respondents; and 3) breakdown by discard destinations as stated by respondents.

The impact of categorizations on individual households was analyzed to determine whether they were homogeneously or heterogeneously impacted by changes in categorization. To do this, two comparison were made: 1) inclusive versus restrictive categorizations; and 2) USDA versus WRAP categorizations. We used simple linear regression to determine if total edible food waste generation by household was correlated between the two categorizations in each comparison.

2.5. Limitations

One of the major limitations of this study is that the use of kitchen diaries to quantify food waste is known to result in underreporting due to social desirability bias, lack of time or desire to track all food, and other omissions in reporting (Moreno et al., 2020; Reynolds et al., 2019). Some studies apply a correction factor to account for this underreporting (e.g. Gillick and Quested, 2018; Hoover and Moreno, 2017a), however, this study did not apply a correction factor because we were interested in relative differences between categorizations rather than identifying a specific quantity of food discarded by households. Another limitation is that study measurement of the 69 food items was limited to foods purchased in the Bay Area of California in the United States and only included twelve repetitions per food type. A larger sample size and purchase of food from multiple geographic areas would allow for study measurement to be representative of produce available in the United States.

3. Results

Below, we describe the differences between the various categorizations and estimations followed by how they impacted outcomes of household level measurement using kitchen diaries. For the qualitative and quantitative comparisons in Sections 3.1 and 3.2, we only analyzed the 69 food items that were included in study measurement based on the inclusive, restrictive, WRAP, and USDA categorizations. Both measured and non-measured items were included when applying categorizations to the kitchen diaries and the respondent-chosen indication of inedibility was also compared to the other four categorizations.

3.1. Qualitative comparisons of categorizations

Of the 69 measured food items, seven items (10%) were consistent across all four categorizations, indicating that most items have at least one part that can be considered either edible or inedible. Items with universal classifications across our categorizations included avocado, egg, and bananas - items with parts that are widely accepted as inedible.

When only comparing the widely used categorizations, USDA and WRAP, 39 items (57%) were consistent between them. We found that the main differences in how edibility is characterized between USDA and WRAP were for the following parts: peels for some vegetables including carrots, cucumbers, and potatoes; stalks and stems for stalky vegetables, including broccoli, cauliflower, and mushrooms; core and outer leaves for cabbages and lettuces; and fat for red meat. In most of these instances (27 of 30 items), USDA had a more restrictive categorization of edibility, meaning more parts were considered inedible.

3.2. Quantitative comparisons of categorizations

The restrictive and inclusive categorizations were designed to represent the spectrum of inedibility that is culturally appropriate for the United States. Of the 69 food items, 8 items (12%) had the same estimated proportion of inedibility (by mass), 11 items (16%) had differences of 10% or less, 23 items (33%) had differences between 11% and 20% and 27 (39%) had differences of 21% or more. The items with the largest differences were citrus items due to the categorization of rinds as edible in the inclusive categorization and inner membranes as inedible in the restrictive categorization. As expected, the restrictive categorization had a higher estimate for the proportion of inedibility for all items. See Fig. 2 for the food items that had the largest ranges of edibility as defined by the restrictive and inclusive categorizations. The percentage differences between the estimations of inedibility for the restrictive and inclusive categorizations were not significantly correlated with differences in purchase conditions (t ¼ −0.20; df ¼ 67; p ¼ 0.84), product size (t ¼ 0.40; df ¼ 68; p ¼ 0.69), or food type (F ¼ 2.39, df ¼ 68; p ¼ 0.06). Due to the lack of correlation, the divergence in estimates of inedibility is primarily attributable to the differences in categorization itself and not characteristics of the food items.

When comparing the USDA and WRAP categorizations, we found that 41 items (59%) had the same estimated proportion of inedibility, 10 items (14%) had differences of 10% or less, 13 items (19%) had differences between 11% and 20% and 5 (7%) had differences of 21% or more. The items with the largest differences were stalky vegetables such as broccoli and cauliflower, due to inclusion of stalks as edible in the WRAP categorization, and red meat because of the inclusion of fat as edible in the WRAP categorization. Grapefruit is also on the list because the USDA categorization considers the inner membranes as inedible. See Fig. 2 for the list of food items with the largest differences in estimations of inedibility between the USDA and WRAP categorizations. The USDA categorization had a higher estimate for the proportion of inedibility than the WRAP categorization for all food items in Fig. 2. The percentage difference between the quantitative estimates of inedibility for the USDA and WRAP categorizations was correlated with purchasing differences (t ¼ −3.0; df ¼ 67; p < 0.01). On average, both items with and without purchasing differences had higher estimates of inedibility under the USDA categorization. Items with purchasing differences diverged more between USDA and WRAP categorizations. The percentage difference between USDA and WRAP categorizations were not significantly correlated with product size (t ¼ 1.20; df ¼ 68; p ¼ 0.24) or food type (F ¼ 0.79; df ¼ 68; p ¼ 0.54).

3.3. Application to real-world data

To appraise how the categorizations impact the outcomes of household-level quantification of food waste, we used analyses common in food waste research: aggregate-level results of total food waste broken down by edibility, top 10 lists of most discarded edible food types, breakdown by loss reason and discard destination for the edible portion, and household-level estimates of edible wasted food. Results for each analysis were compared between categorizations, including the respondent indication of edibility.

3.3.1. Aggregate level analyses

As expected, the restrictive and inclusive categorizations had the lowest (52%) and highest (71%) estimates for proportion of total that was edible, respectively (see Fig. 3). The USDA and the respondent-chosen indication of edibility both had estimates of 55% for edible wasted food and WRAP had a higher estimate of 63%.

In total, approximately 2948 pounds (1337 kg) of food and associated inedible parts from 489 households were recorded in the kitchen diaries as discarded over the period of one week. Comparing the estimates of edible wasted food using the inclusive and restrictive categorizations, there was a difference of 572 pounds (259 kg), translating into

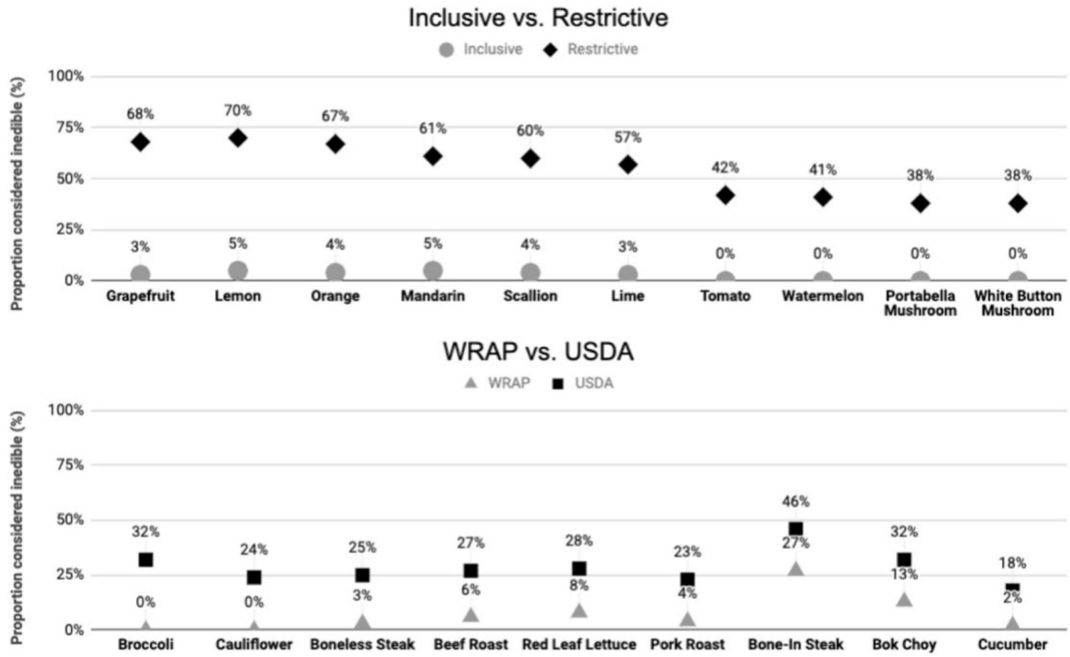

Fig. 2. Top 10 largest ranges of inedibility for inclusive vs. restrictive categorizations (top) and WRAP vs. USDA categorizations (bottom). Above figures display proportion of total food item, by weight, that is considered inedible. In the top diagram, the inclusive definition (circle) always has the lower estimate of inedibility. In the bottom diagram, the WRAP definition (triangle) always has the lower estimate of inedibility. For example, in the top comparison, estimates of inedibility for grapefruit ranges from 3% (inclusive) to 68% (restrictive).

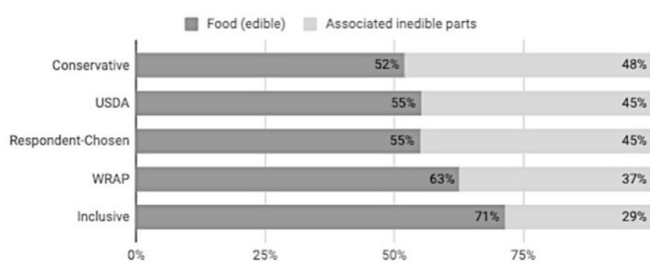

Fig. 3. Breakdown of total food waste by food (edible) and associated inedible parts for each categorization of edibility, including respondent-chosen indication. All estimates, except respondent-chosen indication, were based off of study measurement.

a 1.2 pounds per household per week difference (0.5 kg/hh/week). Comparing the USDA and WRAP categorizations, the difference was 221 pounds (100 kg) of edible wasted food, translating into a 0.5 pounds per household per week difference (0.2 kg/hh/week).

When comparing the inclusive with restrictive categorization and the WRAP categorization with USDA, we identified the food items responsible for the largest changes in the proportion of food considered edible. The magnitude of the difference between estimates of edibility (by mass) is a function of both the proportion of the item considered inedible under each categorization and the frequency that the food item appears in the kitchen diaries. When comparing the inclusive and restrictive categorizations, oranges, apples, lemons, broccoli, cauliflower, and potatoes were the food items that accounted for the largest differences in the estimates of edible wasted food. Broccoli, cauliflower, potato, cucumber, carrot, and lettuce were the top food items when comparing the USDA and WRAP categorizations. The top 10 food items with the largest differences in estimated edible mass between categorizations accounted for approximately half of the total differences. This indicates that a relatively small number of food items accounted for a majority of the differences.

Table 2
Breakdown of edible wasted food by loss reason for each categorization of edibility, including respondent-chosen indication of edibility. Estimates derived from weeklong kitchen diaries in New York City and Denver. May not add to 100% due to rounding.

Loss Reason	Inclusive	Restrictive	USDA	WRAP	Respondent-Chosen
Moldy/Spoiled	25%	31%	30%	27%	34%
Inedible Parts	25%	5%	8%	17%	0%
Don't Want as Leftovers	13%	18%	17%	15%	17%
Left Out Too Long	9%	12%	11%	10%	12%
Past Date Label	7%	9%	9%	8%	9%
Too Little to Save	6%	8%	8%	7%	8%
Don't Like Taste	5%	7%	7%	6%	7%
Improperly Cooked	1%	1%	1%	1%	1%
Other/Blank	9%	11%	11%	10%	13%

Only considering the edible portion, or wasted food, Table 2 shows the breakdowns by loss reason for all categorizations, including the respondent indication. Even though the breakdown by loss reason only includes edible parts, "inedible parts" is still a loss reason because items not considered inedible in the categorizations *were* considered inedible by the respondents. As such, the respondent-chosen indication is the only categorization with no edible food items discarded because they were considered inedible parts. Approximately 5% of edible wasted food was considered inedible by respondents under the restrictive categorization while 25% was considered inedible by the respondents under the inclusive categorization. Notably, the USDA categorization resulted in 8% of edible food discarded because it was considered inedible, while the WRAP categorization had 17% discarded as inedible parts. The largest changes in other loss reasons between categorizations were "moldy/spoiled", "don't want as leftovers," and "left out too long" though the changes were relatively small by percentage.

Table 3
Breakdown of edible wasted food by discard destination for each categorization of edibility, including respondent-chosen indication of edibility. Estimates derived from weeklong kitchen diaries in New York City and Denver. May not add to 100% due to rounding.

Discard	Inclusive	Restrictive	USDA	WRAP	Respondent-Chosen
Destination					
Trash	53%	53%	53%	53%	53%
Compost	27%	21%	24%	26%	23%
Drain Disposal	15%	20%	19%	17%	19%
Fed to Animals	2%	2%	2%	2%	2%
Blank/Other	3%	4%	3%	3%	5%

The breakdown by discard destination (see Table 3) showed very few changes as a result of changing categorizations. The largest, but relatively small, differences were for compost and drain disposal as discard destinations.

3.3.2. Top 10 lists

We created lists of the top 10 most discarded edible food subtypes for each of the four categorizations, in addition to the respondent-chosen indication (for a full list of food subtypes, see Appendix II of supplementary materials). "Other" food categories, which are comprised of items that did not fit in other categories, were excluded. The trends were relatively similar when "other" categories were included. Fig. 4 shows the frequency that food subtypes appeared in the top 10 lists, out of five possible times. Coffee, dairy milk, bread, soup, grains, and noodle dishes appeared on all of the lists. Bread was the top wasted edible food subtype on all lists except for the inclusive categorization, where it ranked second. Additionally, soup and dairy milk were in the top five food subtypes for all categorizations. Citrus only appeared in the inclusive list, but was

Fig. 4. Frequency of appearance in top 10 lists of most discarded edible food subtypes. Top 10 lists were created for inclusive, restrictive, USDA, WRAP, and respondent-chosen categorizations. Estimates derived from week-long kitchen diaries in New York City and Denver. Gray bars represent the number of times a food type appears on top 10 wasted edible food lists (out of five).

the top most wasted edible food subtype on that list.

The USDA categorization and respondent-chosen indication of edibility had the same estimate for aggregate amount of edible discarded food compared to inedible portions. However, the food items included in the estimates were somewhat different. When edibility was indicated by the respondents, some items always considered edible in the categorizations were considered inedible, including bread and pizza crusts. When comparing the top lists of edible foods, red meat and tubers were on the respondent-chosen list, but not on the USDA list.

Comparing USDA and WRAP top 10 lists, the majority of food subtypes were similar. However, the USDA top 10 list included fruits and fruit beverages while the WRAP list instead included stalky vegetables, tubers, and red meat. This finding aligns with the findings that broccoli, cauliflower, potatoes, and beef were some of the items that account for the largest differences between estimates using USDA and WRAP categorizations.

3.3.3. Household-level analysis

To determine whether the different categorizations impacted estimates of edible wasted food at the household level in a heterogeneous or homogeneous fashion, we ran simple linear regression between: 1) the restrictive and inclusive categorizations; and 2) the USDA and WRAP categorizations. Both regression analyses showed a statistically significant relationship between the two categorizations with the restrictive/inclusive comparison having a coefficient of 0.85 (t ¼ 70.8; df ¼ 488; $p < 0.01$), indicating that, on average, household level edible wasted food as defined by the restrictive categorization is predicted to be 85% of that found under the inclusive categorization. The USDA/WRAP comparison resulted in a coefficient of 0.95 (t ¼ 113.09; df ¼ 488, $p < 0.01$), indicating that, on average, household level edible wasted food as defined by the USDA categorization was predicted to be 95% of that found under the WRAP categorization. These findings indicate that changing categorizations have a relatively homogenous impact on households.

4. Discussion

The adage “you cannot manage what you do not measure” is frequently used to encourage investment in measurement. However, it must also be acknowledged that what and how you measure impacts what and how you manage (Espeland and Sauder, 2007). In the case of household food waste, we found that the categorization of edibility influences outcomes of food waste quantification, which impact its problematization and how progress is tracked over time (section 4.1), as well as the identification of hot spots for policy and potential areas to target interventions (section 4.2). While this paper focused on the impact of the categorization of edibility on household-level food waste measurement, it is likely that the categorization also has impacts on other stages of the FSC or when considering all FLW across the FSC.

4.1. Influence on outcomes of measurement and quantification

The categorization of edibility is especially important when the definition of food waste only includes the edible portion of all discarded foods (e.g. USDA), because inedible portions are essentially rendered “invisible.” It is also of increasing importance as more research, policy, and interventions focus on the edible portion of food waste to target for prevention and redistribution.

There are two main ways that studies delineate between the edible and inedible portions of food waste: 1) the project or researcher categorization of edibility is applied to estimate the amount of wasted food from total food waste; or 2) participants in studies are asked to only answer questions or provide information on the "edible" portion of their food waste. The first method allows researchers to standardize the categorization of edibility across all households and is used in quantification studies by UK WRAP, NRDC, and others (e.g. De Laurentiis et al., 2018; Gillick and Quested, 2018; Hoover and Moreno, 2017a). The second method allows the consumer to use their own perceptions of edibility, which may vary greatly between individuals. For example, some household-level surveys approximate the amount of wasted food by asking respondents to estimate the amount of edible food they discard (e.g. Diaz-Ruiz et al., 2018; Stancu et al., 2016).

In this paper, we compared four potential project categorizations and found that the percent difference between the estimate of edible wasted food under inclusive and restrictive categorizations was about 30%, while the percent difference between the USDA and WRAP categorizations was approximately 14%. In terms of average household-level generation of wasted food, the difference between inclusive and restrictive estimates was over one pound (0.5 kg) of edible food discarded per household per week. Comparing USDA and WRAP, the difference was almost one-half pounds (0.2 kg) per household per week. These relatively large differences illustrate that the categorization of edibility is not trivial in terms of estimating the amount of edible wasted food in aggregate.

The categorization of edibility is also important when tracking progress over time, especially for items considered potentially edible. For example, if an intervention aimed at reducing the discard of broccoli stalks reports a reduction in wasted food, it is only a "measured" reduction if they are included within its boundaries of quantification. In the case of the USDA definition of FLW (Buzby et al., 2014), broccoli stalks would not be within the boundaries because inedible parts are excluded, thus these efforts to increase consumption of broccoli stalks should not count as a reduction under the USDA definition. Reporting these reductions could cause "over-reporting" since they would be outside of the boundaries of what is being considered as wasted food or edible food waste.

Finally, transparency and consistency in terms of boundaries, including edibility, are key to ensuring that FLW quantification studies can be compared and verified (Bellemare et al., 2017; Xue et al., 2017) and that progress tracked over time is reflective of actual changes and not an artifact of changes in measurement. Nicholes et al. (2019) recently proposed a systematic method for defining edibility at the country level in a way that captures the majority view of edibility. Specifically, this method uses survey-based data on what parts of food consumers tend to eat and what they consider edible, which are not always aligned (Nicholes et al., 2019). If a standard categorization is not being used, we suggest that parts considered edible be reported in technical appendices for all studies or that studies use multiple categorizations of edibility to provide a range of estimation for the proportion that could be considered edible. One difficulty is that many quantification studies rely on secondary data to estimate FLW. Xue et al. (2017) found that over half of the studies estimating FLW relied on secondary data. This is important because using secondary data may result in forced adoption of the original study's categorization of edibility if they do not transparently provide documentation of how edibility was determined.

The influence of the categorization of edibility not only impacts estimates of the amount of wasted food, but also trickles down to how the impacts of wasted food and its potential for reduction are estimated. Notably, WRAP recently re-calculated UK household food waste estimates and impacts based on a change in how food waste was categorized. They changed from a scale of avoidability (unavoidable, potentially avoidable, avoidable) to edibility (edible, associated inedible parts) to conform to international standards for food waste measurement. They found that the most wasted food items, environmental impacts, and costs of food waste did have some differences between "avoidable" and "edible" categories (Gillick and Quested, 2018), thus suggesting how food is categorized in terms of edibility may have an impact on measurement outcomes other than total quantity of wasted food.

4.2. Identification of hot spots and targets for intervention

In addition to impacting aggregate-level estimates of food waste, the categorization of edibility also impacts what areas are targeted as hot spots for intervention by policy or programs. The differing categorizations of edibility impacted the outcomes of quantification, including breakdown by edibility, top lists of wasted foods, and breakdown by loss reasons. While we found that the impacts on discard destinations and household-level measures were less significant, further investigation should be done to better understand these impacts.

The most wasted edible food items are often identified as hot spots for intervention (e.g. Gillick and Quested, 2018; Hoover and Moreno, 2017a). The inclusion or exclusion of food parts as edible, especially for commonly eaten items, can change the lists of the most wasted foods at the household level, thus altering where policy and consumer campaign efforts might be focused to reduce wasted food. Comparing the WRAP and USDA lists of top wasted food types reveals how each list prioritizes certain food types differently: whereas the USDA version emphasizes fruits, the WRAP version suggests stalky vegetables and tubers are more significant. While both food types are likely important for reducing wasted food overall, this example indicates the potential power of categorizations of edibility to narrow attention too much.

While this paper did not specifically look at the level of heterogeneity in perceptions of edibility among consumers, the findings suggest that respondents have varying perceptions of edibility, consistent with the findings of Nicholes et al. (2019). This is illustrated in the breakdown of edible wasted food by loss reasons (Table 2), which shows that not even the restrictive categorization of edibility captured all items that respondents indicated as inedible. We found that items considered edible under all categorizations, including pizza and bread crusts, were indicated as "inedible" by some respondents. Under the widely used categorizations, USDA and WRAP, we found that between 17% and 8%, respectively, of "edible" food items were considered inedible by the respondents. In addition to showing that no categorization included in this analysis fully encompasses all inedible parts as indicated by respondents, this also indicates that increasing consumption of some food items that people might consider inedible is likely part of the solution to reduce wasted food.

Relatedly, the proportion of total food waste considered edible by respondents was 55%, which was within the range of other estimations. It was the same overall proportion as the USDA categorization, but the items considered edible differed between the two and by household. It is notable that the proportion of total food waste considered edible for the respondent-chosen categorization resulted in estimates that were closer to the USDA and restrictive categorizations. This might suggest that, on average, consumers perceive edibility in a more restrictive, rather than inclusive way.

Prominent information and awareness campaigns targeting both consumers/eaters and consumer-facing businesses focus on reducing the discard of food items that are considered inedible by some people. For example, the Save The Food campaign in the United States has an entire section of their website dedicated to encourage people to eat more parts of food items, including broccoli stalks, cauliflower leaves, cilantro stems, and cheese rinds (Ad Council, s.a.). However, encouraging people to eat parts of food they consider inedible, such as citrus rinds or apple cores, may alienate or discourage people. We suggest focusing on food items that have the most potential for reduction in terms of quantity and social acceptability. Additionally, Nicholes et al. (2019) found that there is sometimes a difference between what parts people consider edible and what they actually eat (i.e. consumers know a part is edible but choose not to eat it because of taste, texture, or other reasons). This suggests that this is not simply an issue of not knowing that a food part is edible, but also an issue of consumer preference, and potentially dietary restrictions.

Additionally, a 2017 report by the World Wildlife Fund (WWF) provided guidance to the hospitality sector to reduce wasted food in their operations. The report included a yield ranking tool based on the proportion of commonly-used fruits and vegetables that are typically considered edible (Pearson and McBride, 2017). The characterization of edibility used by WWF most closely aligns with this study's inclusive categorization, with the WWF categorization sometimes including more parts as edible than even our inclusive categorization. This suggests that the consumer view of edibility may be more restrictive compared to views of people working in food service or upstream in the food supply chain. Perceptions of edibility may be more inclusive in food service and upstream levels of food supply chain as a result of more cooking knowledge, greater access to technologies to transform food parts to make them more palatable, and a direct financial incentive to maximize use of food products. Because of this, food service, manufacturers, and retailers may have higher capacity and ability to maximize the use of potentially edible parts compared to consumers in their households.

In terms of targeting potentially edible food parts to increase their consumption, we found that a small number of food items accounted for a majority of the difference, by mass, in terms of amount of wasted food. Generally, these were commonly eaten items, such as broccoli, and/or items with a large proportion of their total mass considered potentially edible. Arguably, the USDA and WRAP categorizations are the two categorizations that most closely represent the average perception of edibility in the United States. Using the differences between these two categorizations as a guide, the potentially edible food items with the largest impact at the consumer level would be broccoli (stalk), cauliflower (stalk and leaves), potato (peels), cucumber (peels), and carrot (peels). These potentially edible parts were the top 5 items accounting for the largest differences in edible wasted food for those categorizations.

If programs and interventions aim to target potentially edible food items for prevention, we suggest focusing on foods that are commonly eaten (for impact) and with potentially edible parts could be eaten without much effort (social acceptability). However, consumer education campaigns to change consumer perceptions of edibility should not be the sole strategy to increase the consumption of these potentially edible parts. For example, manufacturers sometimes use broccoli stalks for slaw, soups, or other products. Instead of changing consumer perceptions of edibility, consumers could be encouraged to buy only florets if they do not want the stalk, allowing for the stalk to be processed for use in another product instead of discarded at home. This would potentially require manufacturer and retailer change as well to offer options for people to buy items with and without the parts they will use.

5. Conclusions

Our findings demonstrate that edibility is a key concept when quantifying food waste. It is essential that the same categorization of edibility is used when comparing wasted food before and after interventions, or estimating reductions from specific actions. When considering edibility in measurement, it is also important to be transparent about how it is defined. It is imperative to ensure that quantification results are comparable or able to be easily manipulated for comparison. A potential solution is to develop a standard, potentially as part of the existing international Reporting and Accounting Standard, to ensure consistent and rigorous accounting of how edibility is defined as part of a larger effort to ensure transparency and accountability as also suggested by Xue et al. (2017).

There have been suggestions to standardize the categorization of edibility and base it on what is '"usually" eaten by members of the group being studied and/or how a majority of people in a country perceive edibility (Gillick and Quested, 2018; Nicholes et al., 2019). We suggest that it may also be important to consider what food parts are being primarily targeted by food waste prevention campaigns and policies. For instance, if broccoli stalks are going to be targeted by consumer education campaigns to increase their consumption, then they should be included in the categorization of edible wasted food. Inclusion in the categorization will reduce the risk of "over-reporting" progress and ensure that they are captured in the problematization of wasted food.

Finally, perceptions of edibility are a result of material, technological, social, and cultural factors. Encouraging the increased use of potentially edible parts of food items may be part of the strategy to increase the available food supply and reduce wasted food. However, we suggest caution when encouraging people to change perceptions that may be strongly rooted in culture and routine. Additionally, changing consumer perceptions is only one strategy to increase the use of these items. Changes at the manufacturing and retail level also have the ability to reduce waste along the food supply chain, including the consumer level.

Author contribution

Moreno, Laura C.: Conceptualization, Methodology, Formal Analysis, Investigation, Resources, Writing, Supervision, Project Administration, Funding Acquisition; **Tran, Thao:** Methodology, Formal Analysis, Investigation, Resources, Data Curation; **Potts, Matthew D.**: Formal Analysis, Writing, Supervision, Funding Acquisition.

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Appendix A. Supplementary data

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