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Measurement of Frozen versus Fresh Food Waste at the Retail and Consumer Levels:

A Critical Review and Meta Analysis

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Food waste at retail and consumer levels is staggering, with estimates as high as 35 percent of purchases with most discarded in landfills. This study summarizes the literature that shows retail and consumer waste rates for frozen food are substantially lower than their fresh counterparts in almost all cases. The advantage of frozen food is particularly evident for fruit and vegetable products. We also present some of the reasons for frozen food waste identified in the literature, and why rates are lower than for fresh products. We also critique the methodology used in the literature and outline a more ideal methodology for future research on food waste by consumers.

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Food waste at retail and consumer levels is staggering, with estimates as high as 35 percent of purchases with most discarded in landfills. This study summarizes the literature that shows retail and consumer waste rates for frozen food are substantially lower than their fresh counterparts in almost all cases. The advantage of frozen food is particularly evident for fruit and vegetable products. We also present some of the reasons for frozen food waste identified in the literature, and why rates are lower than for fresh products. We also critique the methodology used in the literature and outline a more ideal methodology for future research on food waste by consumers.

0. Executive Summary of Findings

This is a study undertaken by a group of Cornell University researchers, Erika Kliauga (Madeira Trading LLC) and Kai Robertson (independent consultant) on the measurement of frozen versus fresh food waste the consumer and retail level here in the United States and globally. The results in this study are derived from a critical review and meta-analysis of existing studies – the majority of which has been published in peer-reviewed journals.

The main results show that on average fresh food waste is much higher than frozen food for broad food categories at the **consumer level**. For instance,

- The ratio of fresh to frozen food waste for Fruits is 10.3.
- The ratio of fresh to frozen food waste for Vegetables is 3.9.
- The ratio of fresh to frozen food waste for Meat is 2.
- The ratio of fresh to frozen food waste for Fish/Seafood is 1.5.

In terms of specific food items at the consumer level, this study finds,

- The ratio of fresh to frozen food waste for Spinach can be as high as 13.8.
- The ratio of fresh to frozen food waste for Potatoes can be as high as 7.8.
- The ratio of fresh to frozen food waste for Broccoli can be as high as 4.8.
- The ratio of fresh to frozen food waste for Curly Kale can be as high as 1.4.
- The ratio of fresh to frozen food waste for Beans can be as high as 1.3.
- The ratio of fresh to frozen food waste for Red Cabbage can be as high as 1.3.
- The ratio of fresh to frozen food waste for Pasta can be as high as 3.4.

This pattern of fresh food waste being higher than frozen is also evidenced at the **retail level**. However, the number of food categories studied till date is much smaller at the retail level.

- The ratio of fresh to frozen food waste for Green Beans and Blueberries to be 9.47.
- The ratio of fresh to frozen food waste for Broccoli to be 1.19.
- The ratio of fresh to frozen food waste overall across all food items to be 5.82.

1. Introduction

The global frozen food market size in 2021 is valued at USD 290 Billion and projected to grow to USD 504 Billion by 2030. The global retail market for the frozen food industry is dominated by a few large corporations, notably, General Mills Inc (US), Conagra Brands, Inc. (US), Grupo Bimbo S.A.B. de C.V. (Mexico), Nestle SA (Switzerland), Associated British Foods plc (UK), Ajinomoto (Japan), Vandemoortele NV (Belgium), Lantmannen Unibake International (Denmark) and Cargill (United States).[1] The rise in frozen food consumption is attributed to a number of factors: rising opportunity cost of cooking for dual-career couples, ease of online shopping, improvement in the nutritional content and variety of packaged ready-to-eat items, and since 2020, concern for food safety including fear of contamination and a preference for no-touch shopping.[2]

While the surge in sales of frozen food continues, research on the ability of frozen food to reduce food loss and waste vis-à-vis its fresh counterparts has yet to receive adequate attention.[3] Within the United States, a study conducted by the American Frozen Food Institute (AFFI) and the Food Industry Association (FMI) in 2021 show an increase in frozen food sales of 21.0 percent in 2020, driven by increases in the number of frozen food trips and spending per trip resulting in a 19.4 percent increase in spending per buyer. The report also finds that categories that experienced robust sales include seafood, novelties, pizza, breakfast foods, processed poultry, appetizers and potatoes /onions. Figure 1 (from AFFI-FMI Report "Power of Frozen" 2021) shows the growth of U.S. frozen food sales over the 2015-2020 period.

Figure 1

Five-year dollar growth versus year ago
Frozen food department 2015-2020

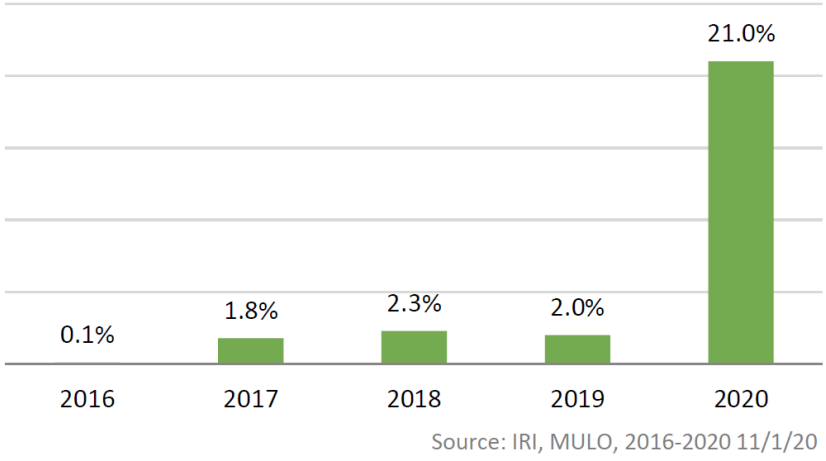


Figure 2 disaggregates the change in sales for each frozen food category between 2019 and 2020 using retail data. In 2019, 35 percent of food went uneaten or unsold – the equivalent of throwing away $408 billion dollars, or 1.9 percent of U.S. GDP.[4] This has major implications for impacts

[1] https://www.precedenceresearch.com/customization/1792
[2] Harvard Business Review "The Future of Contactless Commerce" https://hbr.org/2021/11/the-future-of-contactless-commerce
[3] Food loss occurs before the food reaches the consumer because of issues in the production, storage, processing, and distribution phases while food waste refers to food that is fit for consumption but consciously discarded at the retail or consumption phases. Although food loss and food waste occur at different stages of production and consumption they are lumped together here as "food waste".
[4] ReFED 2021 https://www.prnewswire.com/news-releases/new-data-from-refed-reveals-amount-of-food-waste-has-leveled-off-after-increasing-11-9-since-2010--301220112.html

on greenhouse gas emissions (GHGEs) and natural resource use, food insecurity, and the economy. Over 80 percent of wasted food ends up in landfills.[5]

Figure 2

	Households buying 2x+	Change vs. YA
Total frozen food department	**99.1%**	**+0.0%**
Ice cream	87.5%	+1.2%
Dinners/entrees	82.0%	+0.5%
Plain vegetables	80.9%	+1.9%
Novelties	80.8%	+1.0%
Pizza	73.6%	+2.6%
Seafood	72.7%	+3.6%
Potatoes/onions	71.4%	+3.9%
Poultry	69.5%	+3.8%
Breakfast food	66.4%	+3.7%
Meat	65.4%	+3.7%
Appetizers/snack rolls	65.3%	+4.2%
Processed poultry	64.8%	+3.3%
Soups/sides	55.4%	+1.2%
Bread/dough	53.2%	+3.2%
Desserts/toppings	52.4%	+3.2%
Fruit	39.7%	+3.4%
Pies	38.3%	+0.6%
Pasta	25.0%	+1.7%
Juices	14.2%	+2.2%

Source: IRI, All outlets, 52 weeks ending 11/01/2020; excluding categories with sales below $100,000 annually

The seriousness of the issue of food waste has led the Environmental Protection Agency (EPA) and the U.S. Department of Agriculture (USDA) to announce in 2015 a national goal of a 50 percent reduction in food waste by 2030.[6]

Further research is needed to prioritize policies. In the next section we outline a comprehensive process that can help shape research questions on food waste for fresh versus frozen food.

2. Research Agenda for Study of Frozen vs Fresh Food Waste

With increasing public and private interest in reducing food waste, data limitations (either existence or public availability) preclude a systematic analysis of food waste along the food supply chain. While this paper provides evidence that frozen products generally are discarded at lower rates than their fresh counterparts, additional research would be valuable to better understand the role of frozen food as a solution to reducing waste by consumers and retailers. As a starting point we propose for future research the following steps:

1. A systematic review of existing studies that have empirically estimated food waste along all parts of the food supply chain (production, processing, transportation, storage, wholesale, retail, and household) for frozen food,
2. Review the literature that discusses measures such as volume/weight, nutrients, environmental impacts, or economic value of food waste at each stage of the supply chain for frozen food, and where available fresh vs frozen comparisons,
3. Assess the various methodologies used to collect data on food waste,
4. A review of the data sources, especially household data, that have been used to date in the study of food waste with particular focus on data that pass a "quality threshold" (survey design, number of observations, frequency, local vs. regional vs. national, etc.),

[5] U.S. EPA, 2018 Wasted Food Report (PDF), 2020, and U.S. EPA, Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM) Organic Materials Chapters (PDF), 2020. https://www.epa.gov/recycle/preventing-wasted-food-home

[6] https://www.usda.gov/foodwaste/faqs

5. Identify the gaps in existing data that prevent meaningful comparison of food waste in frozen vs fresh food categories (meat, seafood, dairy, vegetables, and fruits) along the supply chain, and
6. Summarize collected data sets to identify what can be said credibly today about freezing and food waste reduction.

A key challenge to understanding food waste for either fresh or frozen foods (much less a comparison between fresh and frozen) is the availability and/or the possibility of high quality, high frequency data at various stages of the food supply chain. As examples, while data on shrinkage for fresh food might be available between the wholesale and retail stages, data on loss due to pests or contamination at the transportation/storage stage may not be. Likewise, while the carbon footprint in the processing stages of some food groups might be available, data on the volume of food waste at the household level is typically difficult to access. In the following sections we focus on a comparison of food waste between fresh and frozen foods at the retail and at the consumer / household level. This exercise allows for a review of the literature, identification of the gaps in existing data that prevent meaningful comparison of food waste between fresh and frozen foods and undertake a meta-analysis of the extent of food waste of frozen and fresh foods based on the available datasets at the retail and consumer levels. Thus, this paper partially fulfils our research objectives 2, 5 and 6 but only at the retail and consumer levels. We proceed in two steps: (i) develop a matrix that identifies the various sources of data available along the entire food supply chain for different food categories and (ii) identify food supply stages for these food categories where meaningful food waste comparisons can be undertaken either between frozen and fresh food or for specific categories of frozen foods alone.

3. Critical Review of Existing Food Waste Studies for Frozen Food at the Retail and Consumer Levels

There are three sub-sections in this part that respectively review:

(i) 7 studies that exist in the literature that measure frozen vs. fresh food waste and 1 study that measure only fresh food waste at the consumer level using original and secondary data,

(ii) 5 studies that exist in the literature that measure frozen vs fresh food waste and 1 study that measure only fresh food waste at the retail level suing secondary data., and

(iii) an assessment of the methodologies used in these 14 studies at the retail and consumer level.

Note that some studies conduct **both** consumer and retail level studies (USDA-ERS, Neff et.al (2021) and Canals et.al. (2008) for frozen and fresh foods, while Gooch and Nikkel (2019) only for fresh foods) and these studies appear as separate studies in our classification of the studies above, and in the summary Tables 1 and 5 in sub-sections 2.1 and 2.2 respectively.

3.1 Studies on Frozen vs. Fresh Food Waste at the Consumer Level

For ease of understanding, we present in Table 1 below a summary of the 8 studies conducted at the consumer level. Table 1 highlights the frozen and fresh food categories that were studies in

each of the papers, alongside the countries where the studies were undertaken, the methodology used and the main conclusions.

Table 1: Summary of Studies on Frozen Food Waste for Consumer-level Studies

Article	**Food Category**	**Summary/Conclusion**	**Limitations**
Martindale (2014) UK	Broad food categories (vegetables meat, fish, poultry, etc.)	▪ 10.4% of fresh food is waste ▪ 5.9% of frozen food is wasted ▪ 43.3% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 1.76 times that of frozen food	Estimated food waste based on self-reported data
Martindale and Schiebel (2017) Austria	Fruit Vegetables Fresh bread Pasta Meat Fish	▪ 9.3% of fresh food is wasted ▪ 1.6% of frozen food is wasted ▪ 83% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 5.8 times that of frozen food	Estimated food waste based on self-reported data
Janssen et al. (2017) The Netherlands	Vegetables (spinach, broccoli, green beans, etc.) Fruit Fish	▪ 10% of fresh food is wasted ▪ 8% of frozen food is wasted ▪ 13% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 1.15 times that of frozen food.	Estimated food waste based on self-reported data
Neff et al. (2021) United States	Seafood	▪ 3.78% of fresh food is waste ▪ 2.52% of frozen food is wasted ▪ 33.3% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 1.5 times that of frozen food	Estimated food waste based on self-reported data
Canals et al. (2008) Spain and the UK	Broccoli	▪ 20% of fresh food is waste ▪ 5% of frozen food is wasted ▪ 75% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 4 times that of frozen food	Insufficient information to assess the limitations
Gooch and Nikkel (2019) Canada **(Only Fresh)**	Fruits & Vegetables Diary/Eggs Meat/Poultry Marine	▪ Dairy & Eggs: preparation waste = 0.53MT, avoidable plate waste = 0.4MT ▪ Field Crops: preparation waste = 1.05MT, avoidable plate waste = 0.94MT ▪ Produce: preparation waste = 0.85MT, avoidable plate waste = 0.69MT ▪ Meat/Poultry: preparation waste = 0.11MT, avoidable plate waste = 0.10MT	Insufficient information to assess the limitations

		▪ Marine: preparation waste = 0.07MT, avoidable plate waste = 0.06MT MT = Million Tons/year	
Withanage (2020) Canada	Broccoli	▪ 25% of fresh food is waste ▪ 5.2% of frozen food is wasted ▪ 79.2% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 4.8 times that of frozen food	Secondary data, and no details about how data from different sources is combined
USDA ERS United States	Vegetables and Fruits	▪ 19% of fresh food is waste ▪ 25% of frozen food is wasted ▪ 34% more frozen food waste rate compared to fresh ▪ Fresh food is wasted 0.79 times that of frozen food	Unknown data source that shows the opposite result to other similar studies

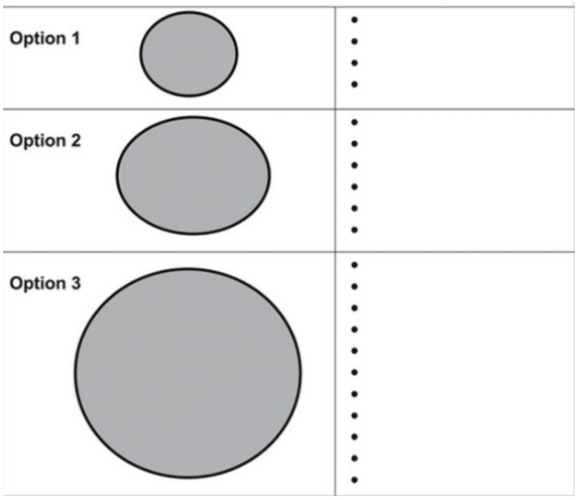
Next, we discuss in detail the methodologies used in each of the papers and highlight the pros and cons of each study.

Martindale (2014) studies consumer food waste and concludes that a typical household waste 10.4 percent of fresh food and 5.9 percent of frozen food. In effect, the frozen food waste rate is 43 percent lower than the rate of waste for fresh food.[7] Another way of stating this is fresh food is wasted 1.76 times that of frozen food.[8] Martindale (2014) also calculates differences in the level of food waste: frozen food waste is 47 percent lower than fresh food waste based on a food waste index. Martindale's (2014) study is based on two consumer surveys. In the first survey, questionnaires were sent to 255 Sheffield, UK residents on-line using the Survey Monkey that determine fresh and frozen food use in the home.[9] Consumers are asked to respond yes/no on whether they consume fresh and frozen foods. The survey gives the consumer options for the food categories of meat, fish, poultry, and vegetable products. The sample was made up of Sheffield residents who were panelists on food sensory testing programs at Sheffield Business School and the questionnaire was designed as a series of "tick box" questions so that the demographic, lifestyle, and product choice data for households could be determined.

From this, only consumers with a wide range of consumption across products, and both fresh and frozen) are chosen for the more detailed survey on food waste. Hence, the second survey was sent to 100 selected respondents from the 255 residents.

[7] Martindale (2014) does not report this number. We calculated it so to be able to compare to other studies below.
[8] Twice Martindale (2014) states "47 percent more fresh food was wasted as compared to frozen food" which is clearly incorrect: that number should be 87 percent.
[9] The study was funded by Iglo Food Group and Sheffield Business School.

Consumers are asked what proportion of food prepared for a cooking session is wasted over a one-week period. Each respondent ticks one of three oval shapes corresponding to 5, 10 and 20 per cent of a typical meal plate. The second column allows the respondent to indicate the type of food wasted. For example, an SKU purchased for frozen green beans is 800-1,000 grams, and it is stored for a month. In contrast a SKU of fresh green beans is 75-120 grams and is stored for a week. This was found to have a large impact on waste.



Respondents are asked to select and indicate **an oval** that corresponds to what they perceived as the typical amount of fresh and frozen food waste from each meal they prepared.[10]

The study does not describe the situation if no shapes correspond to the waste amount. In that case, one would expect the respondent to state a number or the fraction of a shape that matches their estimated amount of waste—however more details about how to proceed with the survey is given. Martindale (2014) does not provide data on the actual level of food purchases or food consumption, nor a frozen versus fresh food breakdown. An index of food waste is provided for each of fresh and frozen food. The implied ratio of frozen to fresh food purchases is 0.94 but this is inconsistent with the data on percent of food purchases wasted; our analysis shows that the ratio of frozen to fresh food purchases should be 0.53. It appears Martindale's (2014) frozen food waste is overestimated unless we misinterpret his food waste index.

Martindale and Schiebel (2017) studies consumer food waste via an online survey of 2800 Austrian households in 2015. This study offers some interesting insights: (i) 9.3 percent of total fresh food purchased is wasted; 1.6 percent of total frozen food purchased is wasted -- fresh food waste is 5.8 times frozen food waste, (ii) fresh food has higher food waste rates in every category except fish (fresh waste is 0.9 of frozen waste), (iii) fresh spinach waste is 13.8 times frozen spinach waste, (iv) fresh fish waste is 2 times greater than fish stick waste and (v) the greatest differences between fresh and frozen food groups are seen for fruit where fresh is 10.3 times greater than frozen, and potatoes where fresh is 7.8 times greater than frozen.

Janssen et al. (2017) creates a waste index as follows: Each household receives a survey. The first part results in some households being excluded from the overall survey. Households excluded are those that (a) never store food in a freezer; and (b) never threw any food away for any product.[11]

[10] The oval shapes are fine but to have fewer dots in 2nd column for the # of products may create a bias i.e., smaller rate of waste for fewer products.

[11] If households do not consume a food category for the entire year, then the data is excluded from the CF (and therefore, will be excluded from the DF, which is fine – if you do not consume, then you cannot waste). If households do not waste food for the entire year, then the data is excluded from the DF (but that means the DF results are biased upwards but 0.05 which is close to zero). And subsequently there will be no FPD reported.

Households receive a monetary reward for completing the entire survey. Households in the remaining part of the survey are given food products organized according to how they are preserved - fresh, frozen, and canned/jarred products. Each household is first asked how often the household consumes each product in a year -- the annual consumption frequency (CF). CF is measured with a 7-frequency scale. They can only pick one frequency for each product. If the response is "never" for one product, it counts as a zero in the CF measure, and later questions for food waste were skipped. Then one can add up all individual frequencies into an aggregate CF for each product.

Scale for frequency:
≥2–3 times per week
1 time per week
2–3 times per month
1 time per month
2–3 times per year
1 time per year

Each household is then asked how often the household disposes of each product in a year -- the annual disposal frequency (DF). DF is also measured with the same 7-frequency scale.[12] They can only pick one frequency for each product. If a household reported "never" for DF, the later question on the fraction of food waste was skipped. Then one can add up all individual frequencies into an aggregate DF for each product. Obviously, if the household picked "never" for CF, then that household is not part of DF. Hence, the number of households reporting CF (#C) is greater than the number of households reporting DF (#D).

Finally, the household is asked what fraction of purchased food is disposed of (FPD)[13] for each specific food product. A 5-point scale is used. This is how a weighted average FPD_j for *i* individuals and product *j* is calculated:

Scale for FPD:	
(Almost) all bought	1
Half of the purchase	0.5
A quarter of the purchase	0.25
2–3 tablespoons	0.1
Practically nothing	0.05

$$FPD_j = \frac{\left(N1_j*1+N2_j*0.5+N3_j*0.25+N4_j*0.1+N5_j*0.05\right)}{\#D}$$

where N1 …. N5 are the number of households in each of the five frequency scales. Janssen et al. (2017) also tests the significant differences in #D, DF and CF. The results are shown in the table below:

#D*	DF	CF
Compared to fresh counterparts: ▪ #D for frozen broccoli, red cabbage, frozen red berry fruit and frozen potato	Compared to fresh counterparts: ▪ DF of frozen curly kale, frozen red cabbage and frozen red berry fruit is significantly lower	Compared to frozen counterparts: Except for peas and peas with carrots:

[12] Notice the much wider range of fractions allowed in their answers compared to Martindale (2014).
[13] Janssen et. al. (2017) use Fraction Purchased Volume (FPV) which is not as informative at FPD.

products is significantly lower		▪ All fresh food products have a significantly higher CF

However, Janssen et.al (2017) does not mention significance tests for differences in food waste rates. Jansen et. al's (2017) survey also has the potential to introduce bias. This is because each respondent first answers all questions in the fresh table, then switches to the frozen table, and then to the canned/jarred table. Not having fresh and frozen spinach next to each other in the survey, for example, may increase or decrease the bias in the questionnaire. Furthermore, Janssen et al. (2017) aggregate the individual weighted FPD_j for each product j into a Waste Index WI_j:

$$WI_j = \left(\frac{DF_j * \#D_j}{CF_j * \#C_j} \right) * FPD_j$$

where #C is the # of households reporting consuming a certain food product in a year and #D is the # of households reporting disposing a certain food product in a year. We showed #C must be greater than #D. Data confirms that #C for all food products is larger than #D. #D is deemed a subset of #C, meaning that #D should always be less than or equal to #C (again, if you do not consume, you cannot waste).

However, a concern for us is how the weight $\left(\frac{DF_j * \#D_j}{CF_j * \#C_j} \right)$ on FPD is justified? If DF is higher for a product relative to CF, then aggregate waste is higher which means waste is disposed more often. Since FPD_j simply measures the fraction of food purchase wasted, the weight is needed to extract how often the food is wasted.

An example can illustrate the issue. Fresh and frozen red berry fruit have the same weighted average FPD. Does that mean fresh and frozen red berry are wasted the same amount over a year? No. Frequency matters. Suppose, on average, fresh red berry fruit is consumed 64 times per year and is wasted 20 times per year. Frozen red berry fruit is consumed 24 times per year (significantly less often than fresh) and is wasted 6 times per year. In this case, $\frac{DF}{CF} frozen = 0.25$ which is less than $\frac{DF}{CF} fresh$ which is equal to 0.31. The DF relative to the CF for frozen red berries is lower than that for fresh berries. The aggregate waste should be lower for frozen red berries. Thus, without a frequency weight, $FPD_{fresh} = 0.12 = FPD_{frozen}$.. But weighted with frequency, we find that:

Weighted $FPD_{fresh} = \frac{20*146}{64*465} \cdot 0.12 = 0.012$ and Weighted $FPD_{frozen} = \frac{6*35}{24*217} \cdot 0.12 = 0.005$.

Thus, we can improve upon Janssen et.al's (2017) predictions by accounting for the frequency of purchases, that the weighted FPD for frozen berries is lower than that for fresh berries. This means that at each consumption of red berry fruit in a year, only a portion of 0.5 percent of the frozen red berry purchased is wasted, compared to 1.2 percent of fresh berries wasted.

To summarize the results of Janssen et al. (2017), the rates of food waste are similar for frozen and fresh for peas, carrots and for unbattered fish (the latter is a surprising result, given our review of the literature on food waste for frozen vs. fresh fish). The only food products where the amounts wasted per consumption event are higher for frozen than for fresh are readymade meals. The main reasons for disposal of food products from the refrigerator by households were: the food product was no longer edible, i.e., 'the product had gone off' (51%), followed by 'too much was prepared' (44%), 'the food product was forgotten' (40%), and 'the expiry date had passed' (5%). Food products from the freezer were disposed of because 'the expiry date had passed' (38%) and/or 'the product was forgotten' (32%). Foods from canned storage were disposed of mainly because 'too much was prepared' (24%).

Neff, et. al (2021) provides waste rates for both consumers and retail separately for seafood overall (no sub-categories for seafood are given). We discuss the methodology and conclusions in this paper for consumers in this sub-section and discuss the methodology and conclusions for retailers in the next. An online two-week consumer food diary in October and November of 2018 was undertaken. Consumers took pre-and post-diary surveys and a two-week food diary. People who (a) go grocery shopping at least once a month, (b) cook food at home at least once a month, and (c) eat seafood at least once a week (excluding canned tuna) are qualified to participate. In the pre-diary survey, consumers are asked 17 questions about seafood consumption attitudes and behaviors and demographic information. No questions about food waste are included. The seafood waste diary aims at calculating the waste percentage. Participants received three initial daily questions asking if they prepared, purchased, or wasted seafood that day. If yes, they answer follow-up questions about the relevant behaviors and seafood items. Responses affect the length of the diary. Finally, in the post-diary survey, consumers should answer 24 primarily closed-ended questions on diary experience, general seafood and waste behaviors, and seafood knowledge.

The data is not publicly available. Neff et al. (2021) reports that the average household wasted an estimated 10.5 g/day of seafood over two weeks, which is equivalent to 10.5 percent of the seafood purchased or 25.0 percent of the seafood prepared. 36 percent of the seafood wasted is fresh seafood, and 24 percent of the seafood wasted is frozen seafood (see Table 4). Food waste is equivalent to 10.5 percent of the seafood purchased. If one assumes 100 tonnes of food purchases, the total food waste is then 10.5 tonnes. Fresh food waste is $10.5 \cdot 36\% = 3.78$ tonnes, while frozen food waste is $10.5 \cdot 24\% = 2.52$ tonnes. Therefore, fresh food waste is 1.5 times greater than frozen food waste (see Table 5). The average household wasted an estimated 10.5 g/day of seafood over two weeks, reflecting 10.5 percent of the seafood purchased or 25.0 percent of the seafood prepared. For consumers, fresh and frozen products were both wasted in similar percentages to the amount purchased. Consumers who bought mostly frozen reported that proficiency (if they knew how to prepare frozen food) (79%), convenience (68%), and perishability (61%) were the most important considerations.

Table 2: Neff et al. (2021). Percent of seafood items purchased, prepared, and wasted during the two-week food diary

Seafood	Purchased at Retail (n = 209)	Prepared at Home (n = 195)	Wasted (n = 59)
Fresh	36%	36%	**36%**

Frozen	23%	31%	**24%**
Shelf-stable	20%	21%	12%
Prepared/cooked	12%	6%	24%
Other	8%	6%	5%
Total	100%	100%	100%

Table 3 below summarizes Neff et. al's (2017) food waste for fresh and frozen seafood with fresh seafood waste at 1.5 times higher than that of frozen.

Table 3: Summary of Neff et al. (2021) for Consumers

		Consumer
[A]	% of fresh food wasted	3.78%
[B]	% of frozen food wasted	2.52%
[C]	% difference in frozen food waste rate compared to fresh food	-33.3%
[D]	Fresh food waste rate *times* frozen food waste rate	1.50

Canals et.al. (2008) concludes that the rate of fresh broccoli wasted is almost 5 times that of frozen broccoli (Table 4) but there is insufficient information to assess the limitations of this study.

Table 4: Summary of Canals et al. (2008) for Consumers and Retailers

		Consumer
[A]	% of fresh broccoli wasted	25%
[B]	% of frozen broccoli wasted	5.2%
[C]	% difference in frozen food waste rate compared to fresh food	-79.2%
[D]	Fresh food waste rate *times* frozen food waste rate	4.81

Gooch and Nikkel (2019) consumer waste rate is based on secondary data. First, Statistics Canada (STC) data is used for food waste. Then, assuming similarity between Canadian and U.S. consumers, Gooch and Nikkel (2019) applies ERS's estimated food waste distribution to the STC's estimated waste to obtain a Canadian estimate of household-level food waste rate. However, no details are given as to how the data was combined.

Withanage (2020) analyzes food waste at the consumer level. Based on the results from 16 samples of green bin waste generated by households in the region of Waterloo, Canada, 43 percent of all food waste is avoidable, and 86 percent of avoidable food waste is plant-based, indicating that fresh fruits and vegetables are the most frequently wasted food item in households. This study assumed a waste rate of 0.052 kg for frozen broccoli and 0.25 kg for fresh broccoli (per 1 kg), based on Canals et al. (2008) and Gooch and Nikkel (2019). According to Canals et al. (2008) retail fresh broccoli waste rate is 2.5 percent, and retail frozen broccoli waste rate is 2.1 percent. Correspondingly, consumer fresh broccoli waste rate is 25 percent, and consumer frozen broccoli waste rate is 5.2 percent. Table 3 summarizes the fresh vs. frozen broccoli waste in Canals et al.

(2008) for consumer and retail. Fresh and frozen broccoli are wasted more at the consumer level than retail. At the consumer level, fresh broccoli waste rate is 4.81 times frozen waste rate, while at the retail level, fresh broccoli waste rate is only 1.19 times frozen waste rate. Canals et al. (2008) assumption for waste at home for fresh broccoli is 20 percent, whereas for frozen broccoli, a figure of 5 percent is used.

The **USDA Economic Research Service (ERS)** use published and unpublished data to capture food waste at the consumer level. The USDA-ERS considers various fruits and vegetables. These include Apricots, Blueberries, Raspberries, Cherries, Peaches, Strawberries, Apples and Plum (Fruits) and Asparagus, Lima Beans, Snap Beans, Carrots, Potatoes, Spinach, Cauliflower and Broccoli. At the consumer level, the USDA-ERS's findings suggest that frozen items have a higher waste rate than fresh but uncertainty about data sources precludes us from critically evaluating the findings.

3.2 Studies on Frozen vs. Fresh Food Waste at the Retail Level

Like Table 1 for consumers, Table 5 below summarizes the 5 studies that estimate food waste for frozen vis-à-vis fresh food and 1 study only for fresh food at the retail level.

Table 5: Summary of Studies on Frozen Food Waste for Retail-level Studies

Article	Food Category	Summary/Conclusion	Limitations
Neff et al. (2021) United States	Seafood	▪ 5% of fresh food is wasted ▪ 0.005% of frozen food is wasted ▪ 99.9% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 1000 times that of frozen food	Estimated food waste based on self-reported data
Pacific Coast Food Waste Commitment (2021) United States	Broad food categories (Produce, dairy and eggs, fresh meat, etc.)	▪ 6.4 % of fresh food is waste ▪ 1.1 % of frozen food is wasted ▪ 83% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 5.82 times that of frozen food	Insufficient data and analysis on food waste
Canals et al. (2008) Spain and the UK	Broccoli	▪ 2.5% of fresh food is waste ▪ 2.1% of frozen food is wasted ▪ 16% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 1.19 times that of frozen food	Insufficient information to assess the limitations
USDA-ERS United States	Multiple Fruits and Vegetables	▪ 12% of fresh Green Beans is wasted ▪ 8.9% of fresh Blueberries is wasted	Insufficient information to

		▪ Fresh green beans waste is 2 times that of frozen ▪ Fresh blueberries waste is 1.5 times that of frozen	assess the limitations
Gooch and Nikkel (2019) Canada **(Only Fresh)**	Fruits & Vegetables Diary/Eggs Meat/Poultry Marine	▪ Dairy & Eggs: 0.16 MT ▪ Field Crops: 0.78MT ▪ Produce: 0.28MT ▪ Meat/Poultry: 0.05MT ▪ Marine: 0.04MT ▪ MT = Million Tons/year	Insufficient information to assess the limitations
Heller and Keoleian (2017) United States	Green beans Blueberries	▪ 2.8% of fresh food is wasted ▪ 0.3% of frozen food is wasted ▪ 89% less frozen food waste rate compared to fresh ▪ Fresh food is wasted 9.47 times that of frozen food	Insufficient information to assess the limitations

Neff, et. al (2021) provides seafood waste rates for retail (no sub-categories for seafood are given). Semi-structured interviews were conducted with employees at eight grocery stores and supermarkets in the Baltimore, MD, area in 2018. Each retailer reported selling 20–130 stock keeping units (SKUs, distinct products) of seafood where the frozen percentage ranged from 40 to 90 percent. All interviewees report that lower waste rates for frozen seafood than that for fresh seafood. Reported fresh waste rates are within a range of 3–7 percent per week, while frozen waste rates are zero or close to zero. No information is given on how they quantify the waste rates.

Table 6: Summary of Neff et al. (2021) for Retailers

		Retail	
[A]	% of fresh food wasted	3%	7%
[B]	% of frozen food wasted	0.005%	0.005%
[C]	% difference in frozen food waste rate compared to fresh food	-99.8%	-99.9%
[D]	Fresh food waste rate *times* frozen food waste rate	600	1,400

The **Pacific Coast Food Waste Commitment (PCFWC)** studies food waste at the retail level. Table 6 reports a very low rate of food waste for frozen products compared to all other categories of food (at the retail level only). Food waste rate for frozen is the lowest 1.1 percent, while for produce, fresh meat and seafood is 6.4 percent and 5.7 percent respectively.

Table 7: 2019 Retail food waste rates reported by PCFWC retailers

Product	Waste rate[14]
Produce	6.4%
Frozen	1.1%
Bread and Bakery	7.4%
Dairy and Egg	2.6%
Prepared food	9.3%
Fresh meat and Seafood	5.7%
Dry goods	1.5%
Ready-to-drink beverages	2.0%

The methodology used is an online waste calculator specific to ReFED. ReFED provides measurement guidelines and food waste metrics in the online ReFED Grocery Retail Calculator tool. Retailers are to use the calculator tool to report relevant data. In addition, one-on-one support to retailers is available to address problems during data reporting.

We take the example of produce from Table 7 to compare food waste for fresh and frozen produce. As Table 8 shows, fresh produce is wasted 5.82 times that of frozen food.

Table 8. Pacific Coast Food Waste Report (2021)

[A]	% of produce wasted	6.4%
[B]	% of frozen food wasted	1.1%
[C]	% difference in frozen food waste rate compared to produce	-83%
[D]	Produce waste rate *times* frozen food waste rate	5.82

Canals et.al. (2008) concludes that the rate of fresh broccoli wasted at the retail level is almost 1.19 times that of frozen broccoli (Table 9) but as in the case for consumer level estimates, there is insufficient information to assess the limitations of this study.

Table 9: Summary of Canals et al. (2008) for Retailers

		Retail
[A]	% of fresh broccoli wasted	2.5%
[B]	% of frozen broccoli wasted	2.1%
[C]	% difference in frozen food waste rate compared to fresh food	-16%
[D]	Fresh food waste rate *times* frozen food waste rate	1.19

The **USDA Economic Research Service (ERS)** use published and unpublished data to capture food waste at the retail level. The same fruits and vegetables considered for the consumer level food waste is also used for the retail level study. These fruits and vegetables once again are:

[14] 2019 grocery unsold food rates.

Apricots, Blueberries, Raspberries, Cherries, Peaches, Strawberries, Apples and Plum (Fruits) and Asparagus, Lima Beans, Snap Beans, Carrots, Potatoes, Spinach, Cauliflower and Broccoli. However, unlike the consumer level findings, the USDA-ERS finds that food waste for fresh to be much higher than that for frozen. However, once again, uncertainty about data sources precludes us from critically evaluating the findings.

Gooch and Nikkel (2019) estimate 5.8 percent waste rate for fresh produce at the retail level and 22 percent at the Hotels, Restaurants, and Institutions (HRI). The methodology employed for the study of only fresh produce is as follows: Retail and HRI waste rates are based on primary data provided by retailers through two online surveys. 251 retailers provided either a) detailed food waste data from formal measurement programs, or b) estimates based on experience and informal tracking of food waste. Percent waste was calculated from the data given or used directly if a percentage was provided.

The final study we review in this sub-section is that of **Heller and Keoleian (2017)**, who partnered with a major retailer (200 stores) to measure retail food waste for fresh vs. frozen green beans and blueberries over two years of sales. Table 8a shows that fresh food waste is 9.47 times that of frozen food. However, no methodology is specified as to how retail partners reported the data.

Table 10: Retail Food Waste Rates for Green Beans and Blueberries; Heller and Keoleian (2017)

		Green beans	Blueberries	Total
[A]	% of fresh food wasted	4.9%	0.72%	2.8%
[B]	% of frozen food wasted	0.27%	0.33%	0.30%
[C]	% difference in frozen food waste rate compared to fresh food	-95%	-55%	-89%
[D]	Fresh food waste rate *times* frozen food waste rate	18.22	2.21	9.47

For the one fruit and one vegetable under study, the results match up with USDA findings using data from LAFA.

3.3 Assessment of the Methodologies used in Consumer and Retail Level Studies

Below we describe how the data was collected, measurement methods, and the pros and cons of the research methodologies. Details about the pros and cons of the studies are summarized in Table 11a and Table 11b.

3.3.1 Data Collection

Consumer studies:

- Martindale (2014), Martindale and Schiebel (2017), and Janssen et al. (2017) use online consumer **surveys** to collect their household food waste data that is then transformed into waste rates.

- Neff et al. (2021) use a two-week food **diary** with pre- and post-diary surveys to collect household food waste data.

Retailer studies:

- Neff et al. (2021) collect retail waste rates by **interviews**, during which interviewees report a number, a range, or just a description of the amount of seafood waste.
- Heller and Keoleian (2017) collect food waste data **directly** from their retail partner, but no data collection method is described.
- Retail food waste data in the Year-End Report for the Pacific Coast Food Waste Commitment (2021) is **reported by retailers** using the online ReFED Grocery Retail Calculator tool.

3.3.2 Food Waste Measurement Methodology

Consumer:

- Martindale (2014) uses **visual tools** to quantify the amount of food waste. Consumers are asked to pick an oval shape to indicate how much of a meal is wasted.
- Martindale and Schiebel (2017) directly **ask consumers to report** the percentage of food purchased that goes to waste.[15] Compared to Martindale (2014), percentage is easier for consumers to report without the aid of visual tools to specify the food waste amount.
- Janssen et al. (2017) collect data on frequency of disposal using a **7-point frequency scale**, ranging from "more than or equal to 2-3 times per week" to "never". They also measure the proportion of purchases disposed of using a **5-point scale**, ranging from "all bought" to "practically nothing".
- Neff et al. (2021) use a diary to track household food waste. Consumers should **measure the weight of waste** in grams and report it every day.

Retailer:

- Neff et al. (2021) ask retailers directly **self-report** the waste rate during interviews.
- Heller and Keoleian (2017) use original data for retail food waste only, but **no methodology is described**.
- For the Year-End Report for the Pacific Coast Food Waste Commitment (2021), ReFED provides **measurement guidelines** and food waste metrics in the online ReFED Grocery Retail Calculator tool. In addition, one-on-one support to retailers is available to address problems during data reporting.

3.3.3 Pros and Cons of Methodologies Used

A summary of the pros and cons of methodologies used is given in Table 11a and Table 11b below.

[15] For example: what percentage of fresh food from your household purchases do you throw away?

Table 11a: Pros and Cons of Methodologies for Consumer-level Studies

Article	Data collection	Food waste measurement	Strengths	Weaknesses
Martindale (2014) UK	Online survey Sample size: 100	Use oval shape to indicate how much of a meal is wasted.	▪ Low costs ▪ Obtain data on demographic and other characteristics of respondents	▪ Small sample ▪ Indirect measurement of food waste ▪ Short timeframe (weekly) ▪ Self-reported food waste can be less accurate
Martindale and Schiebel (2017) Austria	Online survey Sample size: 2800	Ask consumers to report the percentage of food waste relative to food purchased	▪ Large sample ▪ Low costs ▪ Obtain data on demographic and other characteristics of respondents ▪ Assess causes of food waste	▪ Indirect measurement of food waste ▪ Short timeframe (weekly) ▪ Self-reported food waste can be less accurate
Janssen et al. (2017) Netherlands	Online survey Sample size: 1167	▪ Frequency of disposal: 7-frequency scale, ranging from "more than or equal to 2-3 times per week" to "never" ▪ Proportion of purchase disposed of: 5-point scale, ranging from "all bought" to "practically nothing"	▪ Large sample ▪ Long timeframe (yearly) ▪ Low costs ▪ Waste index over a year can better reflect reality ▪ Captured long-term household food waste behaviors	▪ Indirect measurement of food waste ▪ Self-reported food waste can be less accurate
Neff et al. (2021) United States	Food diary with pre- and post-survey Sample size: 43	Consumers measure the weight of waste in grams	▪ Direct measurement of consumer food wastes ▪ Obtain data on demographic and other	▪ Small sample ▪ High reporting burden ▪ Self-reported food waste can be less accurate

			characteristics of respondents through additional questions ▪ Assess causes of food waste	

Table 11b: Pros and Cons of Methodologies for Retail-level Studies

Article	Data collection	Food waste measurement	Strengths	Weaknesses
Neff et al. (2021) United States	Retailer: interviews Sample size: 8	Retailers self-report seafood waste rates during interviews	▪ Obtain data on demographic and other characteristics of respondents ▪ Assess causes of food waste ▪ Obtain additional information as interviews go	▪ Small sample ▪ Self-reported food waste can be less accurate ▪ Indirect measurement of retail food waste
Heller and Keoleian (2017) United States	Sample size: 200	Retailers self-report food waste data	▪ Firsthand data ▪ consistent communication on data with retail partners	Insufficient information to assess the methodology
Pacific Coast Food Waste Commitment (2021) United States	Online ReFED Grocery Retail Calculator tool	Retailers self-report food waste data using the online ReFED Grocery Retail Calculator tool	▪ Measurement guidelines provided ▪ One-on-one support for data reporting ▪ Data validation	▪ New measurement tool may cause greater reporting challenge to retailers ▪ Only unsold food rate is provided, no exact food waste data

4. Meta Analysis Comparison Across All Studies

Our review in the past section points to frozen foods, in general, being wasted less than their fresh counterparts at the consumer and at the retail level. Table 12 below summarize the consumer level studies at the aggregate level while Table 13 provides fresh vs frozen waste comparison for specific food categories (Spinach, Fruits, Potatoes, Fish and Broccoli). We further calculate the fresh to frozen waste ratio across various food items analyzed by the consumer level studies and present this information in Figure 3. Table 14 summarizes the retail level studies at the aggregate level while Table 15 does the same for two specific food items – green beans and blueberries. Table 16 compares the fresh versus frozen food waste rates across the retail level studies. Note that the data presented in Tables 12 and 14 below are derived by calculating the fresh food waste rate *times* the frozen food waste rate at the consumer and the retail level for the various studies. These numbers are also available in the last row of Tables 3, 4, 6, 8, 9 and 10.

Consumer Studies: Table 12 summarizes the studies for consumers only. In Martindale and Schiebel (2017), the fresh food waste rate is 5.81 times the frozen food waste rate, the highest among all consumer waste studies. Martindale (2014) and Janssen et al. (2017) report about 2 times more fresh food waste than frozen. Canals et al. (2008) and Withanage (2020) show that fresh broccoli waste rate is about 4 times that of frozen broccoli. According to Neff et al. (2021), fresh seafood is wasted 1.5 times that of frozen seafood.

Table 12: Consumer Fresh vs Frozen Food Waste Comparison of All Studies

Article	**Fresh food waste rate *times* frozen food waste rate**	
Martindale (2014)	1.76	
Martindale and Schiebel (2017)	5.81	
Janssen et al. (2017)	Waste Index 1.3	Fraction of purchases wasted 1.11
Neff et al. (2021)	1.5	
Canals et al. (2008)	4	
Withanage (2020)	4.81	
USDA ERS	0.79	

Table 13 gives a summary of specific food products for consumers only. Fresh spinach is wasted the most across 4 products, the rate being 13.8 times frozen spinach waste rates. Fresh fruit waste rates are 10 times frozen fruit waste rates. While for fish, that number declines to 1.4. Waste is more severe in the fresh produce category.

Table 13: Consumer Fresh vs Frozen Food Waste Comparison for Specific Food Products

Article	**Spinach**	**Fruit**	**Potatoes**	**Fish**	**Broccoli**
Martindale and Schiebel (2017)	13.8	10.3	7.8		
Janssen et al. (2017)	1.67	2.2	1.63	1.4	1.67
Neff et al. (2021)				1.5	
Withanage (2020)					4.81
USDA ERS					1

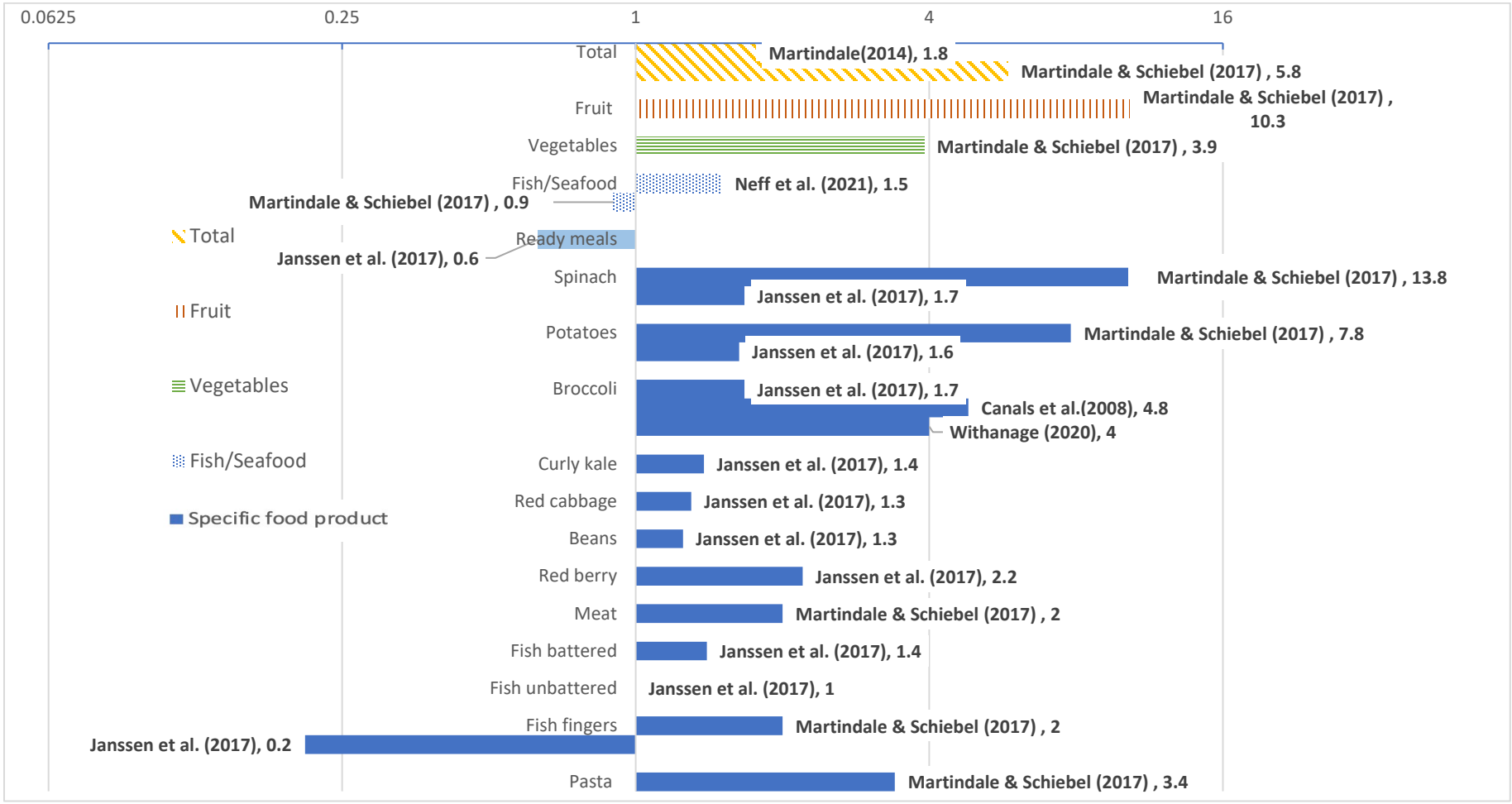
Martindale and Schiebel (2017) and Janssen et al. (2017) compare the fresh and frozen waste rates for spinach, fruit, and potatoes. Although both studies report higher waste rates for fresh than frozen, fresh waste rates in Martindale and Schiebel (2017) are much higher. For example, fresh spinach is wasted 1.67 times that of frozen spinach in Janssen et al. (2017) and 13.8 times in Martindale and Schiebel (2017). The same is true for fruit and potatoes. Characteristics such as eating and wasting habits of Dutch vs. Austrian households and food waste measurement (weighted vs. unweighted waste rates[16]) may cause this rather significant difference. As for broccoli, fresh broccoli waste is about 4 times frozen broccoli waste in Withanage (2020). While in Janssen et al. (2021) and USDA ERS, fresh broccoli is wasted at about the same level as frozen

[16] See Section 2 for more details.

broccoli. The more consistent result is found across studies for fish/seafood. For example, Janssen et al. (2017) show that fresh fish is wasted 1.4 times that of frozen fish; that number in Neff et al. (2021) is 1.5.

For the consumer level studies analyzed, Figure 3 presents a ratio of fresh to frozen food waste rates calculated by the Cornell University authors. The axis is centered on 1 and scaled in proportion to 4. A ratio greater than 1 indicates that the rate of consumer food waste for a *fresh* product was greater than the *frozen* equivalent. By comparison, a ratio lower than 1 indicates that the rate of food waste for a *frozen* product was greater than the *fresh* equivalent. Note that the scale to the left of 1 is much smaller than that to the right of 1.

Figure 3. Ratio of Fresh to Frozen Food Waste Rates at the Consumer Level



Retail Studies: Table 14 summarizes fresh vs. frozen waste at the retail level. The Pacific Coast Food Waste Report (2021) and Heller and Keoleian (2017) both show that fresh food is wasted more than frozen food, with Heller and Keoleian (2017) it is about two times greater. Neff et al. (2021) show a wide range of 600-1400, meaning that fresh seafood is wasted at least 600 times that of frozen seafood at the retail level. Canals et al. (2008) study fresh and frozen broccoli, where fresh broccoli waste rate is only 1.19 times frozen waste rate. In general, fresh food seems to be wasted more at the retail level than at the consumer level. Specifically, fresh green beans are wasted 1.5 times that of frozen green beans at the consumer level in Janssen et al. (2017), while in Heller and Keoleian (2017), fresh green beans are wasted 18.22 times that of frozen at the retail level.

Table 14: Retail Fresh vs Frozen Food Waste Comparison of All Studies

Article	**Fresh food waste rate *times* frozen food waste rate**
Pacific Coast Food Waste Report (2021)	5.82[17]
Heller and Keoleian (2017)	9.47[18]
Neff et al. (2021)	600-1400
Canals et al. (2008)	1.19

Table 16 gives a summary for specific food products for retail only. Fresh produce is wasted more than frozen produce (e.g., green beans and blueberries) at the retail level. Heller and Keoleian (2017) report a relatively high figure of 18.22 for green beans, meaning that fresh green beans are wasted 18.22 times that of frozen green beans. When it comes to blueberries, the number declines to 2.21.

Table 15: Retail Fresh vs Frozen Food Waste Comparison for Specific Food Products

Article	**Green beans**	**Blueberries**
Pacific Coast Food Waste Report (2021)	5.82	5.82[19]
Heller and Keoleian (2017)	18.22	2.21

Interestingly, all retail level studies show that frozen food is wasted less than fresh food (Table 14). Among retailers participating in the Pacific Coast Food Waste Commitment, the difference in the rate of waste is notable with items in fresh produce departments discarded nearly six times more than items sold frozen. Results from a few product-specific studies confirm that at retail the

[17] Fresh produce waste rate (6.4 percent) is compared to frozen waste rate (1.1 percent).
[18] An average of fresh waste rate as well as frozen waste rate of green beans and blueberries is calculated for the total fresh waste rate and total frozen waste rate.
[19] We use the "Produce" category in Pacific Coast Food Waste Report (2021) to represent green beans and blueberries.

rate of waste for frozen products is lower than that of the fresh equivalent but, not surprisingly, the ratio of fresh to frozen waste rates does vary among different types of products.

Table 16. Summary of Retail Food Waste Rates

	Pacific Coast Food Waste Commitment (2021)	**Heller and Keoleian (2017)**	**Canals et al. (2008)**	**Neff et al. (2021)**
Frozen Products	1.1% (frozen food)	0.27% (green beans) 0.33% (blueberries)	2.1% (broccoli)	~ 0 (frozen fish products)
Fresh Products	6.4% (fresh produce)	4.9% (green beans) 0.72% (blueberries)	2.5% (broccoli)	3 – 7 % (fresh fish)
Ratio of Fresh to Frozen Food Waste Rates	*5.82*	*9.47*	*1.19*	*600-1,400*

5. Consumer Awareness and Behavior

Martindale (2017) summarizes the potential reasons why frozen food waste is lower than that for fresh food in the Martindale (2014) and Martindale and Schieble (2017) summarized in Section 2 above. The reasons include frozen foods provide a better way to optimize the utilization of a food product for consumption, decreasing the frequency of purchases, reducing the periodicity of disposal, extended shelf-life, and use car less with frozen food purchases so lower GHGEs. Key reason why frozen foods have lower waste rates is that it improves meal planning. The study emphasizes the importance of food product development that is aligned to the portioning of food in meal preparation. If one can optimize there, then there is less food waste. This relationship between method of food preservation and portioning is also apparent with other food groups such as potatoes and pasta.

van Herpen and Jaegers (2022) uses an online experiment to study consumer attitudes on frozen bread given the information that frozen bread can reduce food waste. During the experiment, participants are provided frozen bread accompanied by (1) a communication message about food waste, (2) a communication message about product quality, or (3) no communication message (control condition). Results show that the waste communication message successfully boosted participants' perception that purchasing frozen bread contributes to diminishing food waste. Emphasizing food waste reduction influenced general attitudes toward frozen bread.

Kölzer, et. al (2020) undertakes a representative online survey in Germany to investigate different aspects of consumer behavior concerning frozen foods. 2053 respondents were questioned about their general handling habits regarding eight different food groups: fruit, vegetables, meat, fish, bread, pastries, ready-to-eat meals, and leftovers. The focus was on freezing, pre-handling, packaging, and thawing – depending on the age of those questioned and combined with best practice advice regarding quality storage of frozen products. Findings include older participants act more efficiently towards quality storage, but more education about freezing and frozen storage would be generally helpful to maintain quality of frozen foods and increase utilization of freezers, using their full preservation potential.

Szymkowiak, et. al (2020) conducts an online survey to assess consumer attitude and behaviors on food preservations. The results showed an inconsistency between the consumers attitudes towards the attributes and their shopping behavior. For example, the processing method was the most important declared attribute for consumers, meanwhile this information was the least searched for during purchase. Shelf-life period marked as the least important was the main information searched for by consumers when shopping.

Martindale (2017) provides further policy implications of his two studies in Section 2 where frozen food waste is lower than fresh food. Frozen foods have lower waste rates, which implies it improves meal planning. Frozen foods may also provide a better way to optimize the utilization of a food product for consumption, decrease the frequency of purchases, reducing the periodicity of disposal, extending shelf-life, and using the car less with frozen food purchases so GHGEs are lower.

van Herpen and Jaegers (2022) suggest that the waste communication message successfully boosted participants' perception that purchasing frozen bread contributes to diminishing food waste. Emphasizing food waste reduction can influence consumer attitudes toward frozen bread and the bakery department. Kölzer et al. (2019) find that most Germans can freeze food and keep their freezers full or medium loaded. More education about freezing and frozen storage would be helpful to maintain the quality of frozen foods and increase the utilization of freezers, potentially to reduce food waste and improve energy efficiency. Szymkowiak et al. (2020) highlights the inconsistency in consumer perception and actual behaviors. For example, the shelf-life period marked as the least important is the primary information searched for by consumers when shopping. Consumers' concerns about the shelf-life period and expiration dates may help reduce food waste.

6. Conclusions

The main purpose of this study was to assess the rate of frozen food waste at the consumer and retail levels. In general, the literature concludes frozen foods are wasted substantially less than their fresh counterparts.

Consumer Food Waste: Seven studies look explicitly at the rate of food wasted by consumers for frozen food in general, or for a selection of specific frozen products compared to comparable fresh products. In nearly all cases, frozen products are wasted less than fresh items.

The degree to which waste rates vary depends on the products under consideration. Figure 1 compares the ratio of fresh to frozen food waste rates at the consumer level. These vary across products and studies. For example, while one study shows that fresh food is wasted nearly two times that of frozen, another study reports that it is six times higher. Moreover, the difference in rates of food waste varies among different types of food. For most fruits and vegetables studied, frozen products are wasted much less than fresh products. However, for fish and seafood products, the findings are mixed.

In terms of why consumers waste food, in the Janssen et al. (2017) study, the greatest number of respondents said for frozen food it was because 'the expiry date had passed' (38%) and/or 'the product was forgotten' (32%). By contrast, food waste of fresh or refrigerated foods were largely driven by the ‘food product was no longer edible (51%),' and/or too much was prepared' (44%). A similar proportion of consumers noted that fresh foods were also wasted when 'the food product was forgotten' (40%).

It is important to note that since the consumer-level studies are mostly based on self-reported data, it is highly likely that the actual food waste is underestimated but, presumably, the bias in fresh and frozen food waste estimates go in the same direction. In addition, temporal and cultural variations may explain the difference among households in the United Kingdom (Martindale 2014), Austria (Martindale 2017), and the Netherlands (Janssen et al. 2017).

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