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Who Cleans the Plate? Quantity and Type of Food Waste in 78 Primary Schools' Canteens in Italy

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Abstract

In advanced economies, most food waste occurs at the downstream stages of the supply chain; within the EU, it has been estimated that 64.57% of food waste occurs at the consumption stage, with about 5.4 million tons (9.45% of the total) being generated in food service. This study aims to contribute to this stream of research by providing evidence about the quantity of food waste produced in Italian primary schools and discussing the results against the evidence available in other EU countries. This research is based on a large-scale study involving 78 primary schools and over 11,000 students for a total number of almost 110,000 monitored meals. The results show that the amount of food not consumed at lunch is 21.7% of the food prepared every day. Plate waste accounts for almost 90 g/day per capita and the total amount of wasted food, including unserved food, accounts for 117 g/day per capita. To our knowledge, this study represents the largest sample size monitored in Italy under the framework of the EC Delegated Decision (EU) 2019/1597 on food waste measurement. Given its scale and adherence to the EU's standardized methodology, this dataset should serve as the reference data for Italy reported to Eurostat, as it is based on direct measurements rather than estimates or secondary data sources. This underscores the importance of systematic, comparable data collection for tracking progress on food waste reduction at both national and European levels.

Keywords: Food waste; school canteens; plate waste; food service; citizen science; public procurement

Academic Editor: Xiaowei Li

Received: 24 December 2024
Revised: 25 July 2025
Accepted: 14 August 2025
Published: 31 August 2025

Citation: Falasconi, L.; Boschini, M.; Giordano, C.; Cicatiello, C.; Alboni, F.; Nassivera, F.; Troiano, S.; Marangon, F.; Segrè, A.; Franco, S. Who Cleans the Plate? Quantity and Type of Food Waste in 78 Primary Schools' Canteens in Italy. *Sustainability* **2025**, *17*, 7836. https://doi.org/10.3390/su17177836

1. Introduction

Up to one-third of global food production is lost or wasted along the food supply chain [1]. In advanced economies, most food waste occurs at the downstream stages of the supply chain [2,3] within the EU; it has been estimated that 64.57% of food waste occurs at

the consumption stage, with about 6.4 million tons (11% of the total) being generated in food service [4].

The challenge of reducing food waste has been recognized as one of the key issues to assure sustainability at the global level, and one specific objective tackling the reduction in food waste and food losses (SDG 12.3) has been included among the Sustainable Development Goals [5]. The obligation for EU Member States to report food waste quantities was established in Directive (EU) 2018/851 [6]. However, several countries, including Italy, had already initiated food waste measurement efforts based on the FUSIONS methodology, which was later formally adopted in 2019 through EC Delegated Decision (EU) 2019/1597 [7].

The school food service represents a sector of major interest for intervention against food waste, because of its relevance in shaping future generations' approach to food and its capacity to educate and influence students' habits regarding food sustainability [8]. In general, there is a lack of information on the amount of food waste produced by companies and institutions [8]. However, several studies have assessed the quantity of food waste in school canteens [9–13], using different methodologies in different settings.

The present paper aims to contribute to this stream of research by providing evidence about the quantity of food waste produced in Italian primary schools.

This manuscript builds on our previous work [10], where we first tested the methodology in a pilot study [10] and then analyzed the causes of food waste in school canteens [14] by providing more detailed insights into the quantities of food waste generated at schools under different conditions, and elaborating on the types of foods that are more frequently wasted at Italian school canteens. Besides providing a large-scale dataset of 78 schools and nearly 110,000 meals, this study not only delivers a comprehensive quantification of food waste in Italian primary schools, but also enables a direct comparison with similarly sized studies from other countries. Unlike our previous studies, which focused on methodological validation and causal analysis, this study offers detailed percentage metrics of food waste, serving as a benchmark for future research and policy interventions. By adhering to the EU's standardized methodology, it ensures systematic and comparable data collection, making it a valuable reference for tracking progress on food waste reduction at both national and European levels.

2. Literature Review

An extensive literature review was conducted to provide an overview of the evidence about the amount of food waste generated by school food services. To this purpose, a search of the Scopus database was conducted combining the keywords "food waste" AND "at a school". The abstract of the resulting 278 documents (search conducted on 24 February 2024) was screened to select only papers where a direct measurement of food waste at school had taken place, which was the case in 36 documents. After careful reading, we identified the studies providing comparable figures of food waste at school; only contributions providing a percentage assessment of the food waste over the quantity of food prepared or served were considered. For example, Derqui et al. [8] were excluded because data were expressed only in grams per pupil per day, which does not allow for comparability with other studies. Other articles were excluded, such as Niaki et al.'s [15], because the results were expressed in percentage of calories rather than of quantities. For each selected paper, the figures of plate waste, defined as the weight of food left on the plate, with respect to the weight prepared or served, are noted in Table 1.

Table 1. Plate waste measured in previous studies at school canteens.

Author	Year	Country	N. Schools	N. Meals	Grade	Methodology	Food Categories	Plate Waste	% [1]
Sundin et al. [16]	2024	Sweden, Germany, Austria	24	37,344	Primary	Weighing (plate waste tracker)	-	Reduction of 17% from the baseline	% food served
József Tóth et al. [17]	2023	Hungary	66	3491	Secondary	Weighing	First course/Second course/Side dish	Max 40%–Min 9%	% food served
Egaña Txurruka et al. [18]	2023	Spain	90	-	Primary	Visual estimation	25 types of food items	Max 40%–Min 5%	% food served
Rigal et al. [19]	2022	France	2	-	Secondary	Weighing	Starters, main dish, filling and dairy	Max 75%–Min 47%	% food served
Lonska et al. [20]	2022	Latvia	7	7064		Weighing	First course/Second course/Side dish	28.75% (overall average)	% food served
Kasavan et al. [13]	2021	Malaysia		7721		Weighing	Carbohydrate and protein-rich meals, vegetable, fruit	17.40% (overall average)	% of food prepared
Garcia-Herrero et al. [12]	2021	USA	1	-	Primary and secondary	Visual estimation and weighing	13 food categories	Max 53%–Min 28%	% food served
Liz Martines et al. [21]	2020	Portugal	21	-		Weighing	Soup, main dish, main carbohydrate source, fruit	Max 21.4%–Min 14.4%,	% food served
Favuzzi et al. [22]	2020	Italy	12	-	Secondary	Weighing	First course/Second course/Side dish	35%	% food served
Chapman et al. [23] [a]	2019	USA	4	3446	Elementary 1st–5th grades	Weighing	Main entrée Fruit Vegetable Milk	Max 40%–Min 20 Max 32%–Min 8 Max 62%–Min 29 Max 40%–Min 29	% food served
Farris et al. [24] [b]	2019	USA	7	861 + 952	Elementary	Visual quarter-waste method	Breakfast in cafeteria/in classroom	Max 43%–Min 38%	% of food prepared
Garcia-Herrero et al. [25]	2019	Italy	18	233,836	Kindergarten Primary	Visual quarter-waste method	First course Second course Side dish	9% 6% 15%	% of food prepared
Giboreau et al. [26]	2019	France	1	776	Elementary 1st–5th grades	Photographic quarter-waste method	Cold, cooked vegs Side veg/Raw veg Starch Dairy Fruit and dessert Main dish	83% 66% 42% 25% 23% 22%	% food served
Malefors et al. [27]	2019	Sweden Finland Germany	343	4,600,000	Primary	Weighing	All food	19.7%	% food served
Boschini et al. [10] [a]	2018	Italy	5	4364	Primary	Weighing	All courses	22%	% of food prepared
Eriksson et al. [11] [d]	2017	Sweden	26 [a]	NA	Preschool Elementary	Weighing	All food	23%	% food served
Liu et al. [28]	2016	China	6	NA	NA	Weighing	All food	21%	% food served
Bontrager et al. [29]	2015	USA	11	7117	Elementary 3rd–5th grades	Photographic quarter-waste method	Fruits and vegetables	27%	% food served
Cohen et al. [30] [c]	2015	USA	6	NA	Elementary 3rd–5th grades Middle	Weighing	Main entrée Fruit Vegetable Milk	23% 36% 53% 27%	% food served
Silvennoinen et al. [31]	2015	Finland	23	58,982	NA	Weighing	All food	5.7%	% of food prepared
Thorsen et al. [32]	2015	Sweden	23	1558	Elementary 3rd–4th grades	Weighing	All food	23%	% food served

Table 1. *Cont.*

Author	Year	Country	N. Schools	N. Meals	Grade	Methodology	Food Categories	Plate Waste	% [1]
Byker et al. [33]	2014	USA	1	304	Kindergarten	Weighing	All courses [a]	45%	% of food pre-pared
Gase et al. [34]	2014	USA	4	2228	Middle	Visual quarter-waste method	Fruits and vegetables	Max 28.7%–Min 10.2%/	% food served
Martins et al. [35]	2014	Portugal	21	471	Elementary 4th grade	Weighing	All food	27.50%	% food served
Cohen et al. [36] [c]	2013	USA	4	NA	Middle	Weighing	Main entrée Fruit Vegetable Milk	19% 47% 73% 25% [d]	% food served

[1] % of food waste, compared to food prepared or compared to food served. [a] Courses served at schools include main entree, fruit, vegetables, and milk (USA), or first course, second course, side dish, bread, and fruit (Italy). [b] In this paper, 1813 meals were studied, among which 861 were consumed in the cafeteria and 952 were consumed in the classroom. [c] The articles report the percentage of consumed food; the complementary percentage of wasted food was calculated by the authors. [d] In this paper, 30 case studies are analyzed together, among which 26 are schools and 4 are elderly care homes. This figure (23%) is obtained from the data presented (23% is food waste, out of which 33% is plate waste).

The methods used to assess the quantity of food waste are highly comparable and they include the direct weighing of leftovers with an electronic scale or the visual quarter-waste method, which was considered substantially reliable in more than 85% of the cases [37], although it is not considered a method to be used for the measurement required by the EC Delegate Decision 2019/1597 [7].

Early studies, conducted until 2018, typically considered a limited number of schools, 10 on average. Malefors et al. [27] were the first to publish a large-scale study, covering 343 schools across three countries and over 4 million meals, but quite large samples are also considered in subsequent studies, reaching up to 90 schools covered in Spain [18]. The H2020 project Lowinfood tested a technological scale in three EU countries across two years [16].

Figures for food waste are highly variable across countries, food categories, and school grades. In general, vegetables are reported to be wasted more than other components of the menu [23,26,36]. It is not clear whether students in upper-school grades waste more [38] or less than the younger ones [15]. However, several studies measuring the quantity of food waste, with respect to the total food served or prepared, agree that the quantity of plate leftovers is something around 20%, despite some studies reporting outlier values even higher than 60% [19,23,26,36].

While most studies focus their analysis on plate leftovers, it should be remarked that food waste at school canteens also comes from other sources. As it happens, in other types of food service operations, food can also be wasted before consumption, during preparation and serving [10,27,39]. In these phases, much of the waste is trim waste and due to overproduction [40].

The main reasons for food waste at schools have been reviewed in Steen et al. [38] and Boschini et al. [14], suggesting that potential factors linked to the quantity of food waste include the size of the schools and of the dining halls, the distance of the kitchen (if the kitchen is not located in the same building as the school, this refers to the kilometers separating them. In other words, the distance food must travel to reach the school), the type of food provided to diners, and the size of the portions. However, as outlined by Vardopoulos et al. [41], it is hard to compare studies' results due to the extreme differences in the methodological protocols, a common shortcoming for all food waste studies.

3. Materials and Methods

3.1. Study Design, Timing, and Costs

The data analyzed in this study were initially collected as part of a report [42] commissioned by the Ministry of Environment of Italy through the project REDUCE, which aimed to assess food waste at the retail, food service, and consumption stages in Italy through reliable methods. This paper expands on food service stage findings, offering additional insights and positioning the results within the wider European and global food waste measurement frameworks (The Supplementary Materials to this article includes the complete dataset for the entire sample of monitored schools. The data provided cover key variables and may serve as a useful resource for comparative analyses across different national and international contexts). To our knowledge, this study still represents the largest sample size ever analyzed in Italy for this type of research, even after some years from the data collection.

This study was conducted in Italy, and the recruitment of primary schools (children aged 6–11 years) was performed during the 2016/2017 school year in three different regions (Emilia-Romagna, Lazio, and Friuli-Venezia Giulia). Once the consensus from the Regional School Districts was received, a formal participation request was sent via email from the Municipal School Offices to 2013 primary schools. The 173 primary schools that agreed to take part in this study were stratified according to the following criteria [42]:

1. School size (small vs. large), based on the number of students on roll;
2. School location (urban vs. rural area), measured as the degree of urbanization of the municipality, according to the Eurostat definition [43];
3. Kitchen location (internal vs. external to school facilities);
4. Catering provider (public service vs. private company).

In order to ensure a representative sample in relation to the reference population, 78 were included in the final sample: 35 in Emilia-Romagna, 25 in Lazio, and 18 in Friuli-Venezia Giulia. The total number of students involved was 11,518. The direct assessment of food waste took place across a period of 2 weeks (10 school days), out of which 1 week was for the winter menu and 1 week was for the spring menu in order to assess as many meal variations as possible. Overall, the assessment referred to 110,656 meals.

The costs of materials required to conduct the data collection in a school of an average dimension (two bin stations, two weeks of monitoring) was previously estimated at EUR 6.6 per day, not including the travel costs (fuel, motorway tolls) incurred for delivering the materials to the schools [10]. The overall cost of materials to conduct the national study was EUR 4848, to which the work of three researchers was added [10,42]. During the study period, teachers were asked to estimate the time required to conduct the monitoring process, and the estimated average time required was 20 min/day, in line with the results emerging from the pilot test [10].

3.2. Methodology Design and Data Collection

The quantification of food waste at the 78 schools included in this study is based on a direct assessment through the weighing of the food wasted with electronic scales. All measurements refer exclusively to the main meal—lunch—which was provided by all schools, while some schools also offered a mid-morning snack; only lunch-related food waste was quantified. The methodology is fully consistent with previously validated food waste assessment operations in the school setting [10] and with the EC Delegated Decision 2019/1597 [7] of the EU Commission. The data collection process consisted of weighing the amount of (a) prepared food; (b) plate waste, i.e., the food partially uneaten and left on children's plates; (c) unserved food, which included non-served food (i.e., surplus servings not served to diners) and other food items entirely rejected by diners (i.e., portions of bread

and fruit not collected by students from the serving trays); and (d) recovered food, which included all the food not consumed but redistributed for human consumption, such as the portions of bread and fruit taken into classrooms by teachers after lunch and given to the students during the afternoon break [10].

The food was measured separately for each course of the meal, which consisted of a total of three main courses (i.e., a first course consisting of a carbohydrate-rich component, a second course mainly based on a protein-rich component, and a side dish of vegetables), a portion of bread, and a portion of fruit, occasionally replaced by a dessert (e.g., cake, yogurt, or ice-cream), according to the Italian school meal guidelines [44].

Data collection was directly conducted by the food service staff, the teachers, and the students following the briefing and instructions received by the researchers. In each region, one researcher acted as external support to the school staff during the assessment by performing daily remote supervision through interactions via a smartphone with the kitchen and school representatives. The schools were provided with all the materials required, and data gathering was conducted along a three-step process [10]:

1. The food service staff weighed the amount of prepared food; data were therefore recorded daily in a dedicated diary (i.e., kitchen diary) and shared with the researcher;
2. Once the diners completed their meals, the food left on their plates was separated into five bins (one for each meal course) by the students themselves, with a teacher in close proximity to ensure proper sorting;
3. Plate waste and unserved food were weighed at the end of the meal by a single class of students; data were therefore recorded in a specific diary (i.e., school diary) and shared with the researcher.

In order to avoid any possible changes in students' dietary habits due to social desirability bias, pupils were not made aware of the real reasons for this study. Teachers and food service staff were therefore instructed to respond with general answers to students inquiring about the newly introduced procedures.

Given the self-reporting technique used for the data gathering, another potential bias was represented by the effect of the progressive exposition of children to the monitoring process, which consisted of an increase in awareness of the amount of food wasted daily and which may affect results. The effect of this bias was evaluated by comparing median values of dietary intakes across different days in the monitored weeks, in order to spot whether food waste would decrease as the days passed.

3.3. Dataset Management

At the end of the monitoring period, data entry and dataset management were performed. Statistical analyses were conducted in software R (Version 4.4.1) [45]. Several statistical methods were used for data analysis. The Mann–Whitney test was applied to assess whether statistically significant differences existed between two groups (e.g., in the amount of food waste between schools located in rural and urban areas). When the comparison involved more than two groups, the Kruskal–Wallis test was employed. To examine the relationship between quantitative variables, Pearson's linear correlation coefficient was used to measure the strength and direction of the linear association between pairs of variables. The scope of this study was to assess the quantity of avoidable food waste at school canteens; therefore, the non-edible parts were estimated but excluded from the analyses [10], as their waste, mainly consisting of fruit cores and peels, did not depend on the attitude of the diners. The non-edible parts were determined by weighing the inedible fraction of each food item, averaging, and subtracting this from the mean item weight [33]. Moreover, in order to facilitate the interpretation of the results, the dishes were clustered into main groups (e.g., first course with meat, first course with vegetables, etc.), with a

total of 12 groups for the first course, 7 for the second course, and 14 for the side dish. Lastly, dish types were then converted into food categories (e.g., meat and meat products, starch products, vegetables and legumes, etc.), in order to provide comparable data at an international level [10].

The quantification of (a) prepared food, (b) plate waste, (c) unserved food, and (d) recovered food allowed us to calculate the amount of (1) non-consumed food, given by the sum of the quantity of food plate waste and unserved food, and (2) food waste, given by the difference between prepared and non-consumed food (Figure 1).

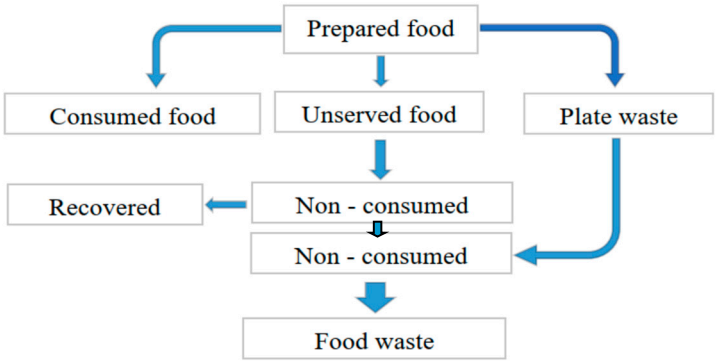

Figure 1. Calculation of non-consumed food and food waste.

4. Results

During the study period, a total of 60.8 tons of food was prepared, with an average of 534.2 g per meal, excluding the non-edible fraction (mainly the inedible parts of fruit), which accounted for 3% of the total prepared food. The recorded waste reflects only the food actually served at lunch, which in 61% of schools was the only meal provided. To enable international comparisons, the results are presented both by dish type (Table 2) and by single food items (Table 3), based on the overall data collected from the full sample of schools involved in this study. On average, 30% of the prepared food was not consumed at lunch, consisting of 16.7% plate waste and 12.7% unserved food. The final food waste amounted to 21.7% of the total prepared food, as 7.8% (primarily bread and fruit) was recovered for human consumption.

Table 2. Per capita amount (g/die) of the avoidable fraction of monitored food [42].

g/Day	Prepared Food	Plate Waste	Unserved Food	Non-Consumed Food *	Recovered Food	Food Waste **
1st course	203.6	44.3	8.9	53.2	0.6	52.6
2nd course	82.6	14.6	2.4	17.0	0.2	16.8
Side dish	95.2	20.2	4.5	24.7	0.3	24.5
Bread	51.1	5.6	16.8	22.4	13.1	9.3
Fruit	101.8	5.3	37.0	42.2	28.1	14.1
Total	534.3	89.9	69.6	159.5	42.3	117.2

* Non-consumed food = Plate waste + Unserved food. ** Food waste = Plate waste + Unserved food − Recovered food.

The daily per capita prepared food exceeded 500 g, with plate waste averaging nearly 90 g/day per person and total food waste reaching 117 g/day per person (Table 2).

The highest levels of non-consumed food at lunch were recorded for:

- Fruit and processed fruit (43.9%);
- Bakery products, mainly bread (41.8%);
- Vegetables and legumes (31.8%).

Although fruit and bread were the most frequently foods left uneaten during lunch, they were often saved for later consumption (e.g., afternoon snack), and therefore not

classified as waste. Consequently, the categories with the highest actual food waste percentages were vegetables and legumes (31.8%), followed by starch staple foods, fish and fish products, eggs and egg products, and dairy products, all ranging between 20% and 30% of the prepared food.

Table 3. Per capita amount (g/day) of edible food per food category [42].

%	Prepared Food	Plate Waste	Unserved Food	Non-Consumed Food *	Recovered Food	Food Waste **
Vegetables and legumes	129.4	32.1	6.7	38.8	0.4	38.4
Fruit and processed fruit	96.4	5.2	36.3	41.5	27.6	13.9
Meat and meat products	38.5	5.3	1.0	6.3	0.1	6.2
Fish and fish products	21.5	4.6	0.6	5.2	0.0	5.2
Eggs and egg products	10.5	2.2	0.4	2.6	0.1	2.5
Dairy products	17.1	3.1	0.5	3.6	0.0	3.5
Starch staple foods	139.8	27.6	5.9	33.5	0.4	33.1
Bakery	55.7	6.1	16.8	22.9	13.1	9.8
Cakes, desserts, ice creams	5.5	0.1	0.7	0.8	0.5	0.2
Condiments, sauces, herbs, spices	19.9	3.7	0.8	4.4	0.0	4.4
Total	534.2	89.9	69.6	159.5	42.3	117.2

* Non-consumed food = Plate waste + Unserved food. ** Food waste = Plate waste + Unserved food − Recovered food.

Among all categories, vegetables and legumes had the highest food waste percentage (31.5%), followed by starch staple foods, fish and fish products, eggs and egg products, and dairy products, which all ranged between 20% and 30% of the prepared food.

The data analysis also revealed significant differences in total food waste, both in terms of plate waste and unserved food, across the three regions included in this study.

The average daily amount of plate waste in Emilia-Romagna and Lazio was approximately 97 g per capita in both regions, while lower values were recorded in Friuli-Venezia Giulia, where plate waste amounted to 65 g per capita per day (Table 4) (the Kruskal–Wallis test yielded a *p*-value of 0.6375 for the average daily amount of plate waste). More marked differences were observed in unserved food waste (unserved food-recovered food): in Emilia-Romagna, the average was 34.1 g per capita, followed by Friuli-Venezia Giulia with 25.4 g per capita, and Lazio reporting the lowest figure at 19.4 g per capita.

Table 4. Per capita amount (g/day) of edible food per region (source: our elaboration).

Region	Plate Waste	Unserved Food	Non-Consumed Food *	Recovered Food	Food Waste **
Emilia-Romagna	97	67.2	164.2	33.1	131.1
Lazio	97.8	43.8	141.6	24.4	117.2
Friuli-Venezia Giulia	65	42.1	107.1	16.7	90.4

* Non-consumed food = Plate waste + Unserved food. ** Food waste = Plate waste + Unserved food − Recovered food.

Interestingly, no statistically significant differences were found between schools located in urban areas and those in rural areas (the Mann–Whitney test yielded a *p*-value of 0.6375) (Table 5).

Table 5. Per capita amount (g/day) of edible food per area (source: our elaboration).

Area	Plate Waste	Unserved Food	Non-Consumed Food *	Recovered Food	Food Waste **
Urban area	92.5	49.3	141.8	24.8	117.0
Rural area	88.5	53.6	142.1	24.7	117.4

* Non-consumed food = Plate waste + Unserved food. ** Food waste = Plate waste + Unserved food − Recovered food.

Moreover, food waste was significantly lower (the Mann–Whitney test yielded a p-value of 1.9×10^{-87}) in schools with on-site kitchens, both in terms of plate waste and unserved food. Specifically, the average waste was 96.2 g per capita per day in schools with internal kitchens, compared to 130.8 g per capita in those relying on external catering services (Table 6).

Table 6. Per capita amount (g/day) of edible food per kitchen location (source: our elaboration).

Kitchen Location	Plate Waste	Unserved Food	Non-Consumed Food *	Recovered Food	Food Waste **
Kitchen internal to school	69.2	37.4	106.6	10.4	96.2
Kitchen external to school	84.2	86.4	170.6	39.8	130.8

* Non-consumed food = Plate waste + Unserved food. ** Food waste = Plate waste + Unserved food − Recovered food.

The size of the school, defined as the number of users accessing the school canteen service, did not show a statistically significant correlation coefficient with the amount of food prepared or with plate waste (the Pearson's correlation coefficient yielded a p-value of 0.0880 for prepared food and 0.5644 for plate waste). Conversely, the correlation coefficient related to the amount of unserved food for the three main courses was statistically significant, although its effect size remained limited (p-value of 1.7×10^{-9} for unserved food.

Seasonal menu variation (winter vs. summer—mainly differing in the types of fruit and vegetables served, as well as some preparation methods for certain dishes) emerged as a significant factor in differentiating the amount of edible plate waste across all three main courses (the Mann–Whitney test yielded a p-value of 5.5×10^{-6}). In particular, the winter menu was associated with higher levels of waste (90.5 g per capita per day) compared to the summer menu (74.6 g per capita per day).

The provision of a mid-morning snack, whether by the food service providers or by families, significantly influences the amount of leftover food on plates (the Mann–Whitney test yielded a p-value of 6.9×10^{-10}). Specifically, the quantity of edible leftovers is nearly 99.7 g per capita per day in schools where the snack is brought from home, whereas it is around 76.8 g per capita per day in schools where the snack is provided by the service provider (Table 7).

Table 7. Plate waste based on the provider of the mid-morning snack.

Mid-Morning Snack Supplier	N. of School	Food Waste G/per Capita/per Day	Δ G/per Capita/per Day	p-Value	Significance
Food service provider	31	76.8	22.9	6.9×10^{-10}	*** [1]
Family	47	99.7			

[1] No * no significance *** maximum significance.

5. Discussion

The results of this study disclose that nearly one-third of the food prepared for lunch at the surveyed canteens is wasted, both as plate leftovers and as serving waste. Some causes of food waste already emerged in our previous study [14] and have been confirmed here: (1) if the mid-morning break includes a meal provided by the caterer, the overall food waste decreases, compared to situations where the children bring a snack from home; (2) if the kitchen is inside the school, the plate waste is less; (3) the summer menu is associated with lower food waste compared to the winter menu; (4) there is no difference in food waste between schools located in urban areas and those in rural areas; and (5) no significant difference in food waste is observed based on school size. In addition to the analyses provided by Boschini et al. [14], in this study, we analyze quantities by food categories, school, and meal provider, thus disclosing detailed insights into the different factors underlying food waste generation at school canteens. For instance, we disclose regional differences in food waste levels: they were higher in Emilia-Romagna and Lazio compared to Friuli-Venezia Giulia, possibly due to a wider presence of schools with internal kitchens, which may influence portion sizes and serving practices. The analysis of foods in plate waste confirms the previous evidence in the literature, with a higher presence of vegetables and legumes, followed by "Starch staple foods", "Fish and fish products", "Eggs and egg products", and "Dairy products". Proposing menus that are dietary-balanced but not palatable to children could be one of the causes for these products being wasted, as highlighted by József Tóth et al. [17]; however, nutritional recommendations cannot be left aside to reduce food waste [22]. Finding a balance among these issues is a key aspect in food waste reduction at schools. Not all the possible causes of food waste in school canteens are related to the food per se, and we can assume that zero waste is hard to achieve when it comes to children eating together. It is worth recalling that eating is not a rational act, in adults or children, and the approach to food in the school environment is affected by a number of factors that are not directly related to the type of food served. For instance, the number of people sitting in the dining room [14] and the example of peers sitting nearby [46] are factors correlated to children's higher food waste at school. The food waste rates observed in the sample of school canteens involved in this study are comparable to the most recent studies in the literature that used direct weighing for quantification. Our findings align with those of Malefors et al. [27], the most extensive study to date on the topic, which reported 16.7% of food waste, out of the total food served. Garcia-Herrero et al. [25] report food waste levels of 9%, 6%, and 15% for the first, second, and side courses, respectively. Although their figures are lower than those in this study, both findings confirm that side dishes generate the highest percentage of waste among the courses served to pupils. This is concerning not only in terms of food waste, but also from a nutritional standpoint, as side dishes are typically vegetable-based. Also, in József Tóth et al.'s study [17], vegetables had the lowest rates of consumption, ranging from 53.5% of consumed food, out of the served food, for vegetable soups, to 82.3% for fresh salads.

The use of a direct weighing method ensured the collection of accurate and reliable data; the use of a self-reporting technique (the teachers were responsible for collecting the weighing data and then sending them in bulk to the researchers, which avoided the need for a researcher to be present at each school) and the distribution of tasks among all subjects involved limited the need for external support. This led to a significant reduction in costs and enabled the collection of data from different schools at the same time. For instance, in Emilia-Romagna, the results from 19 schools were simultaneously collected on a daily basis.

The involvement of pupils in the weighing operations exposes them to the direct observation of food waste, possibly raising their awareness of the phenomenon more

effectively than any theoretical class. Piras et al. [46] demonstrated that a simple theoretical class about food waste has no long-term effect on awareness, and similar results were confirmed by Sundin et al. [16]. However, the possible bias related to the progressive exposition of children to the experimental procedures did not affect the results. In addition, data collection autonomously managed by the schools allowed limiting the observer effect and social desirability bias, which were also limited by not making the children aware of the real reasons for this study.

The present method, by complying with the EU accounting minimum requirements (EC Delegated decision 2019/1597 [7]) and proposing a detailed but affordable protocol, can be applied in the EU Member states (Directive 2018/851 [6]) with only slight adaptations related to menus and service organizations. This would allow a good standardization and comparability of the studies at the EU level, while supporting the mandatory reporting of food waste in the food service sector. Since 2017, technological advancements in AI have accelerated, with recent studies and projects testing fully automated weight scales, often combined with AI recognition tools. In the Lowinfood project, a limitation was noted when using such technologies due to high costs, but these costs are expected to decrease in the near future. These technologies could significantly reduce the burden of data collection, which in this study was mostly performed manually, requiring personnel engagement (e.g., staff, pupils, and researchers) and taking valuable time away from data analysis (see, for example, Sundin et al. [16]). Given the EU Commission's mandate, it is strongly recommended to explore and implement automated solutions for canteens, as they enable large-scale measurements with minimal human effort. However, due to the current cost challenges, the methodology employed in this study remains a viable alternative for the measurements.

However, some limitations need to be reported. To simplify the data collection process, plate waste from school staff and food service personnel, which counted for 6.8% of all participants, was included in the analyses. Secondly, the use of a self-reporting technique might lead to a misreporting of data due to a lack of compliance, forgetfulness, and guilt with regards to eating habits [47]. Nevertheless, as suggested by Livingstone et al. [48], children might show curiosity toward a new procedure and their direct involvement might contribute to their enthusiasm and compliance. On the other hand, the presence of teachers supervising the process and the daily contact of school representatives with the researchers contribute to supervising potential misreporting occurrences. All these limitations could be overcome with the use of fully automated measurement systems, as suggested in Malefors et al. [49], which would eliminate the need for manual data collection (despite introducing new ones to be addressed).

6. Conclusions

Addressing food waste in schools can be linked to promoting healthier eating habits among children. Measuring food waste is a crucial first step in developing strategies for food waste reduction. The methodology used in this study proved effective for large-scale data collection, providing reliable and cost-effective results that are easily scalable at the national level. This approach could support EU Member States in meeting reporting requirements and sustainability goals. It is the most preferred methodology, unless automated technological tools are available.

This study found that nearly one-third of prepared food was wasted, both as plate waste and unserved food. This finding is consistent with the extensive research across other EU countries, which highlights the need for a comprehensive effort to reduce food waste at schools, at the EU level. The food most often wasted included vegetables, legumes, starchy foods, fish, eggs, and dairy products, and particularly high waste rates are reported for

side dishes, primarily composed of vegetables. Factors such as meals provided by caterers during the half-morning break and internal school kitchens helped reduce waste. Balancing nutrition with palatability is key to reducing waste in schools.

Beyond food choices, social factors, like dining group size and peer influence, may contribute to food waste. Interventions should focus on reducing unserved food through better kitchen practices or promoting food donations.

This study can help improve meal planning and encourage sustainable school food services, guiding authorities to reduce waste and enhance dietary intake.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su17177836/s1, Dataset of primary schools that participated in food waste monitoring activities with detailed indicators of the data collected.

Author Contributions: L.F. devised this study, participated in the draft of the manuscript, and provided final approval for this version to be published. M.B. participated in the conception and design of this study, coordinated the acquisition and interpretation of the data, and drafted the manuscript. C.G. supported the conception of this study and participated in the draft of the manuscript. C.C. supported the conception and design of this study and participated in the draft of the manuscript. F.A. performed the statistical analysis and contributed to the interpretation of the results. F.N. participated in the acquisition and interpretation of the data and participated in revising the manuscript. S.T. participated in the acquisition and interpretation of the data and participated in revising the manuscript. F.M. participated in the interpretation of the data and participated in revising the manuscript. A.S. participated in the interpretation of the data and participated in revising the manuscript. S.F. supported the conception of this study and participated in the interpretation of the data. All authors have read and agreed to the published version of the manuscript.

Funding: This study was part of the REDUCE Project (Ricerca, Educazione, Comunicazione: an integrated approach for food waste prevention), funded by the Italian Ministry of Environment [RINDEC-2015-0000088] and coordinated by the Department of Agriculture and Food Science of the University of Bologna.

Institutional Review Board Statement: This study did not involve human participants, personal data, or animal experimentation. The research focused exclusively on the observation and assessment of food prepared, served, and left uneaten on plates. As such, it does not fall within the scope of activities requiring ethical approval from an institutional review board (IRB) or ethics committee.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article and the Supplementary Materials.

Acknowledgments: The authors would like to thank Francesca Roversi for her valuable review of the manuscript (permission received for the acknowledgments).

Conflicts of Interest: The authors state that there are no conflicts of interest.

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