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From plate to waste: Composition of school meal waste and associated carbon footprint and nutrient loss

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ABSTRACT

Food waste significantly impacts the environment and nutrient availability. In Sweden, public meals generate 33,000 tonnes of food waste annually, with elementary schools contributing 9,200 tonnes. A composition analysis of plate waste from 4913 meals in two elementary schools in Uppsala, Sweden identified the wasted food components and quantities. This assessment aimed to gauge the embedded climate impact and nutrient loss. Findings revealed a carbon footprint of 1.0 kg CO2e/kg plate waste. Despite staple foods (potatoes, pasta, rice) being wasted the most (59 %), meat waste constituted the largest portion of the carbon footprint (61 %), despite being wasted the least (10 %). Plate waste was nutrient-dense, containing 4.8 MJ energy/kg and significant levels of protein (57 g/kg), and fiber (19 g/kg). To enhance the sustainability of school meal programs, tailored food waste prevention strategies in Swedish school canteens are recommended to mitigate their environmental impact and preserve valuable nutrients for children's nourishment.

1. Introduction

Food waste is a problem with far-reaching consequences for the planet and global population. Approximately one-third of all food produced globally is either lost or wasted, leading to negative economic, environmental, and social impacts. Global food wastage costs 2.6 trillion USD annually and accounts for 8–10 % of global greenhouse gas emissions (FAO, 2014; UNEP, 2021). However, this estimate does not include the carbon footprint of land use change and residues elimination and/or treatment making the actual proportion likely higher. Food production also dramatically contributes to eutrophication, acidification, and biodiversity loss (FAO, 2014; Scherhaufer et al., 2018). Six out of nine planetary boundaries have already been exceeded on the global scale (Richardson et al., 2023), with current food production and management practices significantly contributing to this problem (Springmann et al. 2018). Although food waste can be utilized as an energy source through anaerobic digestion, thereby lowering the climate impact of the waste, it is more important to avoid producing food that will be wasted in the first place, due to the enormous environmental impact of food production (Scherhaufer et al., 2018). For example, within the European Union (EU), the majority (73 %) of the climate impact from food waste is estimated to originate from the production stage (Scherhaufer et al., 2018). Food loss and waste also have significant food security implications. Food insecurity is on the rise, with up to 3.1 billion people around the world now unable to afford a healthy diet and with 828 million suffering from hunger (FAO et al., 2022). In parallel, a significant level of nutrient loss embedded in global food waste is potentially affecting the health and wellbeing of people and communities (Chen et al., 2020). Moreover, consumer wastage of essential nutrients has been shown to be correlated with nutritional deficit in a typical American diet (Spiker et al., 2017). Thus, due to the devastating socioeconomic and environmental costs, reducing food loss and waste is one of the key measures to achieve sustainable food systems, which are a high priority on the public agenda and included in United Nations Sustainable Development Goal (SDG) 12.3, which aims to halve food waste per capita by 2030 (United Nations, 2015).

The EU is committed to reducing its food waste in order to reach SDG 12.3, through various policies, targets, and action plans (European Commission, n.d.). Within the EU, 88 million tonnes of food waste are generated annually, corresponding to 186 million tonnes of CO_2e, representing 16 % of the EU food system's climate impact (Scherhaufer et al., 2018; Stenmarck et al., 2016). As an EU member state, Sweden has implemented EU goals and also national goals to combat food waste. The interim target states that total food waste in mass per capita in Sweden

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should be reduced by 20 % between 2020 and 2025. However, progress is slow and there are uncertainties about whether this target will be reached on time. Thus, unacceptable levels of food waste continue to be generated throughout the world and Sweden is no exception, with approximately 1.1 million tonnes of food wasted in 2020 (Hultén et al., 2022; UNEP, 2021). Although public meals represent only a fraction of total food waste in Sweden (33,000 tons, with 9200 tonnes generated by elementary schools in 2020), reducing this type of waste is of the utmost importance for several reasons (Malefors et al., 2022a). First, most of the food waste from public meals consists of serving and plate waste, i.e., edible food that has undergone resource-intensive preparation (Malefors et al., 2019; Read et al., 2020). Wasting food in school catering also represents a missed opportunity to nourish school children, as school meals in Sweden are required by law to be nutritious and studies have highlighted gaps in nutrient intake by Swedish school children (Swedish Food Agency, 2022). Additionally, food waste reduction measures are necessary throughout the whole food supply chain, involving all stakeholders at all geographical levels, to reach SDG 12.3 and achieve a sustainable food system (Reynolds, 2022).

Previous studies suggest that plate waste[1] accounts for the second highest proportion of food waste in Swedish public catering, after serving waste (Eriksson et al., 2017; Malefors et al., 2022a; Persson Osowski et al., 2022; Silvennoinen et al., 2015). The amount of serving waste have been found to be especially high in satellite kitchens, due to low flexibility to adjust the amount of food produced, whereas kitchen type does not have a significant impact on the amount of plate waste (Eriksson et al., 2017; Persson Osowski et al., 2022; Steen et al., 2018). This makes it possible to reduce plate waste irrespective of the kitchen type. However, reducing plate waste generated by guests self-serving from a buffet is often seen as challenging by kitchen staff (Sundin et al., 2023), whereas reducing kitchen and serving waste may be easier as waste prevention measures can be directly integrated into work routines, such as improved menu planning and using leftovers from a buffet in warm meals on the following day (Swedish Food Agency, 2020).

In Sweden and many other countries, school meal schemes are a crucial route for providing immediate nourishment to children, while educating them about sustainable eating habits for the future (GCNF, 2022; Swedish Food Agency, 2022). Since 2011, the Swedish School Law mandates nutritious school lunches, aligned with national guidelines initially issued in 2015 based on the Nordic Nutrition Recommendations to facilitate that school meals are also eco-smart, i.e., increasingly plant-based and associated with reduced food waste (Swedish Food Agency, 2022). Annually, Swedish schools serve 260 million meals, funded by local taxes, with efforts over the past decade enhancing food quality and chef skills in school kitchens. Because meals must meet nutritional standards, food waste cannot simply be reduced by decreasing production if wastage is not caused by overproduction, as each school child has the right to receive a school meal that is nutritionally balanced, fulfilling 30 % of their daily energy and nutrient requirements. Plate waste may in fact serve as an indicator that nutritious food is left uneaten, resulting in nutrient losses and unnecessary environmental burdens.

Quantifying food waste is the first step towards achieving food waste reductions, and Sweden has achieved a high degree of success in quantification (Malefors et al., 2022a), but some factors are yet to be resolved. School meals comprise diverse food components such as carbohydrates (potato, pasta, rice), proteins (legumes, fish, chicken, beef), vegetables, bread, fruit, and dairy. Knowledge of the components is common, facilitating the assessment of carbon footprint and nutrient composition of the meals served. While some studies have investigated the components of serving waste in Swedish schools (Eriksson et al., 2017), only few have analyzed the components of plate waste (Silvennoinen et al., 2015), resulting in uncertainties regarding the degree to which various food components are wasted by school children. The carbon footprint and nutrient losses from school meals could differ from the carbon footprint and nutrient content of the served meals, and often rely on estimates or remain unknown (Swedish Food Agency, 2020). This discrepancy can lead to uncertainties in evaluating food waste prevention measures and their sustainability impacts, crucial for policymakers in prioritizing prevention actions (Caldeira et al., 2019). Better knowledge of wasted components would aid in crafting tailored food waste prevention measures, potentially vital for achieving further reductions to meet the target of halving food waste (Malefors et al., 2022a).

The aim of the present study was to fill this research gap by examining the composition of plate waste discarded from 4913 school meals at two elementary schools in Uppsala Municipality, Sweden, with the focus on calculating the carbon footprint and nutrient losses associated with plate waste. The intention was to gain valuable insights into the food components that are wasted instead of being eaten, and the environmental and social implications for school meal schemes.

2. Material and methods

2.1. Study design and material

Plate waste from two elementary school canteens in Uppsala, Sweden, serving pupils aged 6–9 years was quantified and analyzed for its composition during a two-week period in spring term 2023. The selected schools were considered representative samples in Sweden, with a rate of plate waste generation of 27 g/guest close to the national average, and situated within a socioeconomic context reflective of the majority of the Swedish populace, encompassing 60 % of the population. The inclusion criterion for school canteens was maximum 10 kg of plate waste generated per day, making it possible to conduct composition analysis. The participating school canteens are referred to hereafter as canteen A and canteen B.

Canteen A had previously participated in the research project LOWINFOOD in 2022, where it tested waste-tracking devices and educational meals as food waste reduction measures, whereas canteen B had not recently conducted any specific interventions to reduce food waste. Both canteens have a long track record of measuring their food waste and both have satellite kitchens receiving their meals *hot, fully prepared, and ready to be served* from a larger school canteen nearby. Both canteens also have the same six-week rolling menu (Table A.1 in Appendix), of which the two-week observation period was a representative sample in terms of types of meals included (vegetarian, fish, beef, pork, or chicken with potato, pasta, or rice). In addition to the main meals on the menu, a salad buffet comprising vegetables and fresh fruit, such as apples, carrots, broccoli, and olives, as well as bread and milk is provided daily during the lunches. Canteen A uses leftovers from the previous day to reduce its serving waste, and thus provides a slightly larger selection in its buffet than canteen B. Canteen B relies more on its meal planning system when deciding on the amounts of food components to be served. All food is served in a buffet and children help themselves, with the possibility to take second helpings. At the time of the observation, there were no limitations on the amount of food that children were allowed to serve themselves.

Canteen A has about 300 daily guests and canteen B has approximately 320 guests, including pupils and the teaching staff. Both canteens have established routines in place to create a calm meal environment during lunchtime, starting with an enforced 10-minute silence supervised by a teacher. Canteen A serves lunch from 11:00 to 13:00 h, giving all classes 30 min to eat. In canteen B, lunch is served from 10:40 to 12:30 h, where grades 1–3 have 20 min to eat and grade 0 has 30–40 min.

[1] Plate waste refers to everything that a guest has left on their plate, comprising edible food, inedible food such as peels and bones, and other waste, such as napkins (Malefors et al., 2019).

2.2. Data collection

Data were collected for eight days in total, from both canteens over a two-week period. The dates of waste collection were 11–14, 17–19, and 21 April 2023. No plate waste was collected for practical reasons on 20 April, as soup was on the menu, or on 10 April, due to a public holiday. Data collection included all plate waste generated during the school lunches in the canteens, but excluded beverages and any other food waste such as kitchen and serving waste or food waste from breakfast. Both canteens supplied the researchers with their plate waste in plastic bags taken from bins used to collect the plate waste disposed of by guests during school lunches. A plastic container was used to provide a stable resting surface for these plastic bags during transport, to avoid unnecessary mixing of the contents. Waste from canteen B was collected at around 12:30 and taken by foot to a nearby sorting site, while waste from canteen A was collected at around 13:00 and transported by bus to the sorting site. Quantification and composition analysis were conducted on the day of collection.

2.3. Quantification and composition analysis

Quantification commenced by weighing the plastic bags containing the total plate waste and deducting the mass of the plastic bags. An electronic balance with 0.01 kg accuracy was used for weighing (Fig. 1). All results were recorded on a pre-prepared Excel sheet.

In waste composition analysis, different food waste components, such as pasta, chicken, vegetables, and bread, were sorted by hand into plastic containers. On the first day, degree of separation of the plate waste was decided. Complete separation was not possible due to some waste being in liquid form (e.g., sauces) and mixed form (rice with tiny pieces of vegetables). In such cases, sauces and inseparable vegetables were categorized as the main component (see Table A.2 in Appendix for a complete list of waste component categories). The plate waste was categorized into *edible* or *inedible food waste*, where inedible food waste comprised fruit peel and cores, and eggshells. Occasional napkins and spread packages that had accidentally ended up in the food waste bin were separated out into the category *other*. After the sorting process, the plastic containers containing the various plate waste components were weighed one by one, using a tare function on the electronic balance in between each weighing. The waste category with the largest volume, usually the staple food component of the day such as rice or potatoes, was left in the plastic bag for weighing. The mass of the plastic container/bag was deducted, to give the net mass of each waste fraction. The containers were cleaned at the end of each day, to ensure that no food waste was carried over to quantification on the following day.

In carbon footprint and nutrient loss calculations on the plate waste, the quantification data were aggregated from daily mass to total net mass per waste category and canteen.

Fig. 1. Electronic balance weighing a plastic container of plate waste consisting of mixed vegetables. Fotograph Halvarsson R., (2023).

2.4. Carbon footprint calculations

To assess the climate impact of the plate waste, carbon footprint calculations were conducted based on the composition data obtained and emission factors from the RISE Climate Open List (RISE, 2022), which reflect average Swedish food consumption. Currently, the environmental impacts caused by the average Swedish food consumption exceed several boundaries based on the EAT-Lancet framework, including per capita greenhouse gas emissions (Moberg et al., 2020).

The emission factors were presented as kg CO_2e per kg of food, from cradle to producer gate, excluding packaging. For imported food products, transport to Sweden was also included. Other emission sources, such as distribution, storing, cooking, and cooling food, were excluded. Since the emission factors were expressed for uncooked foods, except for bread, some of the plate waste data had to be converted from cooked weight to uncooked weight using average literature values (KF och ICA provkök, 2000). In particular, the waste categories comprising rice, pasta, and Bolognese sauce (beef) were converted, due to large differences between uncooked and cooked weight.

For some waste components, the exact carbon footprint was not included in the RISE Climate Open List (RISE, 2022), and values that were the closest option had to be used. For example, the carbon footprint for *cheese* was used to represent both feta cheese and cottage cheese. To obtain a carbon footprint for the category *mixed vegetables*, an average carbon footprint was calculated using the values for *spinach, green peas, tomatoes, iceberg lettuce, chickpeas,* and *lentils*, which are included in the RISE Climate Open List (RISE, 2022).

After calculating an approximate carbon footprint per waste category and canteen, the results were aggregated to total carbon footprint per waste category and then to total carbon footprint of food waste. The waste category *inedible food waste* was included in the carbon footprint calculation, while the category *other* was excluded. The total carbon footprint was then divided by the total mass of plate waste that the canteens generated, to obtain carbon footprint per kg plate waste.

2.5. Nutrient calculations

To assess the nutrient loss embedded in plate waste, nutrient calculations were conducted based on composition data obtained for the edible fraction of the plate waste, using Nutrition Data (2023) software. The energy, macronutrient, micronutrient, and dietary fiber contents of the plate waste were calculated as total values for the data collection period, in order to express them as mean values per kg plate waste and per guest (by dividing the total values by the total amount of plate waste and the total amount of guests, respectively). Further, the macronutrient content was expressed as energy percent (E%) values, and the micronutrient content as nutrient density value (per MJ), where the mean nutrient values per kg plate waste were divided by the mean energy content per kg plate waste. The number of wasted nutrient days (WND) per kg plate waste, and per canteen and day, during which the plate waste met 30 % of the daily recommended intake (RI) values of the school children (since school meals are required by law to provide 30 % of the daily nutritional needs of children) were calculated. This was done by dividing mean energy and nutrient values by 30 % RI values for children aged 7–10 years with an average physical activity level, according to Nordic nutrition reference 2023 values (Nordic Council of Ministers, 2023).

2.6. Statistical calculations

To evaluate whether there were statistical differences between canteen A and B in terms of the total amount of plate waste and the amounts of the food categories that were wasted, two-sample Student *t*-tests were conducted in Excel. Additionally, Excel was used to calculate totals, mean values, and standard deviation for the number of portions, the amount of plate waste, and the amount of plate waste per portion. To calculate the amount of edible waste, the mass of *inedible food waste* and *other* were subtracted from the total waste. Plate waste as a percentage of total food served was calculated based on the production figures obtained from the two canteens.

3. Results

3.1. Amount of plate waste

The total amount of plate waste collected from canteens A and B during the 8-day collection period was 133.2 kg, of which 125.6 kg (94 %) was edible food waste, 6.4 kg (5 %) inedible food waste, and 1.2 kg (1 %) other type of waste, such as napkins. Total average plate waste was 8.3 kg per canteen and day, and 27 g per guest. Plate waste amounted to approximately 12 % of total food served (1154 kg). There was no statistically significant difference in the amount of plate waste at canteen A and canteen B (p = 0.390). A breakdown of the results per canteen is provided in Table 1.

3.2. Plate waste composition

The food categories wasted in the greatest amounts (of the total waste) were pasta (28 %), potatoes (19 %), rice (12 %), and vegetarian meal options (12 %). Animal-based components, such as pork (1.6 %), beef (1.8 %), and chicken (2.2 %), were among the least wasted categories. An aggregated breakdown of the total results (in kg) and results in kg/per canteen is presented in Table 2 (for a more detailed breakdown, see Table A.2 in Appendix). There was no statistically significant difference in the composition of plate waste between canteen A and B (p = 0.880).

Table 1
Number of guests, amount of plate waste, and amount of plate waste per guest at school canteen A and canteen B. Mean ± standard deviation (SD) for the observation period are also shown.

Canteen	Date	No. of guests	Plate waste (kg/day)	Plate waste (% of prepared food)	Plate waste per guest (g/day)
A	11 April	320	7.6	12	24
	12 April	342	9.6	15	28
	13 April	306	9.5	11	31
	14 April	278	8.0	13	29
	17 April	261	7.8	11	30
	18 April	283	9.5	11	34
	19 April	290	10.4	12	36
	21 April	297	6.6	9	22
	Mean ± SD	294 ± 26	8.7 ± 1.3	12 ± 1.7	29 ± 5
B	11 April	317	6.8	12	21
	12 April	312	9.5	13	31
	13 April	324	9.9	13	31
	14 April	310	6.5	10	21
	17 April	309	8.9	14	29
	18 April	315	8.3	10	26
	19 April	325	7.7	11	24
	21 April	324	6.5	9	20
	Mean ± SD	316 ± 7	8.0 ± 1.3	12 ± 1.8	25 ± 4

Table 2
Breakdown of the food categories in plate waste, expressed as kg per school canteen and total kg, and CO_2e for the observation period.

Food category	Canteen A (kg)	Canteen B (kg)	Total (kg)	Total (CO_2e)
Pasta	19.2	17.8	37.1	10.6
Potato	12.0	13.1	25.1	2.5
Rice	8.0	8.1	16.1	18.1
Chicken	1.4	1.5	2.9	6.1
Pork	1.1	1.0	2.1	9.0
Beef	1.2	1.2	2.4	54.7
Fish	2.5	2.7	5.2	7.8
Cheese	0.1	0.0	0.1	0.6
Eggs & Pancakes	0.9	0.0	0.9	1.0
Vegetarian options	7.0	8.6	15.6	7.8
Mixed vegetables[1]	8.5	5.8	14.3	5.7
Bread	2.1	1.5	3.7	1.5
Inedible FW	4.0	2.4	6.4	1.4
Other	0.8	0.4	1.2	n/a

[1] In addition to vegetables such as broccoli, tomato, and lettuce, the mixed vegetable category comprised olives, carrots, bell peppers, beans, and chickpeas served in a salad buffet.

3.3. Carbon footprint

Total plate waste over the 8-day collection period generated approximately 127 kg CO_2e, corresponding to approximately 1.0 kg CO_2e per kg plate waste or 0.026 kg CO_2e per guest. A breakdown of the total carbon footprint per food waste category is presented in Table 2. The carbon footprint was based on data calculated from cradle to gate (including transport to Sweden), i.e., excluding emissions related to storage and cooking at the canteens.

The wasted food category with the highest carbon footprint, although wasted almost the least in terms of mass, was beef, representing 43 % of the total carbon footprint (

Fig. 2. Total amounts of the wasted food categories (kg) during the observation period (inner circle) and proportion of total carbon footprint (%) per wasted food category (outer circle).Wasted rice had the second highest carbon footprint (14 % of the total carbon footprint), and pasta was third (8 %). The food categories with the lowest carbon footprint, although among the most wasted in terms of mass, were potatoes (2 %), vegetarian meal options (6 %), and mixed vegetables (5 %).

Staple foods such as pasta, potato, and rice comprised 59 % of total plate waste, but only 24 % of the total carbon footprint. On the other hand, animal-based foods (chicken, pork, beef, fish, cheese, and also eggs and pancakes) were wasted to only a minor degree, corresponding

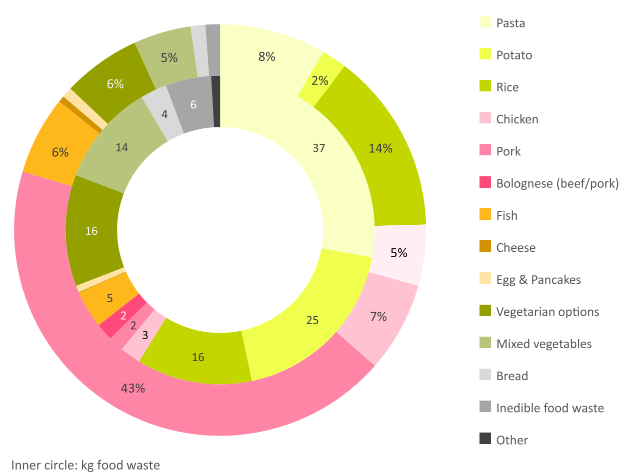

Fig. 2. Total amounts of the wasted food categories (kg) during the observation period (inner circle) and proportion of total carbon footprint (%) per wasted food category (outer circle).

to 10 % of total plate waste, but were responsible for 63 % of the total carbon footprint.

3.4. Nutrient losses

3.4.1. Energy and macronutrients

To assess the nutrient loss embedded in plate waste, nutrient calculations were conducted on the edible part of the plate waste, which contained approximately 4.8 MJ energy/kg plate waste, or 0.13 MJ/guest. The protein, carbohydrate, and fat content per kg plate waste was 57 g, 171 g, and 22 g, respectively (Table 3). Moreover, the plate waste contained 20 E% of protein, 62 E% of carbohydrates, and 18 E% of fat, reflecting a balanced and protein-rich macronutrient content. In terms of WND, each kg of plate waste met the energy needs of two children and the protein needs of seven children.

3.4.2. Micronutrients

Overall, the results indicated considerable nutrient loss as the plate waste was micronutrient-dense, with all except four micronutrients (vitamin D, folate, iron, calcium) meeting or exceeding the recommended micronutrient density for dietary planning (Nordic Council of Ministers, 2023). The plate waste was high in e.g., dietary fiber (3.9 g/MJ), and vitamins A (89.6 RE/MJ), K (21.0 µg/MJ), C (12.9 mg/MJ), and B_6 (0.2 mg/MJ). Assessment of number of WND indicated micronutrient losses of up to 11 days per kg plate waste (Table 4). On average, the plate waste from the canteens could have met the daily micronutrient needs of 4–94 school children, depending on micronutrient (Table 4).

4. Discussion

The composition of plate waste generated from school lunches served in two Swedish elementary schools was analyzed for its carbon footprint and embedded nutrient loss. The results showed that the average carbon footprint (approximately 1.0 kg CO_2e/kg plate waste) was lower than previously estimated (approximately 1.6 kg CO_2e/kg plate waste), since it contained a high proportion of staple foods and plant-based food components. The staple foods that were wasted the most represented 59 % of the total plate waste, but only 24 % of the total carbon footprint. Conversely, animal-based foods were wasted only to a minor degree, corresponding to 10 % of the total plate waste, but were responsible for 63 % of the total carbon footprint. Despite the low proportion of animal-based foods in the plate waste, the results indicated considerable loss of protein (57 g/kg plate waste) and other valuable nutrients, such as dietary fiber (19 g/kg plate waste) and vitamin C (63 mg/kg plate waste). Each of the two school canteens studied could have met 30 % of the daily energy requirements of 18 school children/day if the plate waste had been consumed instead of wasted. Similarly, the plate waste contained enough protein to meet 30 % of the daily requirements of 61 children and the dietary fiber requirements of 28 children.

While the carbon footprint and nutrient loss embedded in food waste generated from school canteens have been under-researched to date, our results were in line with those of a previous study conducted in Sweden (Engström and Carlsson-Kanyama, 2004). In a two-day investigation period in that study, staple foods made up the largest fraction of plate waste, while meat and fish were wasted the least. A study in Finland investigating food waste from 23 schools and day-care centers during a five-day period found overall similar plate waste composition as in our study, but lower percentage wastage of vegetarian meal options (Silvennoinen et al., 2015). However, our results regarding the vegetarian option may be uncertain, since the observation period included only one vegetarian day in the menu, although one day per week in the six-week rolling menu is exclusively reserved for vegetarian meal options. It is also possible that the pupils disliked the vegetarian option was served on the vegetarian day observed (vegetarian lasagna), as quantification of vegetarian options from the other seven observation days indicated lower amounts of plate waste. According to a previous study of popular vegetarian meal options in Swedish elementary schools, these meals do not generate large amounts of waste (Sundin et al., 2023).

Our analysis revealed nutrient loss embedded in the plate waste, which was not surprising since Swedish school meals must be nutritious by law and are thus likely to result in nutritious food waste. However, considering the increasing trend for serving more plant-based school meals, which has also been adopted by school canteens in Uppsala, Sweden (Sjölund, 2021), the high protein density of the plate waste despite the low share of animal-based plate waste was an interesting finding. A common public concern is whether school meals contain enough protein when increasing proportions of vegetarian food options are served in schools, replacing meat options (Sydöstran, 2018; Uppsala Nya Tidning, 2022). However, according to the latest national dietary survey, children in Sweden have satisfactory intake of protein and instead too low intake of dietary fiber (1.8 g/MJ, compared with a recommended 3 g/MJ), which is related to their low intake of fruit and

Table 3
Energy and macronutrient content of the plate waste.

Energy & macronutrients		Per kg plate waste	Per guest	E %	WND[a] Per kg plate waste	WND[1] Per canteen/ day
Energy	MJ	4.8	0.1		2	18
Protein	g	57	1.5	20	7	61
Carbohydrates	g	171	4.6	62		
Fat	g	22	0.6	18		
SFA*	g	9	0.3			
MUFA*	g	7	0.2			
PUFA*	g	3	0.1			

[a] Wasted nutrition days (WND), i.e., number of days the wasted food met 30 % of the recommended daily intake of the children (since school meals must meet 30 % of children's daily dietary requirements), relative to number of school children/day.

* SFA, saturated fatty acids; MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids.

Table 4
Micronutrient content of the plate waste.

Micronutrient		Per kg plate waste	Per guest	Per MJ	WND[a] Per kg plate waste	WND[a] Per canteen/ day
Vitamin A	RE	433	11.6	89.6*	3	27
Vitamin D	µg	1	0.04	0.3	0	4
Vitamin E	mg	5	0.14	1.0*	2	16
Vitamin K	µg	102	2.7	21.0*	11	94
Vitamin B_1	mg	1	0.02	0.2*	3	25
Vitamin B_2	mg	1	0.02	0.1*	2	18
Vitamin C	mg	63	1.7	12.9*	7	58
Niacin	NE	24	0.7	5.1*	7	57
Vitamin B_6	mg	1	0.03	0.2*	4	33
Vitamin B_{12}	mg	1	0.03	0.3*	2	14
Folate	µg	170	4.6	35.1	3	24
Iodine	µg	290	7.8	60.0*	10	81
Phosphorus	mg	825	22.2	170.6 *	6	52
Iron	mg	5	0.14	1.1	2	16
Calcium	mg	224	6.0	46.3	1	8
Magnesium	mg	184	4.9	38.1*	3	22
Selenium	µg	29	0.8	6.0*	2	20
Zinc	mg	6	0.2	1.2*	3	21
Fiber	g	19	0.5	3.9*	3	28

* Value meeting or exceeding the recommended nutrient density for diet planning according to the Nordic Nutrition Recommendations.

[a] Wasted nutrition days (WND), i.e., number of days the wasted food met 30 % of the recommended daily intake of the children (since school meals must meet 30 % of the children's daily dietary requirements), relative to number of school children/day.

vegetables, approximately half the recommended amount of 400 g/day (Swedish Food Agency, 2003). A previous study investigating Swedish school children's energy and nutrient intake from school meals found significant gaps in intake of energy and various nutrients, including dietary fiber (Osowski et al., 2015). Thus if food waste reduction strategies result in a greater proportion of school meals served being eaten, rather than generating plate waste rich in dietary fiber (3.9 g/MJ) and vegetables, this could play an important role in filling gaps in children's nutrient intake. As suggested by previous studies, placing nutrition education on the curriculum for school children or providing them with educational school meals could help tackle food waste and simultaneously improve the dietary habits of school children (Martins et al., 2016; Persson Osowski et al., 2022).

In Sweden, the estimated carbon footprint per kg of food waste is approximately 1.6 kg CO_2e (Swedish Food Agency, 2020), a value based on findings in a study analyzing the carbon footprint of perishable food products from Swedish supermarkets (Scholz et al., 2015), in the absence of other data. We found a carbon footprint for school plate waste of 1.0 kg CO_2e, which is significantly lower than the value reported by the Swedish Food Agency. The difference may be explained by findings that 85 % of the wasted mass from Swedish supermarkets comprises fresh fruit and vegetables, and that the remaining 15 % comprises animal-based products (Scholz et al., 2015), indicating a difference in waste composition in comparison with school canteens. Thus, more studies are needed on the carbon footprint of food waste, as food waste composition can vary greatly between sectors and therefore have different climate impacts.

On comparing the plate waste amounts observed in the present study to global findings, it can be noted that the Swedish elementary schools assessed performed admirably. According to Dou and Toth (2021), who reviewed 18 studies focusing on plate waste and examined 23 datasets encompassing preschools, primary schools, and elementary schools, median plate waste in these establishments is 80 g/meal. In contrast, we found average values of 29 and 25 g per guest for the two canteens studied. Previous studies have reported total food waste quantities of up to 79 g/guest from school canteens in Sweden (Engström and Carlsson-Kanyama, 2004; Eriksson et al., 2017; Malefors et al., 2022a). In elementary schools, average total food waste in 2020 was 42 g per guest (Malefors et al., 2022a).

Various factors affect school meal wastage, such as peer influence, portion sizes, dish popularity, meal sensory attributes, stressful eating environment, and lunch duration (Blondin et al., 2015; Byker et al., 2014; Cohen et al., 2013; Cordingley et al., 2011; Martins et al., 2016; Painter et al., 2016; Piras et al. 2023; Sundin et al., 2023). The influence of schoolchildren's age on plate waste yielded mixed results; while Steen et al. (2018) observed increasing plate waste with age, Cordingley et al. (2011) and Niaki et al. (2017) reported the opposite trend. The observed two canteens had introduced some food waste reduction measures, such as creating a calmer food environment with a 10 min silence and allowing enough time for second helpings, which have been proposed as possible solutions to reduce plate waste in public catering (Swedish Food Agency, 2020). Those solutions can be assigned to actions of food waste prevention which is top priority of the food waste hierarchy (European Commission, 2020). However, the quantification results showed room for improvement, as approximately 12 % of the food served became plate waste. From a strict climate impact perspective, preventing food from being wasted has the most effect for greenhouse gas reduction. Food waste reduction through prevention or reuse was found to be more effective for reaching climate targets (−4.2 kg to −1.3 kg CO_2e per kg food waste), than food waste recycling (material recycling: −0.06 kg to 1.2 kg CO_2e per kg food waste; nutrient recycling: -0.13 kg to 0.09 kg CO_2e per kg food waste; energy recovery: -0.15 kg to −0.002 kg CO_2e per kg food waste) (Albizzati et al., 2021). Similarly, animal-based plate waste would be an effective solution for greenhouse gas reduction, although this would not significantly reduce the overall waste and its associated environmental impacts, or the loss of valuable nutrients. However, there is a growing trend in Sweden for serving more climate-smart meal options and reducing animal-based foods in public catering. Currently the average carbon footprint for the meals served by Uppsala Municipality is 1.5 kg CO_2e per kg purchased food corresponding to 0.5 kg CO_2e per portion with ongoing efforts to achieve a carbon footprint of 1.25 kg CO_2e per kg purchased food by 2030, in line with the Paris Agreement (Uppsala Municipality 2023). This development will likely reduce the carbon footprint of plate waste even if the total amount of food waste is not reduced. Meanwhile, information campaigns could be used to teach school children about the climate impact of food systems and food waste, a measure found previously to be effective in reducing waste (Engström and Carlsson-Kanyama, 2004; Malefors et al., 2022b; Mariam et al., 2020).

For the multiple goals of school meal schemes (nourishing children, environmentally friendly, low waste) to be met in a meaningful way, a fundamental requirement is that all school lunches served are eaten, as highlighted in a previous study (Sundin et al., 2023). To achieve this, school lunches need to be liked by the children. Therefore, reducing unpopular meals and increasing popular nutritious meal options on the school lunch menu has been suggested as a simple, but likely effective, measure (Sundin et al., 2023). However, not all meal options will be equally liked by all children, likely resulting in some plate waste. A recent study found that approximately 60 % of plate waste in Swedish school canteens is generated by 20 % of guests and that 40 % of guests do not waste any food (Malefors et al., 2024). An effective strategy could therefore be to nudge more target groups of school children by awareness-raising interventions, although this is yet to be confirmed by future studies. Some previous studies have shown positive results in terms of reducing plate waste due to educational campaigns, although whether the effects remain long-term is still unclear (Antón-Peset et al., 2021; Malefors et al., 2022b). In the case of plate waste caused by oversized portions, changing the size or shape of plates can be an effective measure to reduce food waste (Reynolds et al., 2019; Richardson et al., 2021). Similarly, reducing the size of serving spoons for potato, pasta, and rice components could be another tailored and yet simple food waste reduction measure targeting specific food components that are wasted the most, but further studies are needed to confirm this.

There were some limitations in the present study that could have affected the results. One was that with the resources available, it was not possible to separate all small pieces of vegetables mixed with rice or sauces from the rest of the food waste. To avoid sauces being mixed with other plate waste, plates could have been collected directly from pupils in the canteens, although this could have introduced bias by altering the food wastage behavior of the pupils. However, the level of separation achieved was deemed to be sufficiently accurate to allow the proportions of different plate waste components to be investigated. Another limitation was the lack of carbon footprint data, as specific values for each food item were not always available. To overcome this, carbon footprint values for food items from similar food groups were used, while also considering the origin of the food item (e.g., Sweden vs. South Europe) to achieve as accurate results as possible. A further limitation was that the carbon footprint did not include carbon emissions from distribution, storage, cooking, or cooling. Moreover, the carbon emission factors applied in the present study were based on life cycle assessment results, which should always be treated as approximate instead of precise values.

We investigated plate waste from only two elementary schools for children aged 6–9 years in Uppsala Municipality, Sweden. The composition of plate waste was consistent between the two canteens investigated and no difference in the quantity of plate waste was detected, suggesting that the results may be generalizable to similar canteens in Sweden and even school canteens outside Sweden with similar meal schemes, although more studies with larger sample size are needed to confirm the findings. Recognizing the small sample size of the present study, it involved plate waste analysis from two schools with approximately 307 daily guests observed over eight days, totaling approximately 4880 portions served, while prior studies varied in sample size from 23 schools with 46,988 portions (Silvennoinen et al., 2015) to as few as two schools with 3600 portions (Engström and Carlsson-Kanyama, 2004) and three schools with 755 portions served (Martins et al., 2016). More studies are also needed to determine whether the results are similar for canteens serving older school children, and to investigate possible differences between different socio-economic areas in addition to investigating their serving waste. Perhaps most importantly, future research should also focus on identifying tailored measures that reduce plate waste while also improving school children's food and nutrient intake, as very little is known at present about the degree to which food waste reduction measures influence the nutrition of school children.

5. Conclusions

Plate waste from the two Swedish elementary schools analyzed in this study was found to be nutritious and could meet previously identified gaps in the dietary intake of school children. The carbon footprint of the plate waste was lower than previously estimated, and the increasing trend for serving plant-based school meals may lead to further decreases. The carbon footprint could also be decreased through tailored food waste prevention measures targeting animal-based food waste. However, such prevention measures alone would not markedly reduce the overall amount of food waste or the nutrient loss embedded in the waste. Therefore, to meet food waste reduction goals while retaining valuable nutrients within the food system and using them as intended, i.e. to nourish school children, it is important to prioritize food waste reduction measures that result in adequate dietary intake of school children.

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CRediT authorship contribution statement

Niina Sundin: Writing – original draft, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Runa Halvarsson:** Writing – review & editing, Visualization, Validation, Methodology, Investigation, Formal analysis, Conceptualization. **Silvia Scherhaufer:** Writing – review & editing. **Felicitas Schneider:** Writing – review & editing. **Mattias Eriksson:** Writing – review & editing, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix

Table A.1
School meal menu during the 10-day observation period in spring 2023.

Date	Weekday	Menu options
10 April	Mon	n/a (public holiday)
11 April	Tue	Pasta ratatouille
		Red lasagna with cottage cheese
12 April	Wed	Red curry with quorn/pork/chicken and basmati rice
13 April	Thu	Broccoli au gratin and cooked potatoes
		Fish au gratin seasoned with taco spice and cooked potatoes
14 April	Fri	Creamy cauliflower and coconut stew with bulgur
		Yakiniku chicken, vegetables, and noodles
17 April	Mon	Pasta with cheese and broccoli/ham/turkey
18 April	Tue	Root vegetable stir-fry with oven-baked beetroot
		Chicken and root vegetable stir-fry with curry sauce
19 April	Wed	Vegetable patties with lime sauce and cooked potatoes
		Fish au gratin seasoned Thai-style and cooked potatoes
20 April	Thu	Soup*
21 April	Fri	Kitchen's choice** including one vegetarian option

* No food waste was collected and analyzed, due to the liquid form of the food served.
** Contained beef.

Table A.2
Food waste components and their weight per canteen and collection day.

Collection date	Food category	Canteen A (kg)	Canteen B (kg)
11 April	Rice with red curry sauce, pieces of vegetables	5.68	5.6
	Chicken	0.42	0.6
	Quorn	0.1	
	Pasta	0.32	
	Mixed vegetables	0.52	0.22
	Olives	0.26	0.22
	Chickpeas	0.18	0.08
	Friarelli bell pepper	0.09	
	Feta cheese	0.02	
	Bread	0.18	0.08
	Other	0.04	0.04
	Total	*7.63*	*6.78*
	*Loss**	*0.11*	*0.04*
12 April	Lasagna (vegetarian)	5.98	8.5
	Chicken	0.14	
	Pasta	0.38	
	Mixed vegetables	0.56	0.48
	Olives	0.14	0.34
	Chickpeas		0.12
	Friarelli bell pepper	0.02	
	Orange peel	1.04	
	Pancake	0.16	
	Bread	0.86	0.08
	Other	0.16	0
	Total	*9.58*	*9.52*
	*Loss**	*0*	*0.08*
13 April	Fish, pieces	0.74	0.4
	Boiled potatoes	3.26	3.42
	Fish stew and potato, mushy (inseparable)		2.54
	Fish stew and rice, mushy (inseparable)	2.14	
	Burger (beef)	0.04	
	Sausage (pork)		0.08
	Lasagna (vegetarian)	0.54	
	Mixed vegetables	1.04	0.64
	Olives		0.2
	Chickpeas		0.1
	Carrots	0.22	
	Lemon, including peel	0.86	1.66
	Apple, including peel and core		0.36
	Egg	0.16	
	Pancake	0.08	
	Bread	0.2	0.42
	Other	0.18	0.08
	Total	*9.46*	*9.9*
	*Loss**	*0*	*-0.02*
14 April	Noodles	4.7	4.92
	Chicken	0.28	0.42
	Meatball**	0.08	
	Mixed vegetables	1.2	0.98
	Olives	0.08	0.06
	Carrots	0.24	
	Lemon	0.4	
	Orange	0.82	
	Apple core		0.04
	Egg	0.02	
	Bread	0.08	0.12
	Other	0.08	0
	Total	*7.98*	*6.54*
	*Loss**	*0.02*	*-0.02*
17 April	Pasta and sauce	5.74	7.18
	Ham	0.92	0.82
	Hamburger**		0.02
	Mixed vegetables	0.58	0.48
	Olives		0.12
	Carrots	0.22	
	Chickpeas	0.04	
	Butter beans		0.04
	Lemon, including peel	0.04	
	Apple, including peel and core		0.1
	Feta cheese	0.08	
	Egg	0.08	
	Bread	0.18	0.02
	Other	0.1	0.14
	Total	*7.76*	*8.92*

(*continued on next page*)

Table A.2 (*continued*)

Collection date	Food category	Canteen A (kg)	Canteen B (kg)
	*Loss**	*-0.02*	*0*
18 April	Stir-fry (potato, curry sauce, some vegetables)	4.14	6.06
	Chicken	0.5	0.5
	Meatballs**	0.04	
	Ham	0.22	
	Vegetarian meat substitute	0.02	
	Mixed vegetables	0.54	0.88
	Olives	0.18	
	Carrots	0.3	
	Chickpeas	0.08	
	Apple core		0.1
	Egg	0.16	
	Eggshell	0.08	
	Bread	0.2	0.3
	Other	0.06	0.02
	Total	*9.52*	*8.28*
	*Loss**	*0.12*	*-0.02*
19 April	Fish gratin	1.8	2.26
	Boiled potatoes	4.6	3.62
	Chicken	0.04	
	Meatballs**		0.16
	Vegetable patties	0.34	0.08
	Mixed vegetables	1.06	0.58
	Olives	0.08	
	Carrots	0.36	
	Butter beans		0.04
	Apple core		0.1
	Egg	0.04	
	Pancake	0.14	
	Bread	0.3	0.34
	Other	0.12	0.06
	Total	*10.42*	*7.74*
	*Loss**	*0.1*	*-0.04*
21 April	Spaghetti and sauce	4.96	4.82
	Bolognese**	1.08	1.02
	Sausage		0.1
	Mixed vegetables	0.16	0.12
	Olives	0.12	
	Friarelli bell pepper		0.18
	Apple core		0.04
	Cottage cheese	0.02	
	Egg	0.02	
	Bread	0.14	0.18
	Other	0.08	0.08
	Total	*6.58*	*6.54*
	*Loss**	*0*	*0.04*

* Loss: Difference between the mass of total food waste and mass of the total of aggregated food categories.
** Food category that contained beef.

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