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Food waste and its associated environmental impacts in workplace buffet-style canteens in Beijing, China

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Introduction: Food waste is a significant global challenge, with critical implications for food security, ecosystem services, biodiversity, and human health. Despite growing attention to food waste in food service sectors, workplace buffet-style canteens—particularly in China—remain understudied. This research addresses this gap by quantifying food waste and evaluating its environmental impacts in workplace buffet-style canteens in Beijing, China.

Methods: Field surveys were conducted in four workplace buffet-style canteens in Beijing during August and September 2021. Systematic sampling yielded 656 valid samples. Food waste was measured using a direct weighing method, categorized into eight food types, and analyzed for its environmental impacts using carbon, nitrogen, phosphorus, water, and ecological footprint metrics. Conversion factors were applied to translate cooked food into raw agricultural equivalents for consistent impact assessment.

Results: The study found an average daily *per capita* food waste of 158.4 g, with lunch contributing the highest waste (78.8 g) compared to breakfast and dinner. While vegetables were the largest contributors by weight, livestock products, though comprising only 29.9% of waste, accounted for the majority of environmental impacts, including 96.7% of the ecological footprint and 85.7% of the water footprint. Self-run canteens generated less waste across all meals compared to outsourced ones, and higher food and cuisine diversity were associated with increased food waste.

Discussion: The findings underscore the influence of dietary habits, management models, and food diversity on food waste generation. Livestock product waste poses disproportionate environmental burdens, highlighting the need for targeted interventions such as portion control and educational campaigns on sustainable dining practices. These results provide valuable insights for policymakers aiming to align food waste reduction strategies with Sustainable Development Goal 12.3.

KEYWORDS

food waste, workplace, buffet-style, canteens, environmental impacts

1 Introduction

Food waste is a critical global issue that poses a significant challenge to global sustainability, with its adverse impacts on food security (Foley et al., 2011), ecosystem services (Poore and Nemecek, 2018; Zou et al., 2022), biodiversity (Read et al., 2022), and human health (Springmann et al., 2018). Therefore, food waste reduction has become a priority at global, regional, and national political agendas. For example, the United Nations Sustainable Development Goals (SDGs) target

12.3.1b called for a halving of food waste at the retail and consumer levels by 2030 (UN, 2015). Both the European Union's farm-to-fork strategy (European Commission, 2020) and the Law of the People's Republic of China on Food Waste (China, 2021) have demonstrated the firm commitment to tackle the issue of food waste.

A growing number of studies have focused on the quantification of food waste, especially for the consumption stage (Caldeira et al., 2019; Xue et al., 2021; Lévesque et al., 2022; Zhang et al., 2022). For example, it was reported that a total of 810 million tonnes (Mt) of food waste was observed at the consumption stage globally, accounting for 17% of global annual food production (United Nations Environment Programme, 2021). Approximately 59.9 Mt of food waste (46% of total food waste) was generated at the consumption stage in Europe (Caldeira et al., 2019), while it was 59.3 Mt. of food waste at the consumption stage in China (17% of total food waste along the whole food supply chain; Xue et al., 2021). However, these studies mainly focused on food waste in households (Hanssen et al., 2016; Leverenz et al., 2019; Ananda et al., 2023; Cao and Li, 2023; Di Veroli et al., 2024), but limited studies referred to the food waste in the food service sector (Abiad and Meho, 2018; Dou and Toth, 2021).

Dining out has become increasingly normal with the increase of income and decent living demands (Adams et al., 2015; Robinson et al., 2019; Cui et al., 2022), thus more attention should be paid to the food waste in the food service sector. Unlike food waste at home, the quality and composition of food waste varied significantly across different food service sectors, in terms of their distinct types and serving modes (Beretta and Hellweg, 2019). For example, it was reported that food waste ranged from 50.1 g *per capita* in canteens to 192 g *per capita* in restaurants (Malefors et al., 2019). There was literature research investigated that food waste in the workplace was 71.5 g *per capita* higher than that in schools (Silvennoinen et al., 2019). Food waste also varied in different serving modes (Malefors et al., 2019). It was observed that larger amount of food waste generated in buffet restaurants than that in à la carte restaurants (according to the menu; Wang et al., 2017; Yi-Chi Chang et al., 2022).

As the specific but important food service sector, workplace canteens can offer convenient, cost-effective, and diverse meal options, which can be divided into four different categories, including buffet-style, the cafeteria-style, the set menu, and the à la carte. However, most studies mainly focused on the food waste generated in the canteens of nursery and primary school (García-Herrero et al., 2019; Pancino et al., 2021; Zhang et al., 2024), university (Pinto et al., 2018; Ellison et al., 2019; Zhang et al., 2021; Pandey et al., 2023), and hospitals (Dias-Ferreira et al., 2015; Dhir et al., 2020; Bux et al., 2023), while only a few studies examined food waste in workplace canteens (Sebbane and Costa, 2018), especially for the buffet-style canteens for cadres and workers. However, the buffet-style canteen was the most popular type of workplace canteens in China. Food waste could have become a critical issue due to increased consumer anonymity and higher food abundance (Juvan et al., 2017; Dolnicar and Juvan, 2019).

Unlike many Western countries, where food waste primarily occurs at the household level, China faces unique challenges with substantial food waste generated in its food service sectors due to its specific food culture (Zhang et al., 2020; Wang et al., 2017; Li et al., 2021). Public canteens, particularly buffet-style ones catering to cadres and workers, hold significant importance in the daily life and food service industry of China. However, existing research has predominantly focused on food waste in sectors like schools and hospitals, overlooking crucial insights from workplace buffet-style canteens. This omission is particularly concerning as it impedes the formulation of targeted strategies for addressing food waste within these prevalent establishments.

Furthermore, despite global initiatives like the UN's Sustainable Development Goal 12.3, China has yet to establish specific targets for food waste reduction. A primary reason for this gap is the lack of comprehensive understanding, especially concerning food waste in workplace buffet-style canteens. This underscores the urgency of our study, which aims to fill this crucial gap by investigating food waste in workplace buffet-style canteens in Beijing. Through a combination of weighing and questionnaire surveys, our research seeks to provide detailed insights into the magnitude, drivers, and environmental impacts of food waste in these settings. By shedding light on this overlooked aspect of food waste management, our study not only contributes to filling the existing knowledge gap but also lays the groundwork for targeted interventions aimed at mitigating food waste in China's food service sector. Ultimately, our findings are poised to inform policy formulation and advance global efforts toward sustainable food systems.

2 Methodology

From agricultural production to food waste management, each stage in the food supply chain involves the use of energy, water, land, and other resources. Importantly, the environmental impact of food waste is not confined to the consumption stage—it also accumulates throughout the supply chain. For instance, the carbon footprint accounts for emissions generated from agricultural inputs (such as fertilizers and pesticides), food processing, distribution, consumption in canteens, and waste treatment. Nitrogen and phosphorus footprints reflect impacts on soil, water, and air environments across fertilizer production, agriculture, processing, and waste management. Water and ecological footprints are primarily linked to inefficient water and land use in agricultural production. In this study, we quantify food waste and evaluate its environmental impacts through carbon, nitrogen, phosphorus, water, and ecological footprints, aiming to capture the comprehensive environmental costs associated with food waste. This broad approach highlights the importance of sustainable practices across the entire food system.

Beijing, the capital of China, serves as a paramount hub for political, cultural, and economic decisions, standing as the administrative nucleus of the nation. In its capacity as a swiftly evolving urban center in northern China, Beijing exerts profound influence and casts a broad impact on the neighboring provinces across economic and cultural spheres. Investigating Beijing offers insights that resonate with the future trajectory of its surrounding regions. The rapid urbanization of Beijing has precipitated a notable surge in its urban populace, concomitant with a steady decline in arable land on the city's outskirts. Since 1978, the urban population has burgeoned from 4.79 million to 19.161 million in 2021, constituting a rise from 55.0 to 87.5% of the permanent population, respectively. Concurrently, the arable land area has dwindled from 429,000 hectares to 122,000 hectares in 2021 (Beijing Municipal Bureau of Statistics, National Bureau of Statistics Beijing Survey Office, 2022).

This surge in urbanization has profoundly reshaped residents' lifestyles, with a marked increase in dining out frequency. Consequently, the mounting strain on resources and the environment stemming from dining out waste has escalated. As of June 2022, Beijing boasted 81,944 registered catering service establishments, including

21,638 canteens. Approximately 75% of the food consumed in Beijing originates from other regions (Beijing Municipal Bureau of Statistics, National Bureau of Statistics Beijing Survey Office, 2022), with staple foods primarily sourced from Northeast China, vegetables from Shandong, Hebei, and other locales, and meat predominantly originating from Henan and Inner Mongolia (Zhang et al., 2016b). The food waste conundrum in Beijing not only amplifies environmental stress within the city but also poses a grave menace to the ecological equilibrium of food supply areas. Hence, selecting Beijing as a case study holds profound practical significance for delving into cafeteria food waste and its attendant environmental ramifications.

2.1 Scope of the study

In workplace buffet-style canteens, food waste can be divided into the 'pre-consumer waste' and the 'post-consumer waste'. The former referred to food waste in the kitchen during food storage, preparation, and cooking, while the latter included leftovers and plate waste (Kaur et al., 2021). Our study mainly focuses on the plate food waste (edible part) in the workplace buffet-style canteen, while the non-edible part of food additives, flavorings, cooking oil, and bones were not considered in this study.

2.2 Sample selection

We investigated four workplace buffet-style canteens, considering their distinct management modes (e.g., self-run or outsourced) and administrative levels (e.g., local or national). When the selected workplace buffet-style canteen includes multiple canteens, we choose the largest one for the sampled workplace. More detailed characteristics of sampled canteens were shown in Table 1.

All sampled workplace canteens utilized the same buffet-style food service system, which was run as follows: consumers firstly paid for meals at checkout when they enter the canteen, then they selected food from serving tables by themselves. After finishing their meals, they should return any leftover food and tableware to the designated food residue and tableware recycling spot.

For each canteen, we conducted field surveys at the recycling spot based on a systematic sampling method and planned to select about 80 samples each day with 30% at breakfast, 40% at lunch, and 10% at dinner, respectively. The first sample was selected randomly, followed by the second sample, which was chosen after every k customers, with k representing the sampling interval. The sampling interval was calculated as shown in Equation 1:

$$k = \frac{N}{n} \tag{1}$$

Where n was the sample size (the total number of sampled consumers), and N was the served population per day.

2.3 Data collection and measurement

The field surveys were conducted from Monday to Friday in August and September 2021, because most civil servants have the weekend off. Due to time and budget constraints, each workplace canteen was surveyed for only 2 days. In most cases, consumers choose their own food and do not share it with others; thus, each sample customer's plate was the basic unit of our survey. The direct weighing method was employed, with the electronic loading balances that ranged from 1 g to 5 kg for on-site physical weighing. We weighed three to five times to minimize potential random errors and then used their averaged values as the reference value. Taken together, we collected a total of 656 valid samples. In addition, the methodology employed in this study, particularly our on-site survey and weighing techniques, draws upon the approach utilized in university cafeterias (Qian et al., 2021) and restaurant settings (Wang et al., 2017), thereby fortifying the reliability and comparability of our analysis.

The filed survey steps were as follows (see Figure 1 for a few photos in our survey):

Step 1: we weighed all kinds of empty tableware for each canteen before their meal service.

Step 2: our samples were selected at the food residue and tableware recycling spot. To avoid potential intervention, investigators were dressed as cafeteria staff. Then, we collected plates, marked the sampled consumers, and recorded their genders.

Step 3: After the meal service, we weighed leftovers (including tableware) for each sample collected. All food waste was categorized into eight types, and we separated different categories of wasted food for each patron according to our classification criteria (see Table 2). For each category, we distinguished between their edible and non-edible parts, which were then weighed and recorded individually. The food was divided into eight categories (see Table 2). In cases where it was difficult to distinguish categories for some wasted food, we used the proportion of each type as they were served. Only the solid ingredients were considered, while the liquid portion was excluded.

For each sample plate, the amount of food waste was calculated as shown in Equation 2:

$$W_{\mathrm{w}} = W_{\mathrm{e}} = W_{\mathrm{r}} - W_{\mathrm{ine}} - W_{tableware} \tag{2}$$

Where W_{w} represented the amount of food waste per plate; W_{r} was the total amount of food leftovers; W_{e} was the amount of edible part; W_{ine} was the amount of non-edible part, and $W_{tableware}$ was the amount of tableware.

TABLE 1 Characteristics of sampled workplace buffet-style canteens.

Item	Canteen 1	Canteen 2	Canteen 3	Canteen 4
Administrative level	National	National	Local	Local
Management mode	Self-run	Outsourced	Self-run	Outsourced
Number of institutions served by canteen	1	3	1	8
Served population per day	1,008	798	761	1,689
Valid samples (breakfast/lunch/dinner)	166(65/81/20)	160(60/80/20)	164(63/81/20)	166(61/85/20)

FIGURE 1
Photos of investigation.

TABLE 2 Classification criteria for food waste.

Staple food	Vegetables	Meats	Soy food	Seafood	Eggs	Fruits	Nuts
Rice, noodles, steamed bread and others made by cereals	Tomatoes, potatoes, broccoli, cabbage, turnip, cucumber, eggplant, pumpkin, celery, onion, lotus root mushroom, bitter gourd, green peppers, red peppers, leaf mustard, apium graveolens, and Chinese chives	Pork, beef, mutton, poultry, and others	Soybean, tofu, and tofu skin	Fish, shrimp, shellfish, and squid	Henapple, duck eggs, goose eggs, and quail eggs	Apples, watermelons, Hami melons, bananas, and other fruits.	Pine nuts, peanuts, walnut, and other nuts

The food waste *per capita* per meal ($\overline{W}_w$) was then calculated as shown in Equation 3:

$$\overline{W}_w = \overline{W}_e = \frac{1}{n}\sum_{i=1}^{n}\sum_{j=1}^{d} W_{ij} \tag{3}$$

Where W_{ij} represented the waste amount of food category j in plate i; n was the number of plates surveyed, and d was the number of food categories, $d = 8$.

2.4 Quantification of the environmental impacts of food waste

The environmental impacts of food waste are quantified using five key metrics: carbon footprint (CF), nitrogen footprint (NF), phosphorus footprint (PF), water footprint (WF), and ecological footprint (EF). Each metric reflects specific environmental burdens or resource demands across distinct stages of the food supply chain. Figure 2 illustrates the system boundaries used for quantifying the environmental impacts of food waste.

2.4.1 Carbon footprint

Defined as the total greenhouse gas (GHG) emissions associated with food waste across the food supply chain, covering five stages from production to waste treatment (Zhang et al., 2016b). Agricultural Production: CF encompasses four main sources of emissions: (1) emissions from agricultural inputs (fertilizers, pesticides, plastic mulch, diesel, and electricity for irrigation); (2) CH_4 emissions from rice cultivation; (3) N_2O emissions due to soil disturbance during crop cultivation; (4) CH_4 and N_2O emissions from enteric fermentation and manure management in livestock. Processing: Emissions from primary grain processing and soy reprocessing. Distribution: Emissions from transporting food from primary supply regions to Beijing. Canteen Consumption: Emissions from cooking energy use. Waste Treatment: Emissions from transporting and processing food waste. The carbon footprint calculation is represented as shown in Equation 4:

$$\mathrm{CF} = \mathrm{CF}_{agricultural} + \mathrm{CF}_{processing} + \mathrm{CF}_{distribution} + \mathrm{CF}_{consumption} + \mathrm{CF}_{treatment} \tag{4}$$

Where:

$CF_{agricultural}$: GHG emissions from agricultural activities, including CH_4 emissions from rice paddies, N_2O emissions from chemical and organic fertilizer application, soil background, and CO_2 and N_2O emissions from fuel use and electricity use. For animal food, it included CH_4 emission from enteric fermentation, CH_4 and N_2O from manure management, and CO_2 emissions from electricity use and feed input,

$CF_{processing}$: emissions from energy used in processing (mainly primary processing),

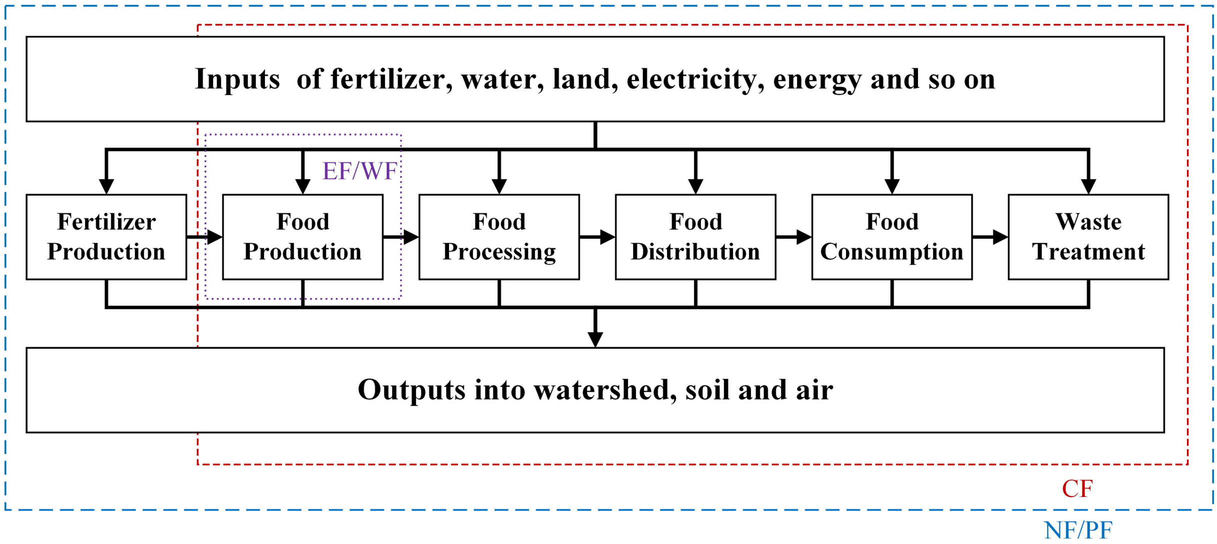

FIGURE 2
System boundaries for quantifying environmental impacts of food waste.

$CF_{distribution}$: emissions from transporting food to Beijing,

$CF_{consumption}$: emissions from energy for cooking and preparation,

$CF_{treatment}$: emissions from waste decomposition and final transport.

2.4.2 Nitrogen footprint

Defined as the total nitrogen input required to generate 1 kg of food waste, encompassing both nitrogen applied during production and nitrogen embedded within wasted food (Zhang et al., 2017). This footprint captures environmental impacts such as N_2O emissions, nutrient runoff, and leaching that affect soil, water, and air quality across five critical stages: Fertilizer Production, Agricultural Production, Processing, Canteen Consumption, and Waste Treatment. The nitrogen footprint calculation is represented as shown in Equation 5:

$$NF = N_{w-fertilizer} + N_{w-production} + N_{w-processing} + N_{w-food} \quad (5)$$

Where:

$N_{w-fertilizer}$ represents nitrogen loss during fertilizer production,

$N_{w-production}$ represents from agricultural activities, including runoff, soil erosion, soil accumulation, cultivation, and livestock management,

$N_{w-processing}$ represents nitrogen loss during food processing,

N_{w-food} represents the nitrogen content of wasted food.

2.4.3 Phosphorus Footprint (PF)

PF quantifies the environmental impacts associated with phosphorus (P) emissions across five stages: Fertilizer Production, Agricultural Production, Processing, Canteen Consumption, and Waste Treatment. Defined as the total phosphorus input needed to produce 1 kg of food waste (Zhang et al., 2016c). The phosphorus footprint calculation is represented as shown in Equation 6:

$$PF = P_{w-fertilizer} + P_{w-production} + P_{w-processing} + P_{w-food} \quad (6)$$

Where:

$P_{w-fertilizer}$ represents phosphorus loss during fertilizer production,

$P_{w-production}$ represents phosphorus loss during agricultural, including loss through agricultural runoff, emissions due to soil erosion on farmland, accumulation in farmland, and emissions from livestock manure management,

$P_{w-processing}$ represents phosphorus loss during food processing,

P_{w-food} represents the phosphorus content of wasted food.

2.4.4 Ecological footprint

Ecological footprint means the land resource demands associated with food waste (Zhang et al., 2016a), which was calculated as shown in Equation 7:

$$EF = \sum_{k=1}^{m}\sum_{j=1}^{d}\frac{C_j}{Y_j} \times R_k \quad (7)$$

Where C_j represented the amount of food waste j, Y_j represented the average productivity of land used to produce food j; R_k represented the equivalence factor of k productive land. The productive land included farmland, grassland, water, and forests.

2.4.5 Water footprint

Water footprint represents the total amount of water consumption associated with food waste, which was calculated as shown in Equation 8:

$$WF = \sum_{j=1}^{d} C_j \times WF_j \quad (8)$$

Where WF factors referred to the freshwater (including surface water, groundwater, and soil water) consumed per unit of primary agricultural food products, which was obtained from the existing literature (Wu et al., 2011). It provided the WF factors per unit amount of vegetative and animal food production of Beijing.

To accurately assess the environmental and resource impacts, we converted cooked food data collected in our survey to their equivalent raw agricultural products. For instance, cooked rice was converted to its primary form, paddy rice. The parameters used for these raw-to-cooked conversions, along with relevant environmental metrics, are provided in the supporting information (SI).

3 Results

3.1 Food waste at the workplace buffet-style canteen

Heterogeneity in food waste generation was observed across different meals at four workplace buffet-style canteens (Figure 3). The largest amount of food waste was found at lunch, with an average of 78.8 g *per capita*, which was about 2.8 times and 1.5 times greater than generated during breakfast and dinner, respectively. As a result, daily food waste *per capita* could reach 158.4 g at the workplace buffet-style canteen. Specifically, 85% of sampled consumers generated food waste at breakfast, slightly lower than that at lunch (93%) and dinner (95%). Individual food waste varied more significantly at lunch and dinner, compared with food waste at breakfast. Nearly two-thirds of total individual food waste at breakfast ranged between 5 to 60 g *per capita*.

Furthermore, due to the varying dietary cultures and health considerations, significant differences were found in the composition of food waste at breakfast, lunch, and dinner. Staple food remained the primary source of food waste for all three meals at the workplace buffet-style canteen, especially at breakfast (86.7%). However, livestock products contributed to almost one-third of food waste at lunch and dinner. Vegetables contributed the largest share of food waste for all three meals, even accounting for more than half of total food waste at breakfast and dinner. Meat was also a large share of food waste at lunch and dinner, even contributing to 29.8% of total food waste at lunch. In China, only a small amount of meat was consumed at breakfast, resulting in the meat waste of only 6.90 g *per capita* (4.1%), much lower than that observed at lunch and dinner. The staple food contributed to a larger share (24.6%) of total food waste at breakfast, with an average of 6.9 g *per capita*. Staple food waste during lunch was approximately 14.0 g *per capita*, accounting for about 17.8% of total food waste at lunch. For dinner, staple food waste was only 4.1 g *per capita*, with a share of 8.0%. For the remaining food items, no significant differences were observed among these three meals.

3.2 Characteristics of food waste in different conditions

Significant differences of food waste generation were observed between the self-run canteen and the outsourced canteens for all three meals lower for the former than the latter (Figure 3). For administrative levels, the amount of individual food waste was nearly the same at breakfast and dinner, with their waste amounts of 28 and 51 g, respectively. Food waste at lunch presented statistically significant differences ($p < 0.001$) between national and local government canteens, with about 20 g *per capita* higher in national workplace buffet-style canteens than that in local workplace buffet-style canteens. While some differences in food waste were observed among four different workplace buffet-style canteen for all three meals, there were no statistically significant differences of food waste at breakfast and dinner for any of these canteens. Notably, personal food waste was only 37.43 g at lunch in canteen C, which was statistically significantly

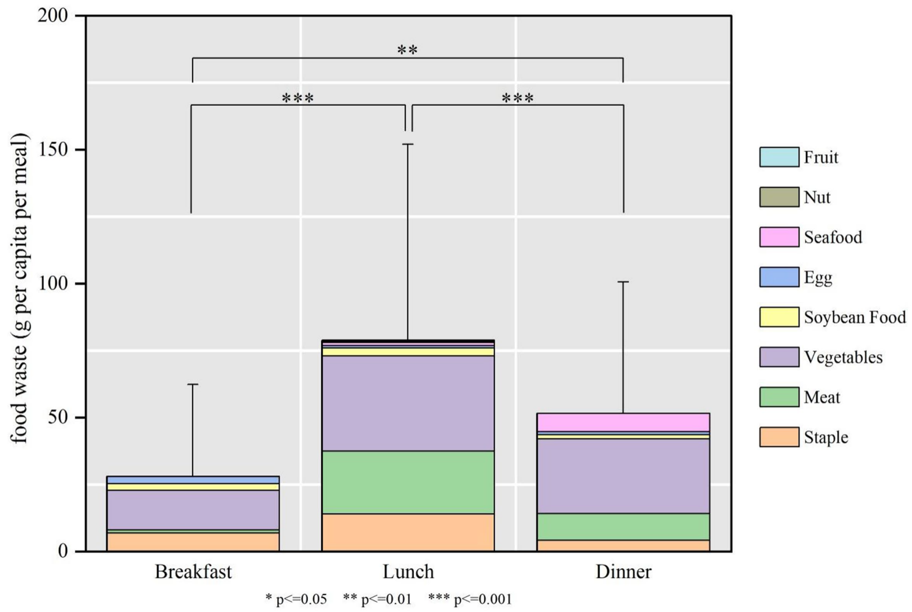

FIGURE 3
Food waste and its composition at the workplace buffet-style canteen for breakfast, lunch and dinner.

lower than the other three canteens. Food diversity and cuisine diversity had significant impact on food waste. Specifically, higher food diversity or cuisine diversity could increase food waste up to 2 times at lunch in these canteens. However, when both food diversity and cuisine diversity were low, food waste was only 37.43 g *per capita* at lunch. Canteen management mode, administrative level, food types, and cooking styles have some influences on food waste at the workplace buffet-style canteen (Figure 4).

3.3 Environmental impacts of food waste

The daily average of food waste was 158.41 g *per capita*, resulting in the ecological footprint (EF) of 3.55 m^2 *per capita*, the water footprint (WF) of 423.67 L *per capita*, the carbon footprint (CF) of 1566.22 g CO_2-eq *per capita*, the nitrogen footprint (NF) of 29.95 g N *per capita*, and the phosphorus footprint (PF) of 3.53 g P *per capita*. The resource consumption and footprints of different types of food varied greatly and had significant impacts on environmental effects of food waste. Livestock products had particularly intensive resource footprints, and only 29.9% of livestock food waste accounted for 96.7% of EF, 85.7% of WF, 63.2% of CF, 56.5% of NF, and 65.6% of PF. In particular, 21.8% of meat food waste contributed more than half of total EF, WF, and CF, as well as 43.2% of total NF and 47.5% of total PF. Vegetables constituted the largest proportion of food waste, but its food waste only accounted for 0.5% of total EF, owing to its higher productivity. Due to more intensive external inputs, the remaining resource footprints had higher shares of total footprints than EF, and their CF accounted for 19.8% of the total CF. Staple food waste was also a significant contributor to total resource footprints, with its PF share reaching 15.9% of total PF. The great differences in food waste composition resulted in substantial differences in resource footprints among these three meals. Food waste at lunch accounted for almost two-thirds of the EF and more than half of other resource footprints due to its higher quantity of livestock food waste. Environmental effects of food waste in the workplace buffet-style canteens were showed in Figure 5.

4 Discussion

Dinning out has become increasingly popular with growing living standards (Adams et al., 2015; Robinson et al., 2019; Cui et al., 2022), leading to increased attention on food waste in food service sectors (see Supplementary Table S9). Canteens, which cater to simple diners, differ from restaurants that typically cater to social diners. Our study found that *per capita* food waste at workplace canteens in Beijing (56.2 g) was significantly lower than that in restaurants across China (93.0 g; Wang et al., 2017) and in Beijing (74.4 g; Zhang et al., 2017). The meal purpose may have great influence on food waste, and previous studies pointed out that plate waste was found to be higher for social diners (like social and business gatherings) than food waste for work or private dining experience (Wang et al., 2017; Cao et al., 2014; Yi-Chi Chang et al., 2022). It was because that individuals may be more susceptible to social cues and consume (and waste) more food in social activities, according to the theory of "Normal Eating" (Herman et al., 2019).

Moreover, our study revealed notable differences in food waste between workplace canteens and other canteens in Beijing. Food waste *per capita* in workplace canteens was slightly lower than that in university canteens (Wu et al., 2019) but significantly lower than that in schools (Liu et al., 2016). This indicates that with higher levels of education, less food waste would be generated, which was similar with the findings of existing studies (Wu et al., 2019; Pinto et al., 2018; Ellison et al., 2019; García-Herrero et al., 2021). The results showed that the significant difference between national-level canteens and other levels may be related to the higher subsidies at the national level. Additionally, the significant differences between Institution C and other institutions could be attributed to the academic backgrounds of the staff, with over 63% having expertise related to ecology, environment, and geography. This background leads them to be more conscientious about waste control.

Furthermore, food waste *per capita* in workplace canteens was lower than that in non-buffet canteens (Wu et al., 2019; Zhang et al., 2021; Qian et al., 2021). This may related to that buffet-style canteens allow for on-demand meals and thereby it can reduce food waste [45–47] (Liu et al., 2016; Vaneeckhaute and Fazli, 2020; Strotmann et al., 2022). These findings also contribute to the ongoing debate and practical experience regarding the effectiveness of buffet-style serving in reducing consumer plate waste. However, some studies found that buffet-style serving actually increased food waste. For example, existing research indicated that a university cafeteria where the students and staff were served the same standard meal composition and a limited selection menu, which could have contributed to the high plate waste (Pinto et al., 2018).

According to FAO, food waste was generally higher in high-income countries than that in low-income countries (Gustavsson et al., 2011). However, our findings did not reveal a significant impact of economic levels on food waste at canteen, while their clear impacts on food waste can be observed at the non-buffet restaurant. More specifically, food waste at non-buffet restaurants can reach 154.8 g *per capita* in developed countries like the UK, significantly higher than the 93 g *per capita* in China, 38 g *per capita* in Iraq, and 35.1 g *per capita* in Thailand (Wang et al., 2017; Filimonau et al., 2021; Filimonau et al., 2023; Junkrachang et al., 2024). More food waste would occur at the restaurants with higher economic level. However, economic levels did not present significant impacts on the total amount of food waste at canteens among different countries, but it had some impacts on the composition of food waste. In China, food waste in the canteen was about 74 ~ 78 g *per capita*, but their composition presented great differences between the institution and university. Students have no fixed incomes in the university, and their vegetable and meat waste were less than the staple food in university canteens, due to higher price of vegetable and meat there (Wu et al., 2019). With some economic subsidies, the meal price in workplace canteens was usually lower than the market price, and thus expensive food (e.g., vegetable and meat) presented relative higher food waste there. Meanwhile, this kind of food usually had higher environmental footprints, which could have great impacts on the sustainable resource consumption. Thus, it should take some economic measures to control food waste as well as environmental protection.

This study provides unique insights into quantifying food waste in workplace canteens; however, it inevitably has some limitations. Our field survey was conducted in Beijing from August to September 2021 during the COVID-19 pandemic. Many workplace canteens in Beijing modified their seating arrangements, separating customers to prevent shared seating. This intervention may have influenced food

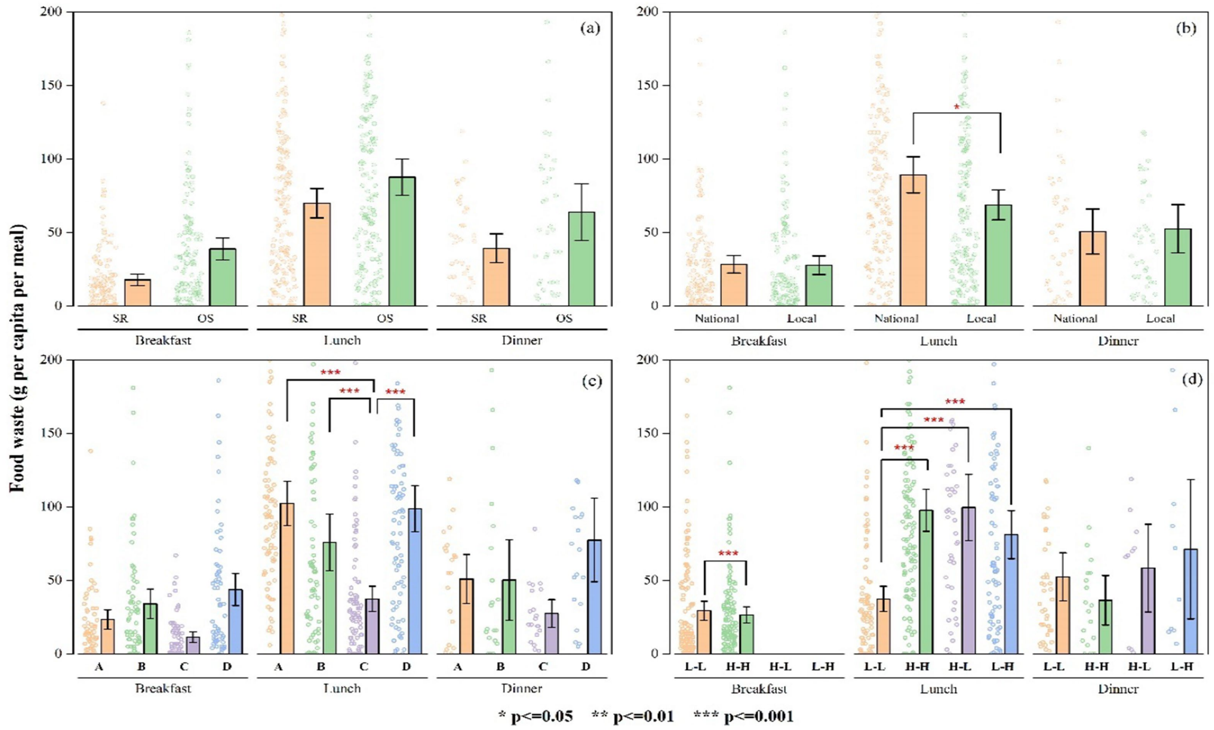

FIGURE 4
Comparison of food waste considering different conditions (a) Workplace buffet-style canteen management mode: SR and OS refer to self-run canteens and out-sourced canteens, respectively; (b) Administrative level: national and local workplace buffet-style canteens; (c) Four different workplace buffet-style canteens of A, B, C, and D; (d) Food diversity and cuisine diversity: L-L, H-H, H-L, L-H, refer to low food diversity and low cuisine diversity, high food diversity and high cuisine diversity, high food diversity and low cuisine diversity, and low food diversity and high cuisine diversity, respectively.

consumption and waste generation. The absence of a communal dining setting likely reduced social pressure to minimize waste, which could result in increased food waste. The normative dimension of food waste showed a negative correlation with individuals' perceptions of others' behavior. In public dining contexts, such as workplace cafeterias, food waste often carries a social stigma, particularly when dining with others, as wasteful behavior becomes more noticeable. In contrast, dining alone may reduce such social awareness, potentially leading to greater waste. Additionally, food waste occurring during storage, preparation, and cooking in canteen kitchens was not included in this study and may be underestimated. Due to the pandemic, we were only able to survey food waste in four canteens, with each surveyed for 2 days. Furthermore, several key factors, including seasonal variations and different subsidy levels, were not considered. Future research should extend to a larger and more diverse sample of canteens, covering all meals throughout the day. Additionally, subsequent studies aim to explore specific reasons for food choice and waste, which could help inform strategies to reduce food waste.

5 Conclusion

This study quantified food waste and associated environmental impacts in workplace buffet-style canteens in Beijing through direct weighing and environmental footprint analysis. Results showed that daily *per capita* food waste averaged 158.41 g, generating ecological, water, carbon, nitrogen, and phosphorus footprints of 3.55 m^2, 423.67 L, 1566.22 g CO_2-eq, 29.95 g N, and 3.53 g P, respectively. Lunch waste was notably higher, driven by cultural dietary patterns, with livestock products, though only 29.9% of waste, disproportionately contributing to 96.7% of EF, 85.7% of WF, 63.2% of CF, 56.5% of NF, and 65.6% of PF. Self-run canteens had lower waste across meals compared to outsourced ones, highlighting the role of management and subsidy models. Food and cuisine diversity also had significant impacts, with higher diversity levels doubling waste at lunch in some cases.

The study's theoretical implications underscore the complexity of food waste drivers in workplace canteens, where unique factors—such as meal purpose, government subsidy levels, and buffet service format—collectively shape waste patterns. These findings highlight a need for nuanced, context-specific strategies for waste mitigation, especially in subsidized canteens where typical incentives may be less effective.

From a managerial perspective, targeted interventions, such as enhanced portion control, expanded meal options with waste-reduction messaging, and refined meal schedules, could reduce waste substantially. Additionally, findings support localized education on sustainable dining practices aligned with cultural and dietary habits, which could further curb waste in buffet-style environments. These insights provide policymakers with actionable recommendations for establishing waste-reduction benchmarks aligned with Sustainable Development Goal 12.3.

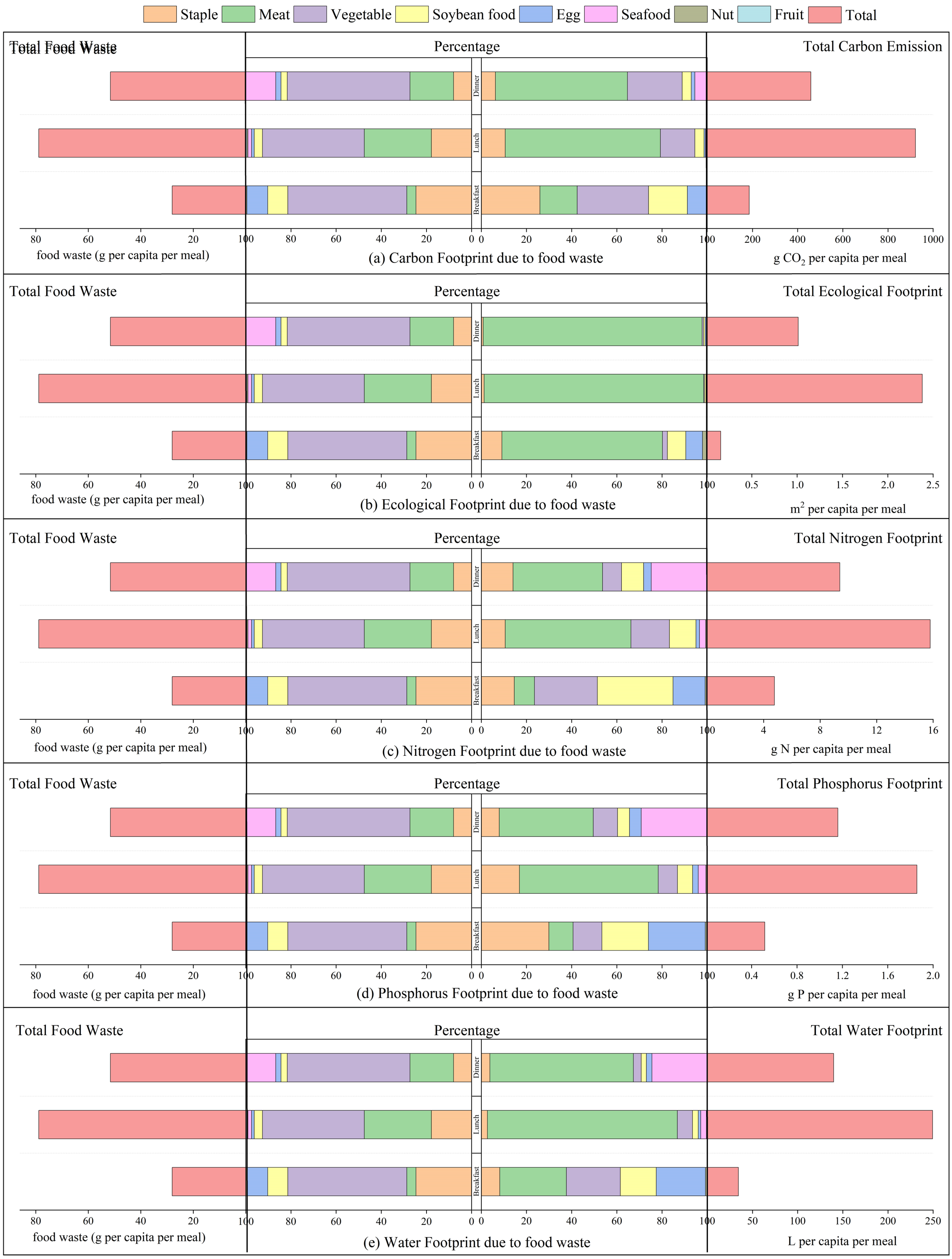

FIGURE 5
Environmental effects of food waste in the workplace buffet-style canteens.

This research is not without limitations. The scope is constrained by a limited survey period, sample size, and lack of seasonal variation analysis, while pre-consumer waste from kitchen processes remains unaccounted for. Future studies should broaden the geographic and temporal coverage, examine deeper behavioral causes of waste, and assess the impact of policy measures on waste reduction outcomes. Such efforts will enhance comparability with studies in Southeast Asia and strengthen strategies for global food system sustainability.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

DZ: Conceptualization, Funding acquisition, Methodology, Resources, Supervision, Writing – original draft, Writing – review & editing. PZ: Conceptualization, Methodology, Writing – review & editing. LX: Conceptualization, Methodology, Writing – review & editing. LW: Data curation, Methodology, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

Generative AI technologies, specifically ChatGPT, were used to enhance the language quality during the manuscript preparation.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2024.1455756/full#supplementary-material

References

Abiad, M. G., and Meho, L. I. (2018). Food loss and food waste research in the Arab world: a systematic review. *Food Secur.* 10, 311–322. doi: 10.1007/s12571-018-0782-7

Adams, J., Goffe, L., Brown, T., Lake, A. A., Summerbell, C., White, M., et al. (2015). Frequency and socio-demographic correlates of eating meals out and take-away meals at home: cross-sectional analysis of the UK national diet and nutrition survey, waves 1–4 (2008–12). *Int. J. Behav. Nutr. Phys. Act.* 12:51. doi: 10.1186/s12966-015-0210-8

Ananda, J., Karunasena, G. G., Kansal, M., Mitsis, A., and Pearson, D. (2023). Quantifying the effects of food management routines on household food waste. *J. Clean. Prod.* 391:136230. doi: 10.1016/j.jclepro.2023.136230

Beijing Municipal Bureau of Statistics, National Bureau of Statistics Beijing Survey Office. (2022). Beijing statistical yearbook 2022. Beijing: China Statistics Press.

Beretta, C., and Hellweg, S. (2019). Potential environmental benefits from food waste prevention in the food service sector. *Resour. Conserv. Recycl.* 147, 169–178. doi: 10.1016/j.resconrec.2019.03.023

Bux, C., Zizzo, G., and Amicarelli, V. (2023). A combined evaluation of energy efficiency, customer satisfaction and food waste in the healthcare sector by comparing cook-hold and cook-chill catering. *J. Clean. Prod.* 429:139594. doi: 10.1016/j.jclepro.2023.139594

Caldeira, C., De Laurentiis, V., Corrado, S., van Holsteijn, F., and Sala, S. (2019). Quantification of food waste per product group along the food supply chain in the European Union: a mass flow analysis. *Resour. Conserv. Recycl.* 149, 479–488. doi: 10.1016/j.resconrec.2019.06.011

Cao, X., and Li, X. (2023). Will healthy diets increase household food waste? *Front. Sustain. Food Syst.* 7:1180741. doi: 10.3389/fsufs.2023.1180741

Cao, S., Xie, G., Chen, W., and Guo, H. (2014). Ecological footprint of raw and derived agricultural products. *J. Nat. Recour.* 29, 1336–1344.

China. (2021). Law of the People's Republic of China on Food Waste. Available at: http://en.npc.gov.cn.cdurl.cn/2021-04/29/c_689496.htm (accessed March 31, 2023).

Cui, N., Dong, X., Liao, W., Xue, Y., Liu, X., Li, X., et al. (2022). Association of eating out frequency and other factors with serum uric acid levels and hyperuricemia in Chinese population. *Eur. J. Nutr.* 61, 243–254. doi: 10.1007/s00394-021-02634-9

Dhir, A., Talwar, S., Kaur, P., and Malibari, A. (2020). Food waste in hospitality and food services: a systematic literature review and framework development approach. *J. Clean. Prod.* 270:122861. doi: 10.1016/j.jclepro.2020.122861

Di Veroli, J. N., Peronti, B., Scognamiglio, U., Baiamonte, I., Paoletti, F., Stefanovic, L., et al. (2024). Food waste behaviors of the families of the Cilento Bio-District in comparison with the national data: elements for policy actions. *Front. Sustain. Food Syst.* 8:1385700. doi: 10.3389/fsufs.2024.1385700

Dias-Ferreira, C., Santos, T., and Oliveira, V. (2015). Hospital food waste and environmental and economic indicators – a Portuguese case study. *Waste Manag.* 46, 146–154. doi: 10.1016/j.wasman.2015.09.025

Dolnicar, S., and Juvan, E. (2019). Drivers of plate waste: a mini theory of action based on staff observations. *Ann. Tour. Res.* 78:102731. doi: 10.1016/j.annals.2019.05.008

Dou, Z., and Toth, J. D. (2021). Global primary data on consumer food waste: rate and characteristics – a review. *Resour. Conserv. Recycl.* 168:105332. doi: 10.1016/j.resconrec.2020.105332

Ellison, B., Savchenko, O., Nikolaus, C. J., and Duff, B. R. L. (2019). Every plate count: evaluation of a food waste reduction campaign in a university dining hall. *Resour. Conserv. Recycl.* 144, 276–284. doi: 10.1016/j.resconrec.2019.01.046

European Commission. (2020). Farm to Fork Strategy for a Fair, Healthy and Environmentally-friendly Food System. Available at: https://food.ec.europa.eu/horizontal-topics/farm-fork-strategy_en (accessed March 31,2023).

Filimonau, V., Algboory, H., Mohammed, N. K., Kadum, H., Qasem, J. M., and Muhialdin, B. J. (2023). Food waste and its management in the foodservice sector of a developing economy: an exploratory and preliminary study of a sample of restaurants in Iraq. *Tour. Manag. Perspect.* 45:101048. doi: 10.1016/j.tmp.2022.101048

Filimonau, V., Nghiem, V. N., and Wang, L. (2021). Food waste management in ethnic food restaurants. *Int. J. Hosp. Manag.* 92:102731. doi: 10.1016/j.ijhm.2020.102731

Foley, J. A., Ramankutty, N., Brauman, K. A., Cassidy, E. S., Gerber, J. S., Johnston, M., et al. (2011). Solutions for a cultivated planet. *Nature* 478, 337–342. doi: 10.1038/nature10452

García-Herrero, L., Costello, C., De Menna, F., Schreiber, L., and Vittuari, M. (2021). Eating away at sustainability. Food consumption and waste patterns in a US school canteen. *J. Clean. Prod.* 279:123571. doi: 10.1016/j.jclepro.2020.123571

García-Herrero, L., De Menna, F., and Vittuari, M. (2019). Food waste at school. the environmental and cost impact of a canteen meal. *Waste Manag.* 100, 249–258. doi: 10.1016/j.wasman.2019.09.027

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R.V., and Meybeck, A. (2011). Global food losses and food waste- extent, causes and prevention. FAO, Rome, Italy.

Hanssen, O. J., Syversen, F., and Stø, E. (2016). Edible food waste from Norwegian households—detailed food waste composition analysis among households in two different regions in Norway. *Resour. Conserv. Recycl.* 109, 146–154. doi: 10.1016/j.resconrec.2016.03.010

Herman, C. P., Polivy, J., Pliner, P., and Vartanian, L. R. (2019). A Theory of Normal Eating. In: *Social Influences on Eating*. Cham: Springer.

Junkrachang, P., Butcher, K., and Yodsuwan, C. (2024). Investigating guest reactions to plate waste reduction strategies: a field experiment in a casual-dining restaurant. *Int. J. Hosp. Manag.* 121:103805. doi: 10.1016/j.ijhm.2024.103805

Juvan, E., Grün, B., and Dolnicar, S. (2017). Biting off more than they can chew: food waste at hotel breakfast buffets. *J. Travel Res.* 57, 232–242. doi: 10.1177/0047287516688321

Kaur, P., Dhir, A., Talwar, S., and Alrasheedy, M. (2021). Systematic literature review of food waste in educational institutions: setting the research agenda. *Int. J. Contemp. Hosp. Manag.* 33, 1160–1193. doi: 10.1108/IJCHM-07-2020-0672

Leverenz, D., Moussawel, S., Maurer, C., Hafner, G., Schneider, F., Schmidt, T., et al. (2019). Quantifying the prevention potential of avoidable food waste in households using a self-reporting approach. *Resour. Conserv. Recycl.* 150:104417. doi: 10.1016/j.resconrec.2019.104417

Lévesque, J., Perreault, V., Bazinet, L., and Mikhaylin, S. (2022). Food waste in a hotel foodservice: a case study identifying hot spots and strategies to prioritize towards a reduction. *Int. J. Gastron. Food Sci.* 30:100600. doi: 10.1016/j.ijgfs.2022.100600

Li, Y., Wang, L., Liu, G., and Cheng, S. (2021). Rural household food waste characteristics and driving factors in China. *Resour. Conserv. Recycl.* 164:105209. doi: 10.1016/j.resconrec.2020.105209

Liu, Y., Cheng, S., Liu, X., Cao, X., Xue, L., and Liu, G. (2016). Plate waste in school lunch programs in Beijing, China. *Sustainability* 8:1288. doi: 10.3390/su8121288

Malefors, C., Callewaert, P., Hansson, P., Hartikainen, H., Pietiläinen, O., Strid, I., et al. (2019). Towards a baseline for food-waste quantification in the hospitality sector—quantities and data processing criteria. *Sustainability* 11:3541. doi: 10.3390/su11133541

Pancino, B., Cicatiello, C., Falasconi, L., and Boschini, M. (2021). School canteens and the food waste challenge: which public initiatives can help? *Waste Manag. Res. J. Sustain. Circ. Econ.* 39, 1090–1100. doi: 10.1177/0734242X21989418

Pandey, S., Budhathoki, M., Perez-Cueto, F. J. A., and Thomsen, M. (2023). Factors influencing consumers' food waste reduction behaviour at university canteens. *Food Qual. Prefer.* 111:104991. doi: 10.1016/j.foodqual.2023.104991

Pinto, R. S., Pinto, R. M. D. S., Melo, F. F. S., Campos, S. S., and Cordovil, C. M. (2018). A simple awareness campaign to promote food waste reduction in a university canteen. *Waste Manag.* 76, 28–38. doi: 10.1016/j.wasman.2018.02.044

Poore, J., and Nemecek, T. (2018). Reducing food's environmental impacts through producers and consumers. *Science* 360, 987–992. doi: 10.1126/science.aaq0216

Qian, L., Li, F., Cao, B., Wang, L., and Jin, S. (2021). Determinants of food waste generation in Chinese university canteens: evidence from 9192 university students. *Resour. Conserv. Recycl.* 167:105410. doi: 10.1016/j.resconrec.2021.105410

Read, Q. D., Hondula, K. L., and Muth, M. K. (2022). Biodiversity effects of food system sustainability actions from farm to fork. *PNAS* 119:e2113884119. doi: 10.1073/pnas.2113884119

Robinson, E., Burton, S., Gough, T., Jones, A., and Haynes, A. (2019). Point of choice kilocalorie labelling in the UK eating out of home sector: a descriptive study of major chains. *BMC Public Health* 19:649. doi: 10.1186/s12889-019-7017-5

Sebbane, M., and Costa, S. (2018). Food leftovers in workplace cafeterias: an exploratory analysis of stated behavior and actual behavior. *Resour. Conserv. Recycl.* 136, 88–94. doi: 10.1016/j.resconrec.2018.04.015

Silvennoinen, K., Nisonen, S., and Pietiläinen, O. (2019). Food waste case study and monitoring developing in Finnish food services. *Waste management*, 97, 97–104.

Springmann, M., Clark, M., Mason-D'Croz, D., Wiebe, K., Bodirsky, B. L., Lassaletta, L., et al. (2018). Options for keeping the food system within environmental limits. *Nature* 562, 519–525. doi: 10.1038/s41586-018-0594-0

Strotmann, C., Baur, V., Börnert, N., and Gerwin, P. (2022). Generation and prevention of food waste in the German food service sector in the COVID-19 pandemic – digital approaches to encounter the pandemic related crisis. *Socio-Econ. Plan. Sci.* 82:101104. doi: 10.1016/j.seps.2021.101104

UN (2015). Sustainable development goals 2030. United Nations. Available at: https://sustainabledevelopment.un.org

United Nations Environment Programme. (2021). Food Waste Index Report 2021. *Nairobi.* Available at: https://www.unep.org/resources/report/unep-food-waste-index-report-2021 (accessed March 31, 2023).

Vaneeckhaute, C., and Fazli, A. (2020). Management of ship-generated food waste and sewage on the Baltic Sea: a review. *Waste Manag.* 102, 12–20. doi: 10.1016/j.wasman.2019.10.030

Wang, L., Liu, G., Liu, X., Liu, Y., Gao, J., Zhou, B., et al. (2017). The weight of unfinished plate: a survey-based characterization of restaurant food waste in Chinese cities. *Waste Manag.* 66, 3–12. doi: 10.1016/j.wasman.2017.04.007

Wu, Y., Tian, X., Li, X., Yuan, H., and Liu, G. (2019). Characteristics, influencing factors, and environmental effects of plate waste at university canteens in Beijing, China. *Resour. Conserv. Recycl.* 149, 151–159. doi: 10.1016/j.resconrec.2019.05.022

Wu, Y., Wang, X., and Lu, F. (2011). Ecological footprint and water footprint of food consumption in Beijing. *Resour. Sci.* 33, 1145–1152.

Xue, L., Liu, X., Lu, S., Cheng, G., Hu, Y., Liu, J., et al. (2021). China's food loss and waste embodies increasing environmental impacts. *Nat. Food.* 2, 519–528. doi: 10.1038/s43016-021-00317-6

Yi-Chi Chang, Y., Lin, J., and Hsiao, C. (2022). Examining effective means to reduce food waste behaviour in buffet restaurants. *Int. J. Gastron. Food Sci.* 29:100554. doi: 10.1016/j.ijgfs.2022.100554

Zhang, D., Cheng, S. K., Gao, L. W., Cao, X. C., Liu, X. J., Liu, Y., et al. (2016a). Ecological footprint of catering industry food waste in Beijing. *Resour. Sci.* 38, 10–18. doi: 10.18402/resci.2016.01.02

Zhang, D., Cheng, S. K., Gao, L. W., Liu, X. J., Cao, X. C., Liu, Y., et al. (2016b). The carbon footprint of catering industry food waste: a Beijing case study. *Acta Ecol. Sin.* 36, 5937–5948. doi: 10.5846/stxb201504150769

Zhang, P., Fu, S., and Liu, X. (2022). The effect of plate and decoration color on consumer food waste in restaurants: a case of four Chinese cities. *Sustainability* 14:3479. doi: 10.3390/su14063479

Zhang, H., Li, S., Wei, D., He, J., Chen, J., Sun, C., et al. (2021). Characteristics, environmental impact, and reduction strategies of food waste generated by young adults: case study on university canteens in Wuhan, China. *J. Clean. Prod.* 321:128877. doi: 10.1016/j.jclepro.2021.128877

Zhang, D., Lun, F., Cheng, S., Gao, L., Liu, X., Cao, X., et al. (2016c). The phosphorus footprint and its environmental analysis for restaurant food waste: taking Beijing as an example. *J. Nat. Resour.* 31, 812–821.

Zhang, D., Lun, F., Cheng, S. K., Liu, X. J., Cao, X. C., and Liu, Z. X. (2017). The nitrogen footprint of different scales of restaurant food waste: a Beijing case study. *Acta Ecol. Sin.* 37, 1699–1708. doi: 10.5846/stxb201510162088

Zhang, P., Zhang, D., and Cheng, S. (2020). The effect of consumer perception on food waste behavior of urban households in China. *Sustainability* 12:5676. doi: 10.3390/su12145676

Zhang, P., Zhang, W., Liu, X., and Sun, F. (2024). Does the frequency of eating snacks increase food waste? A study based on senior high school in China. *Front. Sustain. Food Syst.* 8:1336220. doi: 10.3389/fsufs.2024.1336220

Zou, T., Zhang, X., and Davidson, E. A. (2022). Global trends of cropland phosphorus use and sustainability challenges. *Nature* 611, 81–87. doi: 10.1038/s41586-022-05220-z