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The quantity and composition of household food waste during the COVID-19 pandemic: A direct measurement study in Canada

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ABSTRACT

The COVID-19 pandemic may have amplified the environmental, social, and economic implications of household food waste. A better understanding of household food wasting during the pandemic is needed to improve the management of waste and develop best practices for municipal waste management programs under crisis circumstances. A waste composition study was undertaken with 100 single-family households across the city of London, Ontario, Canada to determine the quantity and composition of household food waste disposed in June 2020, during the first wave of the COVID-19 pandemic. This study examines how household demographic, socioeconomic, and neighbourhood food environment characteristics influence household food wasting. On average, each household sent 2.81 kg of food waste to landfill per week, of which 52% was classified as avoidable food waste and 48% as unavoidable food waste. The quantity and composition of household food waste was found to be strongly influenced by the number of people and children in a household, and somewhat influenced by socioeconomic factors and neighbourhood food environment characteristics, including the availability, density, and proximity of retail food outlets.

1. Introduction

Household food waste represents one of the most important sustainability challenges that current and future municipal governments need to address. In developed countries, it is estimated that approximately 198.9 kg of food per capita is wasted annually, of which over 57% is estimated to be thrown away at the household level [1].

Wasting food is expensive and places logistical and financial burdens on waste management facilities. While it can be challenging to quantify the exact value of food waste, it is estimated that the value of the food wasted globally is approximately $1 trillion USD per year [2].

Environmentally, food waste contributes to climate change. As food waste decomposes, it releases methane, a greenhouse gas about 28 times more potent than carbon dioxide. Project Drawdown ranks reduced food waste as the top individual solution to reducing global warming and has hypothesized that reducing food waste on a global scale could lead to a reduction of 87.4 gigatons of CO_2e by 2050 [3].

There are also social impacts associated with food waste. Food waste often signifies poor food distribution systems and works against minimizing food insecurity. Globally, an estimated 135 million people are acute food insecure, a figure which was predicted to double by the end of 2020 due to the COVID-19 pandemic [4].

On March 11, 2020, the World Health Organization (WHO) declared the COVID-19 outbreak as a global pandemic [5]. As of May 2021, there have been over 152 million confirmed cases and over 3.1 million confirmed deaths across 220 countries, areas, or territories [6].

As Roe et al. [7] stated: "perhaps no phenomenon has so quickly and radically altered household production parameters and daily food

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patterns in the United States as the onset of the COVID-19 pandemic" (p. 1). These shifts in consumer behaviours are not exclusive to residents of the United States. Many Canadians are grocery shopping less frequently during the pandemic but are purchasing more food per trip [17]. These changes in food shopping habits may be a consequence of inconveniences introduced by regional COVID-19 lockdowns and temporary public health measures (e.g., having to wait in long lines to enter brick-and-mortar stores due to reduced indoor capacities), and/or health and safety concerns regarding the risk of community-spread and transmission of the virus in indoor retail spaces. Changes in the frequency of purchasing food during the COVID-19 pandemic were also noted in the United States [7], Italy [8]; this issue), the United Kingdom [9,10], and Tunisia [11]. Countries that have also seen a change in the amount of food purchased per food shopping trip include the United States [12], the United Kingdom [10], and Spain [13].

While there have been notable changes to how often food is purchased and how much food is bought at once, there have also been changes to how consumers prefer to shop for food. Several studies highlight an increase in online food shopping in many areas of the world, including Canada, during the pandemic [8,10,12–17]. There is also some evidence to support an increase in the number of residents buying more food locally [14,15]. An increase in the purchasing of locally grown and/or prepared foods may be related to community movements aimed at supporting local food vendors in a time of economic hardship and uncertainty; however, it could also be a consequence of food safety concerns due to the perceived risk of virus transmission on food products imported from regions with different public health measures in place.

There have also been notable changes to at-home food preparation and management. In parallel with more individuals working and learning from home, there has been an increase in the number of meals prepared and eaten at home since the outbreak [10,12,14–16,18]. Several studies have noted the use of more at-home food management techniques, including pre-planning shopping trips (e.g., checking what food is at home before shopping and making a grocery list), as well as eating leftovers more often than before the pandemic [8,11,14,17,19,20]; this issue; [10].

This study examines, through direct measurement, the quantity and composition of household food waste disposed during the first wave of the COVID-19 pandemic. Additionally, it examines how household demographic, socioeconomic, and neighbourhood food environment characteristics may influence household food wasting in London, Ontario, Canada.

1.1. Household demographics and socioeconomic characteristics

Several studies suggest that household composition, including both the number of people and the number of children in a household, are strong determinants of household food waste generation [21–25]. On average, households with more occupants, often including children, generate more food waste. Household income may also be a determinant; however, findings have been inconsistent [24,26–29]. On an individual level, gender [21,30] and age [24,31,32] have been identified as determinants of food waste generation. Generally, men and young people have been found to waste more food than women and seniors [21,30–32].

During COVID-19, some studies have evaluated if these household demographic and socioeconomic characteristics are still determinants of food waste generation. In Tunisia, age, level of education, and number of household occupants were found to be strong determinants of self-reported household food waste generation [11]. In the United Kingdom, the Waste and Resources Action Programme (WRAP) [10] identified several household demographic and socioeconomic variables correlated with self-reported food waste quantities. Participants who were younger (18–34 years), had children living at home, lived in an urban community, rented their home, and/or worked full-time were more likely to self-report higher levels of food waste, whereas participants who were older (55–65+), lived in a rural community, and/or had no children living at home were less likely to self-report higher levels of food waste [10].

1.2. Neighbourhood food environment characteristics

To date, few studies have explored the relationship between household food waste and the neighbourhood food environment, which can be loosely defined as the proximity, density, and availability of food vendors within a neighbourhood [29,33,34].

In a recent study conducted in Toronto, Ontario, Canada, the neighbourhood food environment appeared to have some associations with household food waste generation [29]. Researchers found significant correlations between household food waste and both the proximity to and density of certain types of food vendors [29]. van der Werf et al.'s [29] findings suggest that households in neighbourhoods with a higher density of supermarkets, and households that are further away from food outlets that predominately sell less processed foods (e.g., bakeries, butcher shops, produce markets, etc.) typically generate more food waste.

1.3. Household food wasting during COVID-19

In Canada, Charlebois et al. [20] surveyed residents to determine if household food waste generation changed during the COVID-19 pandemic. Respondents self-reported that their households generated approximately 2.03 kg of food waste per week prior to the pandemic and generated 13.5% more food waste (2.30 kg per week) during the pandemic [20]. In another study, the National Zero Waste Council (NZWC) and Love Food Hate Waste Canada (LFHW) [17] also surveyed Canadians during the pandemic; however, their findings were contradictory to Charlebois et al. [20]. NZWC and LFHW [17] concluded that 24% of respondents self-reported that their households generated less food waste during the COVID-19 pandemic, while 14% generated more, 50% reported no change, and 12% suggested they never waste food.

In the United Kingdom, WRAP [10] interviewed residents and concluded that 36% of participants generated less household food waste during regional COVID-19 lockdowns, while 4% generated more, and 34% reported no change. In another study by the Food Standards Agency (FSA) [14], residents in England, Wales, and Northern Ireland were surveyed. This study similarly concluded that overall, respondents self-reported a reduction in household food waste [14]. Principato et al. [8] surveyed Italian residents and concluded that overall, households self-reported a reduction of food waste for all six of their food categories (i.e., bread; pasta and rice; meat, fish, and eggs; milk and dairy products; vegetables; and fruit). In another study by Amicarelli & Bux [19], 15 Italian households participated in a food diary study where participants self-reported their food consumption and waste over a seven-day period during the pandemic. Amicarelli & Bux [19] concluded that households generated approximately 1.17 kg of food waste per week during COVID-19, which is nearly 50% less than the estimates in Charlebois et al.'s [20] Canadian study. Aldaco et al. [13] used secondary data obtained by the Spanish Ministry of Agriculture, Fisheries and Food to examine the potential impacts of food waste from COVID-19. Similar to Charlebois et al. [20], Aldaco et al. [13] concluded that households generated approximately 12% more food waste during COVID-19 than before the outbreak.

Jribi et al. [11] surveyed residents during the first two weeks of the lockdown in Tunisia (March 24 to April 7, 2020) and concluded that 93% of respondents declared that they were making an effort to control their food waste generation during the lockdown. Overall, participants self-reported that during the first two weeks of regional lockdowns, they wasted bread and bakery products the most, followed by vegetables, and then fruit [11]. Hassen et al. [15] surveyed residents in Qatar and concluded that 45% of respondents self-reported a reduction of food

waste during the pandemic, while 42% of respondents indicated that their food waste generation had not changed. Ismail et al. [16] used secondary data to examine the potential impacts of food waste in Klang Valley, Malaysia. While this study is limited due to the use of a proportional assumption based on 2019 data, Ismail et al. [16] concluded that food waste generation in Klang Valley had decreased during regional COVID-19 lockdowns.

A cross-national survey was conducted by Brizi & Biraglia [35] in India and the United States to determine how psychological variables, specifically the need for cognitive closure (i.e., the desire for definitive answers without ambiguity), affected food management and waste during the pandemic. The study concluded that both Indian and American survey respondents with a higher need for cognitive closure perceived themselves to own less food during the pandemic, which led to an increase in their food purchasing, thereby leading to a self-reported increase in household food waste generation [35].

Overall, these studies provide a preliminary understanding of household food waste generation during the first wave of the COVID-19 pandemic; however, they are limited by their reliance on indirect measurements of self-reported data. Table 1 provides a summary of these preliminary results. While many of these studies followed similar waste measurement methodologies, varying public health policies, time frames, and cultural norms likely affect the comparability of results.

1.4. Household food waste measurement

The process of establishing an appropriate research methodology is a challenge faced by all food waste scholars. The choice of food waste measurement methodology is largely constrained by budget and expertise. Researchers typically use one of two methodologies to measure household food waste: self-reported recall data or direct measurement of waste composition. Additionally, due to the amplification of feasibility limitations during the COVID-19 pandemic, some researchers have used secondary data to estimate household food waste. However, this methodology is not commonly used to assess food waste at the household level.

Studies using self-reported recall data (e.g., [8,19]) involve research participants who report on their own waste generation and composition through the keeping of diaries and/or the completion of questionnaires and surveys relying on recall of food wasted. There is some agreement among food waste scholars that studies relying solely on self-reported data underestimate waste generation [25,36–39]. The reason for this inaccuracy is twofold. First, self-reported data are prone to potential biases. Thus, the data may not reflect participants' 'normal' waste management practices. The act of reporting in itself could influence participants to change their behaviour, even in diary studies that ask participants to measure their food waste with a kitchen scale, as individuals who are more conscious of the quantity and quality of the materials they are throwing away are more likely to reduce their overall waste generation [25]. Second, the data collected through self-reporting diaries, questionnaires, and surveys are typically subjective and prone to recall bias. Participants are often asked to provide estimates of their waste generation in abstract volumes, such as in handfuls or servings, which are susceptible to independent interpretation. Thus, studies of self-reported data, on their own, do not provide the accurate and up-to-date data needed to assess the effectiveness of our current municipal waste management programs.

Food waste composition studies involve both the weighing and sorting of the waste sample by researchers to determine the amount, nature, and composition of the waste generated by research participants. Studies involving the direct measurement of waste composition provide the greatest level of detail and accuracy of the two popular methodologies as they are not confined by the strong potential for bias commonly found within studies of self-reported recall data.

Studies using secondary data (e.g., [13,16]) are typically used to assess waste generation at the national level, as opposed to the household level. These studies involve the assessment of waste generation using secondary data including, but not limited to, landfill scale tickets, proportional assumptions based on historic data, and government estimates. The use of secondary data to determine household food waste generation is extremely limited, as the data is not directly measured by researchers and may be outdated, not specific to the region being investigated, and/or grounded in proportional assumption calculations that lack accuracy and transparency.

A key component of this research was to answer the research questions using a direct measurement approach (i.e., food waste composition study), where the waste generated by each sample household was collected, weighed, and analyzed to determine the amount and composition of food waste sent to landfill. To date, this study is one of the only (if not the only) direct measurement studies of household food waste generation during the COVID-19 pandemic, and one of the first known Canadian studies.

1.5. Household food wasting in London, Ontario, Canada

The direct measurement and study of household food waste in London is ongoing. Prior to the COVID-19 pandemic, a representative sample of households in London sent 144.72 kg of food waste to landfill annually (2.78 kg/household/week), of which over 63% was classified as avoidable food waste, meaning that the food was at one time edible

Table 1
Summary of preliminary studies of household food wasting during COVID-19.

Study	Region	Time of data collection (2020)	Food waste measurement methodology	Direction of food waste change	Quantity of food waste (kilograms/household/week)
Charlebois et al. [20]	Canada	August	Survey	Increase	2.30
NZWC & LFHW [17]	Canada	June	Survey	No change	Not reported
WRAP [5]	United Kingdom	April	Interviews	Decrease/no change	Not reported
FSA [14]	England, Wales, & Northern Ireland	April to November	Survey	Decrease	Not reported
Principato et al. [8]	Italy	March to April	Survey	Decrease	Not reported
Amicarelli & Bux [19]	Italy	March to May	Food diaries	Not reported	1.17
Aldaco et al. [13]	Spain	Not reported	Secondary data	Increase	Not reported
Jribi et al. [11]	Tunisia	March to April	Survey	Not reported	Not reported
Hassen et al. [15]	Qatar	May to June	Survey	Decrease/no change	Not reported
Ismail et al. [16]	Klang Valley, Malaysia	March to April	Secondary data	Decrease	Not reported
Brizi & Biraglia [35]	India & United States	Not reported	Survey	Increase[a]	Not reported

[a] Specific to survey respondents with a higher need for cognitive closure.

[37]. It is estimated that the average London household throws away about $600 worth of food annually, which totals to a yearly cost of $75 million across the entire city [24]. London households emit approximately 10.8 tCO_2e per year, of which 8% are a result of residents sending food waste to landfill [40]. Locally, in the Middlesex-London region, approximately 14% of households reported experiencing some level of food insecurity (marginally, moderately, or severely) in 2013/2014 [41,42]. As of May 2021, there have been 10,575 confirmed cases of COVID-19 and 201 confirmed deaths in the Middlesex-London region [43].

1.6. This study

The aim of this study is to determine the state of household food waste during the unprecedented circumstances brought upon by a global pandemic. To investigate these circumstances, a municipal food waste composition study was conducted in the city of London in June 2020 during the second stage of Ontario's regional approach to reopening during the COVID-19 pandemic. At this time, some regional restrictions were loosened allowing for more food vendors to re-open. The research questions explored in this study include: (1) What is the quantity and composition of household food waste during the first wave of the COVID-19 pandemic? (2) How do household demographic, socioeconomic, and neighbourhood food environment characteristics influence the quantity and composition of household food waste generation?

2. Material and methods

Research was undertaken in London, Ontario, a Canadian city with a population of approximately 494,069 [44]. The City of London (City) operates a curbside waste collection program for single-family households. Waste is collected every six business days on a rotating cycle, meaning that a household's waste collection day changes each week. The curbside collection system operates as a two-stream program, including waste to landfill (i.e., garbage), containers recycling (e.g., plastic, glass, metal), and paper recycling (e.g., cardboard, boxboard, paper). Residents are able to set out a maximum of three garbage containers per collection cycle. There is no limit for recycling bins. Unlike most mid-to large-sized cities in Ontario, there is currently no municipal curbside organics collection program to divert food and other organic waste from landfill. The City has been working towards the implementation of a 'green bin' program for several years; however, program implementation has been delayed due to the pandemic. In addition, the City sells backyard composters to residents at a reduced rate. Over the last 25 years, approximately 60,000 backyard composters have been purchased and distributed throughout London [37].

2.1. Selection of study households

All study households previously completed a household food waste survey in which respondents indicated their interest in volunteering to participate in future food waste research, including having their curbside garbage collected and analyzed. The complete survey methodology has been reported in van der Werf et al. [24]. Out of a total of 418 survey respondents who indicated their interest in volunteering to participate in future research, a subset of 115 volunteer households were randomly selected for this direct measurement study. Sample households were selected randomly from within each of the City's six municipal waste collection zones, resulting in 12–21 households per zone, randomly distributed throughout the city (i.e., not clustered in groups). Only the survey responses to the household demographic and socioeconomic questions were needed to answer the research questions in this study, and therefore were included in the analysis. The direct measurement of curbside garbage samples, as well as household demographic, socioeconomic, and neighbourhood food environment data were linked by unique household identifiers to ensure participant confidentiality. This study was approved by the Non-Medical Research Ethics Board of the University of Western Ontario.

2.2. Garbage sample collection and analysis

Household curbside garbage samples from one municipal waste collection cycle were collected and analyzed on a household's designated waste collection day between June 9 and 16, 2020. This allowed for the occurrence of the sample collection to remain unknown to residents involved in the study, thereby limiting the potential for bias. Each household's garbage sample consisted of all the solid waste set out for regular, curbside, municipal garbage collection and was labelled with a unique identifier to allow for individual household waste data to be analyzed independently. The number of garbage containers and recycling containers set out by each household was also documented.

Following the sample collection, the samples were taken to an enclosed area for analysis. The total collected garbage sample generated by each household was weighed and recorded. Each household's garbage sample was then individually analyzed to measure the amount and composition of food waste disposed to landfill. Food waste was manually sorted into twelve categories (see Table 2) and individually weighed by category to allow for the collection of direct measurements. First, the food was classified as avoidable (i.e., food that was at one time edible) or unavoidable (i.e., food that was never edible, such as coffee grounds). Secondly, food waste was classified into six categories based on food type, including bread and bakery, meat and fish, dairy, dried foods, fruit and vegetables, and other foods (i.e., foods that do not fit into the previous categories, such as candy, sauces, coffee, and some types of leftovers).

A total of 100 curbside garbage samples were successfully collected, with 15 households (13% of the original sample) missed either because residents did not set out any garbage on the day of the sample collection, or municipal waste collection staff mistakenly collected the sample prior to the arrival of the research team.

2.3. Household demographic and socioeconomic independent variables

Household demographic and socioeconomic data were collected as part of the survey, including the number of household residents, number of children in the household, housing tenure (i.e., live rent-free, pay rent, pay mortgage, or own home outright), and annual household income.

2.4. Neighbourhood food environment independent variables

Characteristics of the neighbourhood food environment were assessed for each household, using point-level retail food outlet data obtained from inspection records maintained by the local public health

Table 2
Food waste sorting categories.

First classification	Second classification	Examples of foods belonging to each food waste category
Avoidable Food Waste	Bread and Bakery	Bread, tortillas, pastries, pizza
	Meat and Fish	Poultry, beef, seafood, eggs
	Dairy	Milk, yogurt, cheese, ice cream
	Dried Food	Rice, noodles, crackers, cereal
	Fruit and Vegetables	Apples, berries, lettuce, potatoes
	Other	Leftovers, candy, sauces, dips
Unavoidable Food Waste	Bread and Bakery	Not applicable
	Meat and Fish	Bones, eggshells, clam shells
	Dairy	Cheese rinds
	Dried Food	Not applicable
	Fruit and Vegetables	Pits, peels, stems, seeds
	Other	Coffee grounds, tea bags

unit [41,42]. Given that the COVID-19 pandemic resulted in the temporary or permanent closure of some food-based businesses, only retail food outlets that were confirmed to be open in June 2020 were included in the analysis. This updated dataset was created by the researchers as part of the Food Retail Environment Study for Health and Economic Resiliency (fresher.theheal.ca).

Retail food outlet types were determined from the local health unit's categorization, updated for the options available during the COVID-19 pandemic situation, resulting in four categories: convenience stores, grocery stores, takeout-only, and restaurants. Convenience stores stock pre-packaged goods on a small scale. Grocery stores (including farmers' markets) sell both fresh and pre-packaged foods and goods on a larger scale than convenience stores. Take-out outlets serve quick-service and takeaway meals with no option for dine-in service. Restaurants serve both quick and slow-service food and beverages with a dine-in or patio option. In June 2020, restaurants in the Middlesex-London region were permitted to offer indoor and outdoor dine-in service [45]. Non-retail food sources, such as food banks and backyard and community gardens, were not included in this analysis.

Distance to closest retail food outlet was calculated by type, using the shortest network path along the public road network from the respondent's geo-coded street address, using the ArcGIS Pro 2.4 Network Analyst toolbox [46]. The public road network includes all publicly accessible streets, paths, and sidewalks [47]. This distance-based measure is used to represent proximity to the nearest type of retail food outlet, demonstrating the ease of access to a particular type of outlet (i.e., convenience, take-out, restaurant, grocery) from the consumer's home [34]. The number of retail food outlets within 400 metres and 1,200 metres of the respondent's street address were calculated by outlet type and aggregated using a network-based buffer along the public road network. This density measure of retail food outlets represents a possible influence on consumer behaviour, whereby the greater number of outlets in an area may result in a higher number of unplanned purchases [57]. Moreover, the availability of convenience stores and grocery stores within 400 metres and 1,200 metres, respectively, captures the ease of making an impromptu purchase in a consumer's local environment [33]. These analyses were completed using the Network Analyst toolbox and Analysis toolbox in ArcGIS Pro 2.4 [46].

2.5. Statistical analysis

Data were analyzed using IBM SPSS Statistics version 27 (Armonk, NY: IBM Corp). The mean and standard deviation were calculated for the 12 food categories, and for the total amount of avoidable, unavoidable, and overall food waste. The Spearman rank correlation coefficient was used to assess the strength and direction of the associations between the dependent variables (i.e., total food waste, total avoidable food waste, and total unavoidable food waste) and the independent variables (i.e., household demographics, socioeconomic characteristics, and the neighbourhood food environment). Correlation coefficients of 0.10, 0.30, and 0.50 were considered small, medium, and large relationships, respectively [48].

Multiple linear regression models were developed to assess the relative effects of various predictors on the total amount of avoidable, unavoidable, and overall food waste. Statistical power was sufficient for the regression modeling given that the sample size was $\geq$10x the number of predictor variables in the models [49]. Predictor variables were included in the multiple regression analyses if they had a bivariate relationship with the dependent variable at the $p < 0.10$ level, or if they were neighbourhood food environment characteristics that had previously been used in food accessibility studies [29,33]. Collinearity diagnostics were obtained as part of the analysis, and multicollinearity was not found to be problematic (VIFs ranging from 1.01 to 1.75). A two-sided p-value of <0.05 was considered statistically significant.

3. Results

3.1. Household demographics and socioeconomic characteristics

The household demographic and socioeconomic profile of the sample households (n = 100) is presented in Table 3. Sample households typically had no children or few children. The sample included more 3–5 person households and fewer 1–2 person households when compared to the most recent census data [44]. Further, most households had a mortgage and, the sample included more households with an annual income greater than $60,000 when compared to census data [44].

3.2. Direct measurements of household food waste

On average, the total amount of garbage sent to landfill was 9.92 kg (SD = 6.75 kg) per household per week. Ninety-two percent of sample households had also set out at least one recycling bin on the waste sample collection day. The average total amount of food waste sent to landfill was 2.81 kg (SD = 2.56 kg) per household per week, which represents approximately 28% of the total amount of overall garbage sent to landfill. As depicted in Table 4, approximately 52% (1.45 kg) of the total amount of food waste sent to landfill by each sample household was classified as avoidable, while the remaining 48% (1.36 kg) was classified as unavoidable.

The composition of avoidable food waste was primarily fruit and vegetables (34%), followed by other foods (20%), and then bread and bakery (18%). The composition of unavoidable food waste was also primary fruit and vegetables (71%). On average, the total weight of all the fruit and vegetables sent to landfill by the sample households was nearly four times greater than the next largest food waste category, namely other foods.

3.3. Correlations between household food waste and household demographic, socioeconomic, and neighbourhood food environment variables

There were several significant bivariate Spearman rank correlations (Table 5). This included strong, positive, and statistically significant ($p < 0.01$) correlations between total waste sent to landfill and avoidable, unavoidable, and total food waste, suggesting that households that set out more garbage on their waste collection day also sent more food waste to landfill. Total food waste, total avoidable food waste, and total unavoidable food waste were also positively and significantly correlated with the number of people in a household and the number of children in a household, and negatively and significantly correlated with the availability of a grocery store within 1,200 metres of a household.

Overall, there were a greater number of significant relationships between the independent variables and total unavoidable food waste

Table 3
Sociodemographic profile of sample households (n = 100).

People in household	S	P	Children in household	S
1	9.0	30.2	0	55.0
2	32.0	34.8	1	16.0
3	17.0	14.8	2	15.0
4	23.0	13.1	3	10.0
5	14.0	7.2	4	2.0
6+	4.0		5+	1.0
Household income	**S**	**P**	**Housing tenure**	**S**
<$40,000	20.2	29.0	Live rent free	5.0
$40–60,000	10.1	17.3	Pay rent	14.0
$60–80,000	17.2	14.0	Pay mortgage	58.0
$80–100,000	20.2	11.2	Own home outright	22.0
>$100,000	32.3	28.4		

S = Percentage of sample households (n = 100); P = Percentage of total London, Ontario population.

Table 4
Average weight of food waste sent to landfill by 100 sample households (grams/household/week).

Food Categories	Avoidable food waste			Unavoidable food waste			Total food waste		
	Mean	SD	%	Mean	SD	%	Mean	SD	%
Bread	267.2	387.3	18.4	–	–	–	267.2	387.3	9.2
Dairy	63.2	157.6	4.4	–	–	–	63.2	157.6	2.3
Dried	168.5	340.2	11.6	–	–	–	168.5	340.2	6.0
Fruit/Veg.	492.2	743.5	33.9	967.8	1403.2	71.1	1460.0	504.9	51.9
Meat	173.5	331.1	11.9	176.7	239.0	13.0	350.1	387.0	12.4
Other food	288.8	693.9	19.9	216.1	355.5	15.9	387.0	1737.1	17.9
Total	**1453.3**	**1806.0**	**100.0**	**1360.6**	**1614.8**	**100.0**	**2813.9**	**2555.0**	**100.0**

Fruit/Veg. = Fruit and vegetables.

Table 5
Avoidable, unavoidable, and total food waste correlations* with waste, household demographic, socioeconomic, and neighbourhood food environment variables.

Variables	Avoidable food waste	Unavoidable food waste	Total food waste
Waste variables			
Total waste sent to landfill	.59**	.54**	.70**
Recycling set-out	-.10	.16	.02
Household demographic variables			
People in household	.25*	.24*	.29**
Children in household	.24*	.31*	.32**
Socioeconomic variables			
Housing tenure: Live rent-free	-.04	.09	-.09
Housing tenure: Pay rent	.07	-.10	-.01
Housing tenure: Pay mortgage	.11	.18	.13
Housing tenure: Own home outright	-.19	-.04	-.12
Household income	.03	.05	.05
Neighbourhood food proximity variables			
Distance to closest convenience store	.12	.16	.13
Distance to closest grocery store	.02	.21*	.12
Distance to closest take-out	.05	.21*	.14
Distance to closest restaurant	.11	.21*	.18
Neighbourhood food availability variables			
Convenience store within 400 m (Y/N)	.01	-.14	-.04
Grocery store within 1,200 m (Y/N)	-.22*	-.23*	-.25*
Neighbourhood food density variables			
Number of convenience stores within 400 m	-.01	-.15	-.07
Number of grocery stores within 1,200 m	-.15	-.21*	-.19
Number of take-outs within 1,200 m	-.03	-.24*	-.12
Number of restaurants within 1,200 m	-.15	-.31**	-.24*
Number of all food vendors within 1,200 m	-.18	-.29*	-.21*

*Correlation is significant at the 0.05 level (2-tailed); ** Correlation is significant at the 0.01 level (2-tailed).

than there was for total avoidable food waste. In addition to the correlations noted above, unavoidable food waste was positively and significantly correlated with proximity to the closest grocery store, take-out only vendor, and restaurant, as well as negatively and significantly correlated with the density of all food vendors within 1,200 metres of a household, and specifically the density of take-out only vendors, grocery stores, and restaurants within 1,200 metres.

Multiple linear regression models were developed to further examine characteristics associated with avoidable, unavoidable, and total food waste. As shown in Table 6, total food waste was positively and significantly correlated with total waste sent to landfill ($p < 0.001$) and the number of children in a household ($p < 0.001$). Total avoidable food waste was positively and significantly correlated with total waste sent to landfill ($p < 0.001$), as well as negatively and significantly correlated with home ownership ($p = 0.01$). Total waste sent to landfill ($p < 0.001$), the number of children in a household ($p < 0.001$), and the distance to the closest grocery store ($p = 0.03$) were all positively and significantly associated with total unavoidable food waste. By analyzing the standardized beta coefficients, total waste sent to landfill was found to be the strongest predictor of total food waste and total avoidable food waste, whereas the strongest predictor of total unavoidable food waste was the number of children in a household.

Table 6
Multiple linear[a] regression analysis of total food waste, total avoidable food waste, and total unavoidable food waste.

	B	SE	β
Total food waste (n = 100)			
(Constant)	161.30	354.60	
Children in household	632.71	156.91	.31***
Total waste sent to landfill	.21	.03	.56***
Model statistics: Adjusted $R^2 = .45$, F (2, 93) = 39.54 $p < 0.001$			
Total avoidable food waste (n = 100)			
(Constant)	−64.63	434.18	
People in household	201.85	103.87	.17
Total waste sent to landfill	.15	.02	.59***
Housing tenure: Pay mortgage	−624.75	352.53	-.19
Housing tenure: Own home outright	−1166.62	418.76	-.29**
Model statistics: Adjusted $R^2 = .40$, F (4, 92) = 16.66, $p < 0.001$			
Total unavoidable food waste (n = 100)			
(Constant)	−266.85	378.16	
Children in household	419.13	122.34	.31***
Total waste sent to landfill	.07	.02	.27**
Distance to closest grocery store	.54	.24	.21*
Model statistics: Adjusted $R^2 = .22$, F (3, 92) = 10.00, $p < 0.001$			

[a] *$p < 0.05$ level; **$p < 0.01$ level; ***$p < 0.001$ level.

4. Discussion

The 2.81 kg/household/week food waste disposed by this sample of London, Ontario households is slightly higher than the results of a pre-COVID-19 study of nine southern Ontario municipalities, where on average 2.4 kg/household/week of food waste was disposed across all households and 2.63 kg/household/week for those households that had no access to a green bin program (as is the case in London, Ontario) [58]. While the results of this study appear similar to the findings in Charlebois et al. [20], there was an 18% (0.51 kg) difference in the total amount of food waste generated in London (2.81 kg/household/week) compared to the self-reported findings (2.30 kg/household/week) in Charlebois et al.'s [20] Canada-wide survey. Underestimating waste generation hinders a municipality's ability to assess the effectiveness of their waste management infrastructure, which is especially critical in

unprecedented circumstances, such as those brought upon by a global pandemic. For example, if the City of London were to use Charlebois et al.'s [20] findings to estimate the possible increased demand on their municipal waste management program during COVID-19, they could be underestimating the amount of food waste sent to landfill across all London households (n = 206,450) [44] by approximately 105,290 kg of food waste per week. However, it should be noted that this is a rough estimate, as the average number of occupants per household was slightly higher in the study households (3.1 people/household) when compared to the most recent census data (2.4 people/household) [44].

Over half (51.9%) of the food wasted by each sample household was classified as fruit and vegetables. These results are similar to recent findings in Italy [19] and in NZWC & LFHW's [17] Canada-wide survey. In both studies, participants self-reported that they wasted vegetables the most, followed by fruit [17,19]. While these foods are highly perishable, fruit and vegetables are also arguably the most important elements of a healthy diet. There is some research to support a shift in dietary trends towards healthier and more sustainable choices during the pandemic [50], including in Canada, where Carroll et al. [51] suggested that eating habits and meal routines have shifted (i.e., eating less take-out and more meals prepared at home) during COVID-19 in households with middle to high income levels and young children. The large quantity of fruit and vegetables sent to landfill by the sample households in this study may be a consequence of residents trying to eat healthier during COVID-19, but also purchasing too much of these highly perishable food items.

Recent studies from around the world have shown that there have been notable changes in food shopping, management, and preparation behaviours during COVID-19 [8,9,11–20]; this issue; [7,10]. It is likely that many residents in our study area are also preparing and consuming more meals at home than they 'normally' would, as 48% (1.36 kg/household/week) of the total amount of food waste sent to landfill was classified as unavoidable, whereas previous direct measurement studies conducted in the city prior to COVID-19, found that only 37% (1.02 kg/household/week) of total food waste was unavoidable [37]. Unavoidable food waste is often a by-product of at-home meal preparation. Therefore, this 11% difference in total unavoidable food waste signifies a probable change in household food behaviours.

During the waste composition study, the researchers observed a large quantity of leftovers (classified as avoidable other foods). While this observation, on its own, does not provide further evidence to support the notion that residents are likely preparing more meals at home, as it is not known where these leftovers were originally prepared (e.g., at home, at a restaurant, etc.), it does provide further evidence to support the claim that many residents are likely consuming more meals at home than they would under 'normal', pre-COVID-19 circumstances.

During the waste composition assessments, the researchers observed a large amount of coffee grounds, coffee pods, and tea bags, which were classified as unavoidable other foods. It is speculated that the total amount of unavoidable other foods may have increased during the pandemic as a result of local COVID-19 public health measures. With many individuals working from home, a greater number of residents may have been consuming these caffeinated beverages more frequently at their homes in June 2020. In this scenario, the total amount of unavoidable food waste generated in London from preparing coffee and tea may not have changed. Instead, a portion of this waste may have been reallocated from places of employment to the household level, representing a change in the point of waste generation. A reallocation of waste to the household level still has the potential to increase demand on many municipal waste management programs, as commercial waste is often managed independent from municipalities.

Consistent with previous research, larger households with more occupants and/or children generated more food waste than smaller households [21–25]. The inclusion of more 3–5 person households and fewer 1–2 person households when compared to census data was expected as the sample excluded households in multi-unit buildings (e.g., apartments) which typically have fewer occupants. Overall, the socio-economic variables included in this study were found to be weak determinants of household food waste. No significant relationships were observed between household income and any of the dependent food waste variables (total food waste, total avoidable food waste, and total unavoidable food waste). Only one significant relationship was observed between housing tenure, specifically owning a home outright, and any of the dependent food waste variables. Home ownership was negatively and significantly correlated with total avoidable food waste, suggesting that respondents who own a home sent less avoidable food waste to landfill than respondents who live rent-free, pay rent, or pay a mortgage. This result is consistent with van der Werf et al.'s [52] finding that homeowners are less likely to send avoidable food waste to landfill. It is possible that housing tenure may be a proxy variable for age in this study, as homeowners who are mortgage-free also tend to be older. Older people may waste less food due to generational influences [31,32], or as a result of having more time to manage food while retired [25].

The neighbourhood food environment appears to have some associations with household food waste generation, especially regarding unavoidable food waste. The small, positive, and significant correlation between total unavoidable food waste and proximity to the nearest grocery store suggests that further distance to a grocery store leads to a greater generation of unavoidable food waste at the household level. It is not immediately clear why grocery store proximity is associated with unavoidable food waste generation. Few studies have examined the associations between the neighbourhood food environment and household food waste generation. Significant correlations have been previously identified between density of supermarkets and household food waste, suggesting that households in neighbourhoods with a higher density of grocery stores typically send more food waste to landfill [29]. However, proximity to the nearest grocery store was not found to be a determinant of household food waste in van der Werf et al.'s [29] study. It is speculated that people who live in close proximity to a grocery store are able to make frequent shopping trips and therefore buy less food each trip, whereas those who live further away from a grocery store are more likely to shop less often and purchase more food each trip. However, since the onset of the pandemic, many people in Canada are grocery shopping less frequently and buying more food per trip [17]. It is possible that people who live close to a grocery store are primarily the individuals reporting this change in shopping frequency, whereas people who live further away from a grocery store may be continuing to shop at the same frequency as before COVID-19. If this is the case, then all households, regardless of their proximity to the nearest grocery store, may be shopping at a similar frequency during the pandemic. The households in closer proximity to a grocery store that may have altered their grocery shopping frequency during COVID-19, may have also started to purchase more less-perishable items as a food management technique (e.g., purchasing frozen or canned vegetables instead of fresh produce). Less-perishable food items likely have little to no unavoidable portions, which may be why households in closer proximity to a grocery store have been found to generate less unavoidable food waste during the first wave of the pandemic compared to households in further proximity. Households further away from a grocery store may not have experienced the same impacts to their grocery shopping behaviours, and therefore their unavoidable food waste generation may not have been affected by the pandemic as greatly. Furthermore, online grocery ordering and delivery services have been popularized during the pandemic, which may have implications for household food management and the decoupling of spatial processes in waste generation [53,54]. This speculation may explain why proximity to the closest grocery store is associated with the amount of unavoidable food waste a household sends to landfill; however, this opinion may be unfounded as the sample households were not asked to share their shopping behaviours in this study. Future research is needed to investigate this relationship further and determine if there are any alternative factors

involved.

There was also a positive and significant correlation between total unavoidable food waste and proximity to the closest take-out only vendor, as well as the nearest restaurant, suggesting that further distance to a take-out vendor or a restaurant leads to a greater generation of unavoidable food waste. A possible explanation for this relationship is that further proximity to a take-out vendor or restaurant may lead to less frequent dining out/ordering in and more frequent at-home meal preparation which often includes the generation of unavoidable food waste.

In addition to proximity, the density of food vendors has some associations with total unavoidable food waste. The negative and significant correlations between unavoidable food waste and the density of food vendors within 1,200 metres of a household suggests that the higher the food vendor density, the less unavoidable food waste generated. In particular, unavoidable food waste is negatively and significantly correlated with three specific types of food vendors within 1,200 metres, including grocery stores, take-out only vendors, and restaurants. Similar to the significant proximity variables, a possible explanation for this association is that access to a greater number of food vendors within a 15-minute walk of a household may lead to residents of that household choosing to dine out/order in more frequently and prepare fewer meals at home. Food vendor proximity, on its own, should not be used to determine food access, as not everyone is a customer at the food vendor closest to their home [55,56]. Thus, the significant relationships found between both the proximity and density variables for these three specific types of food vendors (i.e., grocery stores, take-out only vendors, and restaurants) further solidifies the associations between the neighbourhood food environment and unavoidable food waste generation. Future research should continue to explore the relationships between the neighbourhood food environment and household food waste generation to determine how these predictors of household food wasting can be used to develop and strengthen municipal food waste diversion and reduction initiatives.

Overall, this research has shown that previous studies relying on self-reported data may have underestimated food waste generation during the pandemic. This underestimation could lead to potential issues associated with waste collection schedules, landfill capacity and planning, as well as municipal emission reduction targets. As a direct measurement study, this research can be utilized by mid-to large-sized Canadian municipalities to ensure their waste management infrastructure remains effective for the remainder of the COVID-19 pandemic. Additionally, these research findings may serve as critical resources in municipal waste management resiliency planning and preparation for future, unprecedented circumstances. Further direct measurement studies should be conducted across more mid-to large-sized Canadian cities to better understand the potential economic, environmental, and social implications of changes to household food wasting during the COVID-19 pandemic.

5. Conclusion

The quantity and composition of household food waste sent to landfill in London during the first wave of the COVID-19 pandemic was 2.81 kg per sample household per week, of which 52% (1.45 kg) was classified as avoidable and 48% (1.36 kg) as unavoidable. The quantity and composition of household food waste was strongly influenced by household demographic characteristics, including the number of people in a household and the number of children in a household, and somewhat influenced by socioeconomic factors, namely housing tenure. Neighbourhood food environment characteristics were also correlated with the quantity and composition of household food waste. Most notably, the proximity to, and density of grocery stores, take-out only vendors, and restaurants influenced the quantity of unavoidable food waste.

As one of the only direct measurement studies of household food waste generation during the COVID-19 pandemic, this study fills a gap in our current knowledge and contributes to the growing body of literature published during the pandemic as food waste scholars continue to better understand the short- and long-term implications COVID-19 has had on household food waste generation around the world. Nevertheless, this study is not without limitations. The study may be limited by self-selection bias. Because the sample is comprised of volunteer households, it is possible that the waste quantities reported in this paper may not be fully representative of the wider London community. Additional direct measurement studies are required to further investigate the impact that COVID-19 has had on household food waste generation in Canada and beyond. Moreover, this study has evaluated household food waste during the first wave of the pandemic. Further research is needed to investigate how the impact of the pandemic may have evolved over time.

This research can be used to improve the management of municipal waste during the remainder of the COVID-19 pandemic and assist with the development of best practices for municipal waste management programs under crisis circumstances. These findings can be leveraged to influence policy aimed at developing new, affordable, and sustainable solutions in the waste management industry as we begin to re-imagine our sense of normality and build more resilient communities in our post-pandemic world.

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CRediT authorship contribution statement

Haley Everitt: Conceptualization, Methodology, Investigation, Data Curation, Formal Analysis, Writing – Original Draft, Writing – Review & Editing, Visualization, Project Administration. **Paul van der Werf:** Conceptualization, Methodology, Resources, Formal Analysis, Writing – Review & Editing, Project Administration. **Jamie A. Seabrook:** Formal Analysis, Writing – Review & Editing. **Alexander Wray:** Resources, Formal Analysis, Writing – Original Draft, Writing – Review & Editing. **Jason A. Gilliland:** Conceptualization, Methodology, Data Curation, Writing – Review & Editing, Supervision, Funding Acquisition. All authors have read and agreed to the published version of the manuscript.

Declaration of competing interest

None.

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