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ORIGINAL PAPER

The Proof Is in the Pudding: Using a Randomized Controlled Trial to Evaluate the Long-Term Effectiveness of a Household Food Waste Reduction Intervention During the COVID-19 Pandemic

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Abstract
To halve per capita global food waste by 2030, policies and programs that effectively reduce household food waste generation are needed. Building upon a previous randomized controlled trial, this study evaluated the long-term effectiveness of the "Reduce Food Waste, Save Money" household food waste reduction intervention by comparing direct measurements of household food waste generated by treatment ($n=47$) and control households ($n=52$) over three time periods. The results indicate that there has been a long-term, sustained 30% reduction of avoidable food waste sent to landfill by treatment households following the implementation of this intervention. Additionally, this study assessed the impact of pandemic circumstances on the quantity and composition of household food waste by comparing direct measurements of food waste generated by the same households before (October 2017) and during (June 2020) the COVID-19 pandemic. During the first wave of the pandemic in Ontario, Canada, study households ($n=99$) sent 2.98 kg of food waste to landfill per week, of which 54% was classified as avoidable food waste, and the remaining 46% as unavoidable food waste. During the pandemic, the generation of unavoidable food waste significantly increased by 65% ($p<0.01$). There were also significant changes to the composition of wasted food, including a 78% increase in avoidable fruit and vegetables ($p<0.01$), a 228% increase in avoidable other food ($p<0.01$), and an 84% increase in unavoidable other food ($p=0.02$).

Keywords Organic household waste · Waste management · Waste characterization · Longitudinal study · Direct measurement

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Introduction

To halve per capita global food waste by 2030 and achieve the United Nations' Sustainable Development Goal (SDG) 12.3, further research is urgently needed to develop effective, feasible, and replicable policies and programs that aim to reduce household food waste generation. This research is particularly important in developed nations, where the majority (57%) of wasted food is estimated to be generated at the household level [1]. Food waste refers to discarded food intended for human consumption [2] and may be comprised of avoidable (i.e., food that was at one time edible) and unavoidable (i.e., food that was never edible) components [3]. Wasting food impacts all three pillars of sustainability: the environment, the economy, and society. Greenhouse gas emissions are released as a by-product of food waste decomposition in an anaerobic landfill environment; however, the environmental consequences of wasting food are felt far beyond landfill emissions. When food is wasted, all the embedded energy used to grow, harvest, transport, prepare, and store that food is also wasted [4, 5]. At the municipal level, food waste places logistical and financial burdens on waste management facilities. At the household level, wasting food results in unnecessary, and often preventable, increased personal expenses [6]. Food waste often signifies poor food distribution systems and works against minimizing food insecurity. It is estimated that one in eight Canadian households are food insecure, meaning that they lack access to sufficient and nutritious food due to financial constraints [7]. While reducing food waste on its own will not eliminate food insecurity, food waste prevention is an important component to achieving equitable food distribution. Food waste prevention and reduction also contributes to achieving a substantial reduction in overall waste generation (SDG 12.5), as a considerable portion (up to 35% [8]) of household waste is food.

Household Food Waste Reduction Interventions

Knowledge-based interventions are the most implemented and studied within pro-environmental behavior research [9]. Despite this prevalence, knowledge-based household food waste reduction interventions have had mixed success (Table 1). Wijnen [10] and van der Werf et al. [6] found that their household food waste reduction interventions resulted in significant decreases (42% and 31%, respectively) in food waste generation post-intervention. Soma et al. [11] evaluated the effectiveness of three household food waste reduction interventions and found that only one, a passive information campaign implemented through a gamification approach, resulted in a marginally significant decrease in food waste generation post-intervention. Another household food waste reduction intervention study found no statistically significant decreases in food waste generation post-intervention [12]. Our current understanding of household food waste reduction intervention efficacy is largely limited by an over reliance on self-reported recall data (e.g., [10, 13–15]) and a lack of longitudinal studies [16, 17]. Consequently, it is unknown if previously studied interventions have resulted in long-term behavioral changes, or if participants reverted to their pre-intervention food wasting behaviors following these short-term, post-intervention evaluations. Due to an overall lack of robust evidence in determining the effectiveness of food waste reduction interventions, Reynolds et al. [16] proposed a standardized guideline for evaluating consumer-level food waste reduction interventions, including monitoring and measuring the outcomes of the intervention using the highest standard of food waste measurement, namely food waste composition studies; reporting results in a manner that

Table 1 Summary of studies evaluating knowledge-based household food waste reduction interventions

Study	Country	Sample size	Food waste measurement methodology	Time of post-intervention measurement	Change in food waste quantity post-intervention
Romani et al. (2018)	Italy	210 participants (G1: pre-test, intervention, & post-test = 57; G2: pre- & post-test = 56; G3: intervention & post-test = 49; G4: post-test = 48)	Food diaries	1 week	G1 (treatment): −47% decrease in avoidable food waste generation ($p < 0.001$) G2 (control): −23% decrease in avoidable food waste generation
Schmidt (2016)	Germany	217 survey respondents (experimental = 108, control = 109)	Survey	4 weeks	Positive intervention effect on the perceived ability to prevent household food waste ($p < 0.01$)
Shaw et al. (2018)	England	60 households (treatment = 40, control = 20)	Food waste composition study	1 week and 2 weeks	−2% decrease to +42% increase in avoidable food waste generation
Soma et al. (2020)	Canada	501 households (information group = 140, community group = 119, game group = 122, control = 120)	Food waste composition study and survey	12 weeks	−13 to −18% decrease in avoidable food waste generation ($p = 0.07$ for game group)
van der Werf et al. (2021)	Canada	112 households (treatment = 54, control = 58)	Food waste composition study	1 month	−30% decrease in avoidable food waste generation ($p = 0.05$)
Wijnen (2021)	The Netherlands	115 survey respondents (tools & motivation group = 41, tools only group = 74)	Survey	2 weeks	−42% decrease in total food waste generation ($p < 0.01$)
Young et al. (2017)	England	2018 survey respondents (intervention groups = 1,549, control = 469)	Survey	2 weeks and 5 months	−9 to −19% decrease in total food waste generation ($p \leq 0.05$)

ensures they are replicable and repeatable; and considering the systemic effects of food waste reduction interventions.

The "Reduce Food Waste, Save Money" Household Food Waste Reduction Intervention

A household food waste reduction intervention called "Reduce Food Waste, Save Money" was developed and pilot-tested on single-family households in London, Ontario, Canada, in 2017 [6]. The theoretical framework underpinning this intervention was Ajzen's [18] theory of planned behavior, a psychology theory designed to predict and understand human behaviors in specific contexts. The "Reduce Food Waste, Save Money" intervention was designed to strengthen perceived behavioral control by providing residents with food literacy messaging that encouraged a reduction in avoidable food waste generation as a means to save money. Study households were provided with an intervention package that included the following items: an explanatory letter, a four-liter reusable food storage container, a "Reduce Food Waste, Save Money" postcard and fridge magnet, freezer stickers, and a grocery list pad. The messaging included tips to improve food planning, purchasing, storage, and preparation, and directed participants to a purpose-built website (www.foodwaste.ca) which included further details and food waste reduction strategies. Further descriptions of the intervention design and materials have been reported in van der Werf et al. [6].

To assess the effectiveness of the intervention, pre- and post-intervention food waste composition studies were conducted. In September 2017 (time 1), prior to the implementation of the intervention, a food waste composition study was conducted to establish a pre-intervention baseline assessment of the quantity and composition of food waste sent to landfill by the study households. Following the audit, the researchers implemented a randomized controlled trial, where the sample households were divided into two categories: treatment and control. Treatment households were then provided with the intervention package. In October 2017 (time 2), a post-intervention food waste composition study was conducted to evaluate the short-term effectiveness of the intervention. As reported in van der Werf et al. [6], treatment households generated 30% less avoidable food waste in time 2, whereas control households that did not receive the intervention generated similar amounts of food waste across both time periods. These results indicate that the intervention was successful as it led to a short-term reduction in the quantity of avoidable food waste sent to landfill by treatment households. Nevertheless, it is unknown if the positive impacts of the "Reduce Food Waste, Save Money" intervention demonstrated in October 2017 were sustained among treatment households over a longer period of time.

Household Food Waste Measurement

To evaluate if a household food waste reduction intervention is effective and sustained over time, researchers must not only compare food waste measurements pre-intervention (i.e., baseline) and post-intervention, but there should also be follow-up measurement periods several weeks, months, and/or years after the intervention has been implemented. There is considerable agreement among food waste scholars that studies relying solely on self-reported recall data, including surveys and food/kitchen diaries, substantially underestimate waste generation [19–24]. For example, the quantity of food waste self-reported in surveys has been found to be underreported by 53% when compared to the quantity of food waste self-reported in food dairies [25], and the quantity of food waste reported in diaries

has been found to be underestimated by as little as 20% [19] and as much as 40% [21, 26] when compared to data collected through the direct measurement of waste composition. Therefore, self-reported methodologies should primarily be used as qualitative tools to help researchers better understand when, why, and how household food wasting occurs, rather than serving as quantitative tools to measure the quantity and composition of food waste.

The direct measurement of waste composition is most often achieved through food waste composition studies. This methodology requires researchers to directly interact with waste samples thereby eliminating the high potential for recall bias observed in studies of self-reported recall data. In communities with curbside waste management programs, household curbside garbage samples are typically collected on a household's municipally designated waste collection day [8]. This allows for the sample collection time to remain unknown to residents involved in the study, thus eliminating any potential for social desirability bias to impact results. Following the sample collection, food waste is manually sorted into various categories and weighed by category to measure the quantity and composition of food waste [27]. Food waste composition studies are often thought to be less feasible than studies of self-reported recall data [28]. Since these studies are typically expensive to conduct, they are generally limited to much smaller samples sizes when compared to surveys. A key component of this study was to follow the same direct measurement approach a third time, 31 months after treatment households received the "Reduce Food Waste, Save Money" intervention, to evaluate its long-term effectiveness. Furthermore, because this study was conducted during the COVID-19 pandemic, it also provided an opportunity to determine if pandemic circumstances have altered the quantity and composition of household food waste.

Household Food Wasting During COVID-19

The World Health Organization declared the COVID-19 outbreak as a global pandemic on March 11, 2020 [29]. As of April 2022, there have been over 500 million confirmed cases, over 6.1 million deaths, and over 11 billion vaccine doses administered globally [30]. The pandemic has transformed many aspects of life, and as a consequence, may have also altered food wasting behaviors. Quested et al. [31] suggested that behaviors resulting in food waste are often more closely related to household food provisioning than waste management. Shifts to food shopping, management, and consumption behaviors during the pandemic, such as changes to how often food is purchased and how much food is bought at once [32–34], may have impacted household food waste generation. However, what this impact has been and perhaps will continue to be is unclear, as recent household food waste measurement findings have been somewhat inconsistent [35, 36].

Several recent studies have examined food wasting and related behaviors during the first year of the pandemic to understand how COVID-19 may have impacted the quantity and/or composition of household food waste (Table 2). Everitt et al. [37] followed a direct measurement methodology and found that Canadian households sent 2.81 kg of food waste to landfill per week during the pandemic, of which 52% was classified as avoidable food waste, and the remaining 48% as unavoidable food waste. Using a self-reported diary methodology, Amicarelli and Bux [38] found that Italian households generated 1.17 kg of food waste per week during COVID-19. Studies relying on self-reported recall data or secondary data in Italy [36], the USA [39], and Malaysia [40] suggest that there has been a decrease in household food waste generation during

Table 2 Summary of studies of household food wasting early in the COVID-19 pandemic

Study	Country	Sample size	Time of data collection (2020)	Food waste measurement methodology	Direction of food waste change	Quantity of food waste (kilograms/household/week)
Aldaco et al. (2020)	Spain	Not applicable	Not reported	Secondary data	Increase	Not reported
Amicarelli & Bux (2020)	Italy	15 households	March to May	Food diaries	Not reported	1.17
Brizi & Biraglia (2020)	India & USA	590 survey respondents	Not reported	Survey	Increase[1]	Not reported
Everitt et al. (2021)	Canada	100 households	June	Food waste composition study	Not reported	2.81
Hassen et al. (2020)	Qatar	579 survey respondents	May to June	Survey	Decrease/no change	Not reported
Ismail et al. (2020)	Malaysia	Not applicable	March to April	Secondary data	Decrease	Not reported
NZWC & LFHW (2020)	Canada	1200 survey respondents	June	Survey	No change	Not reported
Principato et al. (2020)	Italy	1078 survey respondents	March to April	Survey	Decrease	Not reported
Rodgers et al. (2021)	USA	478 survey respondents	April	Survey	Decrease	Not reported
WRAP (2020)	UK	4197 interviewees	April	Interviews	Decrease/ no change	Not reported

[1] Specific to survey respondents with a higher need for cognitive closure (i.e., the desire for definitive answers without ambiguity).

the pandemic. Conversely, a study relying on secondary data (i.e., government report) in Spain [35] and a cross-national, survey-based study in India and the USA [41] suggest that some households may have experienced an increase in food waste generation during COVID-19. Furthermore, studies relying on self-reported data in Canada [33], Qatar [42], and the UK [34] suggest that household food waste generation either has not changed during the pandemic or has decreased in some households while remaining consistent in others. Overall, these early studies have provided a preliminary understanding of how household food waste generation in various geographical settings was impacted within the first year of the pandemic. Nevertheless, further research is needed as most of these early studies are limited by their reliance on indirect measurements of self-reported recall data or secondary data.

Research Questions, Objectives, and Hypotheses

This study will attempt to answer two research questions: (1) Has the impact of the "Reduce Food Waste, Save Money" household food waste reduction intervention been sustained among treatment households over the long-term, during the COVID-19 pandemic situation? (2) How has the COVID-19 pandemic impacted household food wasting?

The specific objectives of this research are twofold: (1) to evaluate the long-term effectiveness of the "Reduce Food Waste, Save Money" intervention by comparing direct measurements of household food waste disposal for the same treatment and control households before and during the COVID-19 pandemic; and (2) to assess the impact of the COVID-19 pandemic on the quantity and composition of household food waste by comparing direct measurements of household food waste disposal for the same households before (October 2017) and during (June 2020) the pandemic. This study builds upon the previous randomized controlled trial intervention study reported in van der Werf et al. [6] by undertaking a comparison of the quantity and composition of food wasted by the study households for an additional, third time period, during the first wave of the pandemic in Ontario, Canada.

This study will test two hypotheses. First, it is hypothesized that the amount of avoidable food waste generated by treatment households will not increase during COVID-19 (June 2020), while the generation in control households will remain consistent between September 2017, October 2017, and June 2020. This would suggest that the intervention has had a long-term, positive impact on avoidable food waste generation. The underlying argumentation for the first hypothesis stems from the significant ($p = 0.05$) reduction in avoidable food waste generation observed in treatment households in October 2017 [6]. Second, it is hypothesized that there will be an increase in the total amount of food waste sent to landfill by all study households (i.e., treatment and control) during the COVID-19 pandemic compared to before the outbreak. The underlying argumentation for this hypothesis steams from preliminary studies exploring changes to food management and wasting behaviors during COVID-19 that have found notable increases to the number of meals prepared and eaten at home during the pandemic situation [32, 34, 43]. A plausible consequence of these behavioral changes is an increase in the generation of household food waste. While some preliminary studies have reported no changes or decreases to the generation of household food waste during COVID-19, most of these results are likely underreported as these studies are limited by their reliance on self-reported recall data.

Material and Methods

This study took place in the mid-sized Canadian city of London, Ontario (population: 383,437) [44]. The City of London operates a two-stream, curbside waste collection program for single-family households, including waste to landfill (i.e., garbage) and recycling (i.e., paper, cardboard, plastic, glass, metal). Households may set out a maximum of three garbage containers per collection cycle. There are no limits on recycling bins. While there is currently no municipal food and organic waste collection program (i.e., green bin) in place, there are an estimated 60,000 backyard composters in use throughout the city [45].

Selection of Study Households

This study targeted households in single-family dwellings and excluded households in multi-unit dwellings with communal garbage disposal and collection. All study households previously completed a food waste survey in which respondents indicated their interest in volunteering to participate in future research. The complete survey methodology has been reported in van der Werf et al. [46]. The survey was completed by 1263 households, of which 418 indicated their interest in volunteering to participate in future food waste research, including having their curbside garbage collected and analyzed. A subset of 160 volunteer households was randomly selected for the pre-intervention baseline audit (see [6] for sample size calculations).

During time 1 (September 2017), a total of 139 curbside garbage samples were successfully collected, with 21 households (or 13% of the original, randomly selected 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. These logistical challenges are not uncommon and therefore were anticipated by the researchers and taken into consideration during sample size calculations. From the 139 households included in time 1, 10 to 12 treatment households were randomly selected for the randomized controlled trial from within each of the City's six municipal waste collection zones, resulting in a total of 66 treatment households. The remaining 73 households, distributed across the six zones, were used as controls. The additional 27 households were missed in time 2 (October 2017) and 13 households were missed in time 3 (June 2020) due to the anticipated reasons noted above (Fig. 1). The final sample in time 3 consisted of 47 treatment households and 52 control households, for a total of 99 study households.

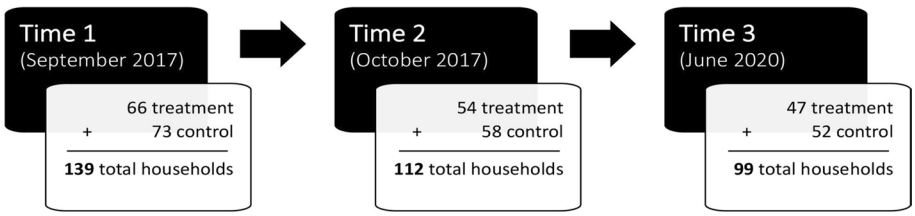

Fig. 1 A breakdown of the number and type of study households included in time 1, time 2, and time 3

Garbage Sample Collection and Analysis

Household garbage samples, which consisted of all the solid waste set out for one curbside garbage collection cycle, were collected and analyzed on a household's municipally designated waste collection day. Each household's garbage sample was labelled with a unique identifier to allow for individual household data to be analyzed independently, while concurrently maintaining participant confidentiality. Following the collection process, the garbage samples were taken to a municipal facility for sorting and analysis. Each household's garbage sample was individually weighed and then analyzed to measure the amount and composition of food waste sent to landfill. Food waste was manually sorted into twelve categories and individually weighed by category to allow for the collection of direct measurements. The food was first classified as either avoidable (i.e., food that was at one time edible) or unavoidable (i.e., food that was never edible), and then further classified into six sub-categories based on food type (Table 3). This methodology was repeated across time 1 (September 2017), time 2 (October 2017), and time 3 (June 2020) to allow for the comparison of results over time.

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 generated across time 1, time 2, and time 3. A split-plot analysis of variance (ANOVA) was used to compare mean differences in total, avoidable, and unavoidable food waste for the within-subjects factor (i.e., time) and between-subjects factor (i.e., treatment/control). A two-sided p-value of < 0.05 was considered statistically significant.

Table 3 Food waste sorting categories

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

Results

Direct Measurements of Household Food Waste in Time 3 (June 2020)

The average total amount of garbage sent to landfill in time 3 was 12.442 kg (SD = 8.777 kg) per household per week. On the waste sample collection day, 92% of study households had set out at least one recycling bin. On average, the total amount of food waste sent to landfill was 2.980 kg (SD = 3.155 kg) per household per week (Table 4), which represents approximately 24% of the total amount of overall garbage sent to landfill. Fifty-four percent of the total amount of food waste sent to landfill by all study households was classified as avoidable (1.613 kg/household/week), while the remaining 46% was classified as unavoidable (1.367 kg/household/week).

Treatment households sent 3.106 kg (SD = 3.051 kg) of food waste to landfill per week, of which 49% was classified as avoidable and 51% as unavoidable. Control households sent 2.867 kg (SD = 3.272 kg) of food waste to landfill per week, of which 59% was classified as avoidable and 41% as unavoidable.

To maximize participant confidentiality and anonymity, only average direct measurements of household food waste are presented in this paper; however, variability in the quantity of food waste sent to landfill by the study households was observed. In time 3, total food waste generation ranged from 0 to 17.119 kg per household per week, total avoidable food waste generation ranged from 0 to 13.154 kg per household per week, and total unavoidable food waste generation ranged from 0 to 8.712 kg per household per week.

Changes to the Quantity and Composition of Household Food Waste Between Time 1 (September 2017) and Time 3 (June 2020)

Between time 1 and time 3, there were no statistically significant changes to the quantity of total food waste ($p = 0.77$), or total avoidable food waste ($p = 0.27$) sent to landfill by all study households ($n = 99$). There was a significant decrease in the quantity of avoidable bread and baked goods ($p = 0.04$, $\eta^2 = 0.04$) and avoidable fruit and vegetables ($p < 0.01$, $\eta^2 = 0.08$) sent to landfill by all study households in time 3. Additionally, the quantity of avoidable other food ($p < 0.001$, $\eta^2 = 0.12$) wasted by all study households significantly increased. Between time 1 and time 3, there was a significant increase in total unavoidable food waste ($p = 0.01$, $\eta^2 = 0.07$) sent to landfill by all study households, and in particular, the quantity of unavoidable other food ($p < 0.001$, $\eta^2 = 0.11$) significantly increased.

There were no statistically significant interactions observed between the treatment and control groups and the generation of total food waste ($p = 0.17$), total avoidable food waste ($p = 0.09$), and total unavoidable food waste ($p = 0.06$) between time 1 and time 3.

Changes to the Quantity and Composition of Household Food Waste Between Time 2 (October 2017) and Time 3 (June 2020)

Between time 2 and time 3, there were no statistically significant changes to the quantity of total food waste ($p = 0.08$), or total avoidable food waste ($p = 0.97$) sent to landfill by all study households. There was a significant increase in the quantity of avoidable other food ($p < 0.01$, $\eta^2 = 0.09$) sent to landfill by all study households in time 3. Between time 2 and

Table 4 Average weight of food waste sent to landfill by sample households (kilograms/household/week) in time 1 (September 2017), time 2 (October 2017), and time 3 (June 2020)

Food categories	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 3 Mean (SD)	Time 1 to 3 % Change	Time 2 to 3 % Change
Treatment households ($n = 47$)					
Avoidable food waste					
Bread & baked goods	0.440 (0.638)	0.316 (0.390)	0.238 (0.312)	− 45.9	− 24.6
Dairy	0.046 (0.137)	0.038 (0.106)	0.087 (0.188)	89.1	128.4
Dried food	0.282 (0.517)	0.243 (0.592)	0.232 (0.402)	− 17.7	− 4.6
Fruit & vegetables	1.203 (1.555)	0.741 (1.027)	0.647 (0.864)	− 46.2	− 12.7
Meat & fish	0.147 (0.236)	0.133 (0.236)	0.125 (0.209)	− 15.0	− 6.2
Other food	0.049 (0.096)	0.028 (0.115)	0.195 (0.327)	298.0	600.8
Total	2.165 (2.331)	1.498 (1.604)	1.523 (1.621)	− 29.7	1.6
Unavoidable food waste					
Bread & baked goods	-	-	-	-	-
Dairy	0.001 (0.003)	-	-	− 100.0	-
Dried food	-	-	-	-	-
Fruit & vegetables	0.923 (1.272)	0.520 (0.756)	1.126 (1.413)	22.0	116.3
Meat & fish	0.213 (0.318)	0.115 (0.263)	0.257 (0.423)	20.7	124.4
Other food	0.088 (0.115)	0.122 (0.238)	0.200 (0.272)	127.3	64.7
Total	1.225 (1.438)	0.757 (0.916)	1.583 (1.776)	29.2	109.3
Total food waste	3.390 (3.343)	2.255 (2.103)	3.106 (3.051)	− 8.4	37.7
Control households ($n = 52$)					
Avoidable food waste					
Bread & baked goods	0.396 (0.536)	0.348 (0.439)	0.325 (0.514)	− 17.0	− 6.6
Dairy	0.035 (0.082)	0.075 (0.148)	0.059 (0.162)	68.6	− 21.5
Dried food	0.166 (0.274)	0.197 (0.459)	0.134 (0.311)	− 19.3	− 32.0
Fruit & vegetables	0.668 (0.787)	0.702 (1.112)	0.500 (1.030)	− 25.1	− 28.8
Meat & fish	0.153 (0.325)	0.221 (0.670)	0.243 (0.451)	58.8	10.1
Other food	0.141 (0.329)	0.161 (0.336)	0.434 (0.966)	207.8	169.3
Total	1.559 (1.681)	1.704 (1.844)	1.695 (2.656)	8.7	− 0.6
Unavoidable food waste					
Bread & baked goods	-	-	-	-	-
Dairy	-	-	-	-	-
Dried food	-	-	-	-	-
Fruit & vegetables	0.641 (0.893)	0.565 (0.770)	0.826 (1.413)	28.9	46.2
Meat & fish	0.130 (0.204)	0.218 (0.486)	0.130 (0.169)	0.0	− 40.3
Other food	0.100 (0.139)	0.106 (0.175)	0.216 (0.417)	116.0	103.8
Total	0.871 (0.939)	0.889 (0.960)	1.172 (1.551)	34.6	31.9
Total food waste	2.431 (2.043)	2.593 (2.277)	2.867 (3.272)	17.9	10.6
All households ($n = 99$)					
Avoidable food waste					
Bread & baked goods	0.417 (0.584)	0.333 (0.415)	0.284 (0.430)	− 31.9*	− 14.7
Dairy	0.040 (0.111)	0.057 (0.130)	0.072 (0.174)	80.0	25.6
Dried food	0.221 (0.410)	0.219 (0.524)	0.180 (0.359)	− 18.6	− 17.6
Fruit & vegetables	0.922 (1.237)	0.721 (1.067)	0.570 (0.953)	− 38.2**	− 21.0
Meat & fish	0.150 (0.285)	0.179 (0.511)	0.187 (0.361)	24.7	4.4

Table 4 (continued)

Food categories	Time 1 Mean (SD)	Time 2 Mean (SD)	Time 3 Mean (SD)	Time 1 to 3 % Change	Time 2 to 3 % Change
Other food	0.097 (0.251)	0.098 (0.258)	0.320 (0.742)	229.9***	227.5**
Total	1.847 (2.028)	1.607 (1.728)	1.613 (2.216)	−12.7	0.4
Unavoidable food waste					
Bread & baked goods	-	-	-	-	-
Dairy	0.000 (0.002)	-	-	−100.0	-
Dried food	-	-	-	-	-
Fruit & vegetables	0.775 (1.093)	0.544 (0.760)	0.968 (1.414)	24.9	78.1**
Meat & fish	0.170 (0.266)	0.169 (0.398)	0.190 (0.321)	11.8	12.8
Other food	0.094 (0.128)	0.113 (0.206)	0.209 (0.354)	122.3***	83.9*
Total	1.039 (1.209)	0.826 (0.937)	1.367 (1.666)	31.6**	65.5**
Total food waste	2.886 (2.766)	2.432 (2.191)	2.980 (3.155)	3.3	22.5

Three decimal places have been included to allow for comparison to the nearest gram.

* $p<0.05$, ** $p<0.01$, *** $p<0.001$.

time 3, there was a significant increase in total unavoidable food waste ($p<0.01$, $\eta^2=0.09$) sent to landfill by all study households, and in particular, the quantity of unavoidable fruit and vegetables ($p<0.01$, $\eta^2=0.08$) and unavoidable other food ($p=0.02$, $\eta^2=0.06$) significantly increased.

There were no statistically significant interactions observed between the treatment and control groups and the generation of total food waste ($p=0.36$), total avoidable food waste ($p=0.94$), or total unavoidable food waste ($p=0.13$) between time 2 and time 3. However, there was a significant interaction between the treatment group and the generation of unavoidable meat and fish over time ($F=5.727$, $p=0.02$, $\eta^2=0.06$), compared to the control group, suggesting an increase in the generation of this unavoidable food waste category by treatment households in time 3.

Discussion

The Long-Term Impact of the "Reduce Food Waste, Save Money" Intervention

As reported in van der Werf et al. [6], between time 1 and time 2, treatment households significantly reduced their avoidable food waste generation by 31% ($p=0.03$). There was no significant change in the quantity of avoidable food waste sent to landfill by control households in this same period. These results indicate that the "Reduce Food Waste, Save Money" household food waste reduction intervention had a positive, short-term impact on the generation of avoidable food waste. While treatment households did not continue to further reduce their avoidable food waste generation after time 2, treatment households did continue to generate a similar amount of avoidable food waste in time 3 (1.523 kg per household per week) compared to time 2 (1.498 kg per household per week). During this same time period, there was no significant change to the quantity of avoidable food waste generated by control households. The insignificant change in avoidable food waste generated by treatment households between time 2 and time 3 indicates a long-term, sustained

30% reduction of avoidable food waste following the implementation of the "Reduce Food Waste, Save Money" intervention, which supports the first hypothesis of this study. While the study's methodology did not allow for potential effects of the intervention and the COVID-19 pandemic to be disentangled, the lack of significant changes in the generation of avoidable food waste in treatment and control households between time 2 and time 3 suggest that neither the intervention nor pandemic circumstances significantly impacted the generation of total avoidable food waste in this sample.

In time 3, all study households wasted significantly less avoidable bread and baked goods ($p=0.04$) and avoidable fruit and vegetables ($p<0.01$) compared to time 1. This optimistic finding suggests that households are willing and able to considerably reduce categories of food waste that have been widely identified as the most commonly wasted types of food [22, 47–49]. Despite this success, all study households sent significantly more avoidable other food to landfill in time 3 than they did in time 2 ($p<0.01$) and time 1 ($p<0.001$). The substantial increase in the generation of avoidable other food could be a consequence of the COVID-19 pandemic. A large portion of the waste classified as avoidable other food was leftover meals (e.g., casseroles and stews) comprised of several ingredients that were not feasible to manually separate during the waste composition study. With a probable increase in the number of meals prepared at home during the pandemic [32, 34, 43], it is likely that the increase in wasted leftover meals is a consequence of residents having to manage more leftovers than usual. Researchers designing future household food waste reduction interventions should consider including messaging and/or solutions to encourage residents to shift their perspectives towards the treatment of leftovers so that more of these meals are consumed rather than thrown away (e.g., freezing leftovers can create ready-made meals for the future). Furthermore, the design of future household food waste reduction interventions should aim to evaluate alternative food waste reduction strategies that have yet to be extensively tested.

In accordance with Reynolds et al.'s [16] standardized guideline for consumer-level food waste reduction interventions, the systemic environmental effects of the "Reduce Food Waste, Save Money" intervention are unknown. It is hoped that this sustained decrease in avoidable food waste generation has benefitted the environment, especially because the City of London is one of the largest Canadian municipalities currently without a curbside organic collection program to divert food waste from landfill. It is thought that treatment households may have saved some money from reducing their avoidable food waste generation since the implementation of the intervention in October 2017; however, the amount of money that residents may have saved and what that money may have been used to purchase is unknown to the researchers. Future household food waste reduction interventions should consider how these systemic effects could be better measured and mitigated.

How the Quantity and Composition of Household Food Waste Changed During COVID-19

During the COVID-19 pandemic, there was a significant increase in the quantity of unavoidable food waste sent to landfill by all study households compared to before the outbreak (between time 2 and time 3, $p<0.01$). With more people working and/or learning from home during the pandemic, there have been notable changes to at-home food preparation and management. Some consumers have reported an increase in the time they spend cooking [42], others have decreased how often they purchase take-out meals from restaurants [34], and overall, the number of meals prepared and eaten at home has considerably increased during the pandemic [32,

34, 42, 43, 50]. An increase in at-home meal preparation is likely associated with an increase in unavoidable food waste, as it is a by-product of preparing some types of food, such as fresh fruit and vegetables with inedible cores, pits, and peels. The 65% (time 2 to time 3, $p < 0.01$) increase in unavoidable food waste generation observed during the pandemic suggests that households in this study area (London, Ontario) are also likely preparing and consuming more meals at home than they did prior to the outbreak. However, the consumption of more meals at home may have also resulted in a reallocation of food waste generation [35, 37]. Prior to the pandemic, individuals likely generated food waste outside their home in other spaces where meals are consumed, such as at school, work, and restaurants. During the pandemic, if the majority, or perhaps all, of the meals an individual consumed were at home, then the entirety of their personal food waste generation would be accounted for within their home. The overall impact of COVID-19 on the generation of food waste beyond the household level depends on how much reallocation there may have been from non-residential spaces (e.g., office buildings, retail shopping establishments, and restaurants) to individual households.

There have also been reported changes to the types of food being purchased and consumed during the pandemic. Some regions have noted a shift towards unhealthier diets, including an increase in the consumption of alcoholic beverages and processed snack foods [35]. Other regions have reported shifts towards healthier diets, with increases in the consumption of fruit, vegetables, and other healthy foods, and decreases in the consumption of processed foods such as candy, cookies, and pastries [42]. Based on the composition of the food waste households sent to landfill during the pandemic, it appears that food preferences in London, Ontario, may have shifted towards "healthier" choices. Study households generated 78% more unavoidable fruit and vegetables ($p < 0.01$) during the COVID-19 pandemic compared to before the outbreak in time 2. This result may be the outcome of residents preparing more meals that include fruit and vegetables and then consuming (rather than wasting) these meals. However, an increase in unavoidable fruit and vegetable waste may also be due to a change in the types of produce residents are purchasing, as some fruit and vegetables have unavoidable portions (e.g., watermelon rinds, banana peels, cobs of corn) while others do not (e.g., raspberries, celery hearts).

While some significant changes to the quantity and composition of household food waste generation were observed during the COVID-19 pandemic, the study's second hypothesis is not supported by these results, as a significant change to the quantity of total food waste generated by all study households was not observed.

Conclusion

As one of the only studies to measure the long-term effectiveness of a household food waste reduction intervention using a direct measurement methodology of sorting and weighing discarded food by categories, this research fills a gap in our current understanding of food waste reduction intervention efficacy. Nevertheless, this study is not without limitations. The waste quantities reported in this paper may not be fully representative of the wider London, Ontario community, as the sample is comprised of volunteer households and therefore may be limited by self-selection bias. Additionally, the food waste measurement methodology only allowed for the measurement of food waste sent to landfill. Food waste that was discarded through alternative methods, such as backyard composters, drain disposal, or feeding pets, was not captured.

It appears that the proof is in fact in the pudding. While the "Reduce Food Waste, Save Money" intervention did not lead to an exponential reduction in avoidable food waste generation over time,

the results from this study indicate that there has been a long-term, sustained 30% reduction in avoidable food waste sent to landfill by treatment households following the implementation of the intervention in October 2017. This finding supports the study's first hypothesis and demonstrates that the intervention has the potential to continue to have a positive impact on the generation of avoidable food waste for at least 31 months post-intervention. Future research should evaluate the effectiveness of this intervention in other regions. Additionally, to halve per capita global food waste in accordance with the United Nation's SDG 12.3, further research is needed to discover a household food waste reduction intervention that is replicable, scalable, feasible, and even more effective than the "Reduce Food Waste, Save Money" intervention.

The second objective of this study was to assess the impact of the COVID-19 pandemic on the quantity and composition of household food waste. During the first wave of the pandemic in Ontario, Canada, there was a 65% increase in the quantity of unavoidable food waste sent to landfill by the study households compared to before the outbreak. There were also significant changes to the composition of food waste sent to landfill, including a 78% increase in avoidable fruit and vegetables, a 228% increase in avoidable other food, and an 84% increase in unavoidable other food. Despite these significant changes, the study's second hypothesis is not supported by these results as there was no significant change to the generation of total food waste observed. Further direct measurement studies should be conducted to explore how pandemic circumstances may have impacted the quantity and composition of household food waste generated in other geographic regions and within other waves of the COVID-19 pandemic.

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Data Availability Not applicable.

Declarations

Ethics Approval The methodology for this study was approved by the Non-Medical Research Ethics Board of the University of Western Ontario (#108899).

Informed Consent Informed consent was obtained from all sample households included in the study.

Competing Interests The authors declare no competing interests.

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