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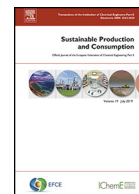
Research article

Behavioral impacts on residential food provisioning, use, and waste during the COVID-19 pandemic

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ABSTRACT

The COVID-19 pandemic caused unprecedented disruptions to food systems, leading to both food shortages and food waste across the supply chain. These disruptions have, in turn, altered how people consume and then ultimately discard food. To better understand these impacts, their underlying drivers, and their sustainability implications, this study surveyed U.S. consumers about food purchasing, use, and waste behaviors during the pandemic. Survey respondents reported an increase in overall food purchases and a slight decrease in food waste generation due to the pandemic, but the linkages between these outcomes and underlying behaviors were complex. For instance, reduced household food waste was significantly correlated with an increase in behaviors such as meal planning, preserving foods, and using leftovers and shelf-stable items. On the other hand, behaviors aimed at self-sufficiency, including bulk purchasing and stockpiling, were significantly correlated with increased food purchase, which in turn led to increased waste. Results may offer insight for future resource and waste management strategies. For example, over 60% of respondents who started or increased efficient food use behaviors stated an intent to continue these activities after the pandemic. In contrast, less than 10% of respondents reported that they began or increased separating or composting food waste during the pandemic, and many stopped altogether due to suspension of local curbside composting services. Findings suggest that it may be easier to shift food consumption and use behaviors but more challenging to alter food waste separation behaviors, particularly those influenced by external factors, such as infrastructure that may be vulnerable to disruption. Identifying ways to facilitate ongoing behavior change and foster robust food waste management systems can contribute to resilience of food systems now and once the immediate threat of the pandemic has subsided.

1. Introduction

The global food system is under immense pressure due to growing population, declining resource availability, and losses that span food production, distribution, and consumption. In the U.S. alone, the food supply chain consumes over 40% of all freshwater withdrawals (Dieter et al., 2018) and over 12% of the entire national energy budget (Canning et al., 2017). But much of the food produced with these resources is never ultimately consumed, resulting in losses and wastes that accumulate across the entire food supply chain. Of the estimated 125-160 billion pounds of wasted food in the U.S. annually (Gunders, 2017), only about 25 percent is recovered or recycled (U.S. EPA, 2018), with the remainder typi-

cally disposed into landfills. Anaerobic degradation of food waste in the landfill environment contributes to the release of greenhouse gases and resultant climate change impacts (Levis and Barlaz, 2011). However, food loss and waste also represent a broader sustainability challenge, magnifying social and economic impacts associated with inequitable food access, public health disparities, and economic losses associated with the value of food never consumed (FAO, 2019).

Sustainability challenges in the food system have become even more evident and immediate due to the far-reaching disruptions created by the COVID-19 pandemic. In some cases, past efforts to make food production more efficient and less wasteful have actually reduced systemic resilience to sudden shifts (Pollan, 2021). For example, food production systems optimized for established patterns of demand and distribution into food service sectors could not quickly respond when schools, restaurants, and hospitality firms were suddenly closed (Chenarides et al., 2020). On the other

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hand, grocery stores saw a drastic uptick in demand as consumers sought to stockpile food and other commodities (Garbe et al., 2020). Mismatched supply and demand led to unsold crops and production waste (Yaffe-Bellany and Corkery, 2020), scaled-up manufacturing operations that left workers vulnerable to COVID-19 exposure and illness (Luckstead et al., 2020), and economic uncertainty associated with food price volatility (Akter, 2020). Economic impacts were further magnified by pandemic-related job loss (CRS, 2020; Parker et al., 2020), leading to rising food insecurity (Schanzenbach and Pitts, 2020) and emergence of new food assistance programs (Jablonski et al., 2020).

Understanding the ramifications of the pandemic on food systems is particularly important at the household level, as this is the point where a significant fraction of food is wasted and also the point where waste reduction can create the greatest economic benefits (ReFED, 2016). Some key shifts in household behavior have been observed during COVID-19, including increased use of online shopping and decreased consumption of food away from home (Ellison et al., 2020). Preparing and eating more food at home is anticipated to create multiple, potentially counteracting, drivers of food waste generation (Ikiz et al., 2021). For example, home cooking may lead to increased preparation waste, such as vegetable scraps and trimmings (Quested and Murphy, 2014), but decreased plate waste (Roe et al., 2018), particularly as consumers gain additional time and practice with food preparation and preservation techniques (Amicarelli and Bux, 2020; Roe et al., 2020).

Even with a growing body of literature on COVID-19 impacts to food systems, the fundamental changes to household food provisioning, use, and waste during the pandemic are still poorly understood, as are the underlying beliefs, behaviors, and controls that influence these outcomes. Here, we present a survey-based study of U.S. consumer behavior related to both the acquisition and disposal of household food resources, focusing on a case study of New York State. We examine the statistical interrelationship of the attitudes, intentions and behaviors associated with food acquisition, consumption, disposal and waste management during the pandemic and identify the major underlying drivers or 'factors' in the surveyed population that related to changes in their food purchasing and waste behavior during COVID-19. Ultimately, this research aims to contribute to the limited yet growing body of literature (see Section 2) that explores the practical implications of food supply chain impacts during the COVID-19 pandemic. It also serves as a unique empirical documentation of human behavior change in a general response to major socioeconomic and sociopolitical disruption in an increasingly interconnected and resource-limited world.

2. Literature review

Over 100 million tons of food are estimated to be wasted each year in the U.S., from industrial, commercial, institutional, and residential sectors (U.S. EPA, 2018). The sustainability implications of wasted food have been widely defined by past literature, particularly relative to the losses of water, fertilizer, and land resources (Kummu et al., 2012), embodied energy (Cuéllar and Webber, 2010), greenhouse gas emissions (Heller and Keoleian, 2015), economic costs (Buzby and Hyman, 2012), and nutritional value (Spiker et al., 2017) associated with food that is never consumed. Further, traditional management of food waste, primarily through landfilling in the U.S., leads to climate impacts associated with the release of carbon dioxide and methane (Bernstad et al., 2016; Bernstad and la Cour Jansen, 2012). However, mitigation of these impacts is possible through alternative food recovery pathways, including rescue and redirection of high quality food surplus (Reynolds et al., 2015) or recycling or composting wasted food to recover the energy and nutrients it contains (Ebner et al., 2018).

Consumers play a key role in both the generation of food waste and in realization of potential solutions (Quested et al., 2013). While the majority of U.S. consumers say that they are knowledgeable about ways to reduce food and bothered by the act of throwing food away (Neff et al., 2015), national estimates show that over 40% of food waste occurs at the household level (ReFED, 2016). One case study estimated that as much as 70% of household food waste may in fact be edible food that could have been consumed (McDermott et al., 2019), although overall generation quantity and composition are likely to vary seasonally (Armington et al., 2020), regionally (Secondi et al., 2015), and in households with varied socio-political characteristics (Swami et al., 2011), income levels (Filipová et al., 2017) and attitudes surrounding food price and convenience (Aschemann-Witzel et al., 2018).

Multiple drivers of household food waste have been identified, including over-reliance on food appearance to determine quality (Aschemann-Witzel et al., 2015; Parizeau et al., 2015), confusions surrounding food date labelling (Van Boxstael et al., 2014; Watson and Meah, 2012), and purchase of food products that were later forgotten (Wansink et al., 2000) or not used before expiring (Katajajuuri et al., 2014). These factors are compounded by consumers' lack of knowledge about how much food waste they produce (Richter, 2017), ecological impacts of food waste (Principato et al., 2015), and methods to minimize waste in the home (Visschers et al., 2016). Several studies have established effective methods for reducing household food waste, including taking inventory of food in the home prior to shopping (Farr-Wharton et al., 2014), following an established shopping routine that reduces excess or impulsive purchases (Schmidt, 2016; Stefan et al., 2013), reusing leftovers (Stancu et al., 2016), and developing food use and preparation skills, such as batch cooking and food preservation (Graham-Rowe et al., 2014).

Similar themes have begun to emerge from nascent literature regarding food use and waste during COVID-19. Case studies in specific regions show that consumers have increased a number of behaviors associated with efficient food use and waste minimization, such as using a shopping list, finding creative recipes to use available ingredients, and preserving food for longer use (Jribi et al., 2020; Roberts and Downing, 2020). Consumers have changed the types of food consumed, towards healthier options in some regions (Ben Hassen et al., 2020) and less nutritional diets in others (Batlle-Bayer et al., 2020). During the pandemic, consumers report spending greater time, attention, and effort on food preparation in the household (Amicarelli and Bux, 2020), including cooking as a form of entertainment (Ben Hassen et al., 2020) and efficient use of food to accommodate less frequent shopping trips (Principato et al., 2020). However, the linkage between behavior changes influenced by the pandemic and ultimate food waste generation have not been fully explored, particularly given the tension between consumer actions that may both increase and decrease waste through different mechanisms (Ikiz et al., 2021). Further, these issues have not yet been widely studied in the U.S., even though we anticipate outcomes will differ from case studies focused on other countries, due to variability in pandemic responses and quarantine requirements (Ellison et al., 2020).

This study aims to address these knowledge gaps by documenting behavioral changes and their impacts on food consumption and waste with specific focus on a U.S. case study. The study has three objectives: 1) to evaluate household-scale changes in the nature and amount of food purchases and wastes during COVID-19; 2) to identify, extract, and describe latent variables associated with food-related behaviors and attitudes and understand their influence on resultant food waste generation; and 3) to assess whether short-term effects of COVID-19 may ultimately lead to longer-term interventions that can minimize household food waste. Lessons learned from this devastating and disruptive epoch may provide new in-

sight into strategies that eventually enhance food supply chain sustainability.

3. Methods

This study was conducted via survey of individuals about their activities, beliefs, and observations related to household food use and waste during the pandemic. The survey was focused on a case study of New York State (NYS), to control for potential variability in responses due to the uneven timing and magnitude of the pandemic spread across the U.S. and state-specific policy responses, such as travel restrictions, business shutdowns, and public health mandates. NYS was selected for this case study because it experienced the most significant impacts early in the COVID-19 pandemic spread across the country. A previous case study in Japan demonstrated that residents of regions most severely impacted by the pandemic had greater awareness of food use and were more likely to change purchase and preparation behaviors in ways that might minimize waste (Qian et al., 2020). NYS also took decisive state-wide action in response to the pandemic, which included mandates that directly impacted food purchase and consumption, including mandatory masking at retail facilities and restaurant and business closures and restrictions, which shifted food purchase and consumption to the home environment. The state also "reopened" over a known time frame for specific zones (NYS, 2020), which could be later matched to respondent zip codes to assess regional variability in survey responses.

3.1. Data collection

Data were collected by an Internet-based survey developed by the authors and administered in August 2020. The full text of the survey is provided in the Supplemental Information (SI). The survey protocol and informed consent process were reviewed and approved by the Rochester Institute of Technology Institutional Review Board. The respondents remained anonymous and had no direct contact with the researchers. The survey was created in Qualtrics and administered through Prolific, a web-based platform for online subject recruitment. Subjects were recruited by Prolific through email and web-based notifications to participants who met the eligibility criteria of being residents of New York State and aged 18 years and older. To recruit a sample that was representative of New York State demographics, sub-panels were created in Prolific to balance key demographics, such as respondent gender. Subject recruitment within each sub-panel was halted once the demographic target was met. A total of 300 survey responses were collected, and relative to the total state population, this provided an estimated margin of error of +/- 5.5% with a 95% confidence level.

The survey instrument consisted of 20 questions designed to gain insight into household purchase and waste of food during COVID-19. The survey included a variety of question types, including multiple choice, matrix ratings, and free response. Rated questions used a five-point bipolar scale. In matrix-based questions, the order of row appearance was randomized. Respondents were instructed to answer all questions of the survey relative to the time period between mid-March and mid-July 2020, the time period spanning the first-wave peak of COVID-19 closures and phased reopenings in NYS. Additional demographic characteristics of survey panel members were provided by Prolific. The full text of the survey questionnaire and all raw data collected are also provided as an online dataset (Babbitt, 2020).

The survey instrument had four major parts. First, respondents were asked about food provisioning, including their perception of changes in the amount of food purchased to eat at home, both overall and for specific food types, and the mode by which food was obtained, including changes to online, in-person, subscription, and bulk purchases. This section also included questions regarding purchases of disposable products and packaged food. The second part of the survey focused on food waste, particularly respondent perceptions about changes to the amount and types of wasted food produced in their households. This section also assessed how household food waste was being managed prior to COVID-19 and any changes that occurred during the pandemic, such as starting, increasing, decreasing, or stopping the use of home or curbside composting.

In the third part of the survey, respondents were queried regarding changes in the ways food was used in the home during COVID-19. Specific behaviors assessed included preserving food, use of leftovers, meal planning, and efforts to save money on food costs. These behaviors were selected from strategies commonly recommended to consumers to reduce food waste at home (U.S. EPA, 2020). Participants were also asked about overarching concerns related to food during COVID-19, such as concern that the grocery store would not have food that was needed, financial strain from higher food prices, and fear of exposure to coronavirus through food. The final part of the survey focused on broader beliefs about COVID-19, including views about the pandemic threat to personal, public, and economic health and any direct economic impacts borne by the household. Questions in this section were informed by the USDA Guide to Measuring Household Food Security, the Census Household Pulse Survey, and the Pew Research Center tracking survey on public reactions to COVID-19.

3.2. Data analysis

Survey responses were extracted from Qualtrics into Microsoft Excel and examined for completeness and quality. Less than 4% of responses were flagged for removal based on respondents that "straight-lined" answers across multiple sets of questions or entered nonsensical text into free response fields. All subsequent data analysis was carried out in Rstudio (RStudio Team, 2020) using R version 4.0.3 (R Core Team, 2020) with custom scripts using the following R packages and their dependencies: psych (Revelle, 2020), likert (Bryer and Speerschneider, 2016), dplyr (Wickham et al., 2020b), tidyr (Wickham, 2020), ggplot2 (Wickham et al., 2020a), gridExtra (Auguie, 2017), RColorBrewer (Neuwirth, 2014), and cowplot (Wilke, 2020). Supplementary documentation and R scripts are provided in the online dataset (Babbitt, 2020). The initial data analysis included estimation of summary descriptive statistics and graphing select variables. Descriptive analyses of bipolar responses related to food purchasing, use, and waste behaviors and beliefs were analyzed and plotted using the likert package in R. Differences in food purchasing and waste outcomes relative to categorical variables (income, income loss, gender, household size, etc.) were analyzed using one-way ANOVA and the Tukey's HSD test for post-hoc comparison.

Composite indicators for food purchasing and food waste generation were created to account for the multiple ways in which these outcomes were measured. Namely, the composite indicator for food purchasing was the addend of a respondent's overall assessment of the change in food purchases in general and the individual measures related to changes in purchasing of specific kinds of food (meat, dairy, canned goods, frozen foods, fresh fruit and vegetables, and single-serve pre-packaged items). Similarly, the composite indicator for food waste generation summed the respondent's overall assessment of change in food wasted and the individual measures related to specific types of food waste potentially generated (failed recipes, unused ingredients, uneaten leftovers, food that spoiled or expired, or vegetable trimmings). A chi-square test of independence was used to assess association between reported food purchase and food waste outcomes.

3.3. Exploratory factor analysis and correlation tests

The response set was also analyzed to identify commonalities in consumer behaviors or beliefs that may explain observed changes to food purchasing and waste during COVID-19. First, an exploratory factor analysis (EFA) was used to reduce the individual response data to a manageable set of intercorrelated latent factors that might describe broader patterns in consumer behavior. The EFA was carried out with the psych package in R using the maximum likelihood (ML) method applied to a polychoric correlation matrix, with a subsequent 'oblimin' rotation to enhance factor loadings on the initial input variables (i.e., direct responses to the survey). The oblique rotation was selected to maintain interaction among the factors. For example, beliefs about COVID-19 impacts on household finances may correlate with behaviors aimed at conserving food or saving money on food purchases. It was observed that changes in the factoring method and/or rotation did not fundamentally alter the number of significant factors or their loadings, suggesting that the results presented here are not an artifact of the methods chosen. Parallel analysis was used to determine that seven factors were required, and subsequent results demonstrated that all seven factors had eigenvalues greater than one. Cronbach's alpha of the polychoric correlation matrix was 0.82, representing good internal consistency. A post-hoc correlation analysis was conducted on the factor scores extracted from the EFA and the composite indicators of observed changes to food purchasing and food waste described above. These correlation tests used Spearman's rank correlation coefficient with an alpha level of 0.05, with p-values adjusted for the number of multiple tests using the Holm correction.

4. Results and discussion

The results presented here describe and analyze key changes in behaviors and beliefs related to food provisioning, use, and waste during COVID-19 as observed in a sample of 300 New York State residents (demographics provided in SI Table S1). Results also explore the relationships between these factors and the resulting changes to overall food purchase and waste generation outcomes as well as the potential for minimizing and managing wasted food beyond the pandemic.

4.1. Consumers increased food-focused activities during COVID-19

Survey responses indicated that the majority of respondents made significant shifts to both the way they obtained food and the way they used it in their household during COVID-19. The largest increases were observed in activities such as cooking meals at home, purchasing food in bulk quantities, and stockpiling food and cooking supplies (Fig. 1). Over half of respondents reported increased use of online shopping, a finding consistent with a longitudinal study (Ellison et al., 2020) on food purchases by a broader set of U.S. consumers. Respondents also reported modest increases in efforts to grow their own food, which has been previously suggested as a path towards increasing food security during the pandemic (Lal, 2020). In contrast, a significant decline was observed for in-person grocery shopping. The most notable changes, however, were in the ways that respondents used foods in their households, specifically through behaviors expected to conserve available food and avoid the need for purchasing additional groceries, consistent with past research on household food waste minimization (Graham-Rowe et al., 2014; Stancu et al., 2016; Visschers et al., 2016). Over 60% of all respondents increased meal planning prior to grocery shopping, finding recipes to use food already at home, and seeking ways to preserve food and save money on food purchases. Almost 30% of respondents even indicated that they were more likely to eat foods past their expiration dates during the pandemic.

Many of the behaviors that increased during the pandemic are related to the strategies commonly recommended to reduce residential food waste (Hebrok and Boks, 2017; U.S. EPA, 2020). Behavioral changes are consistent with, and in some cases even greater than, outcomes observed in a study on U.K. consumers earlier in the pandemic (Roberts and Downing, 2020). This comparison may suggest that efficient food use behaviors are persisting over the duration of the pandemic or are magnified in areas like NYS, where pandemic closures were immediate and severe. However, it is unlikely that environmental motivations for waste minimization were the primary drivers for these shifts (Neff et al., 2015). Instead, we expect that food conservation and preservation actions were motivated by overall concern held by individuals about COVID-19 impacts to health, finances, and food supplies (Jribi et al., 2020). In fact, about 80% of respondents indicated they were worried the grocery store would not have the foods they wanted or needed or that they felt concerned about COVID exposure through food purchases (SI Figure S1). Over half of all respondents reported that they spent more time thinking about food than normal, reported financial strain due to higher food prices, and believed that COVID-19 was a major threat to their household finances. Further, 22% said they strongly agreed with the sentiment "I worried food would run out before I was able to buy more," consistent with past research on pandemic food insecurity (Schanzenbach and Pitts, 2020). Two thirds of all NYS respondents reported a temporary or ongoing income loss or a fear that this loss would occur in the future, findings similar to those documented nationally by the U.S. Census Pulse Surveys (Parker et al., 2020).

4.2. Behavioral impacts changed overall food purchasing and food waste generation

Considering the range of behavioral changes observed, the question then arises if there were resulting changes in the total amounts of food coming into households or ending up as waste (Fig. 2). Results indicate an increase in food purchases (mean = 0.49 on an ordinal scale from -2 to +2) and a slight decrease in food waste (mean = -0.29 on the same scale), as it was assessed here through respondent's self-reported observations. The frequencies of responses regarding the observed changes in food purchase and food waste were strongly interdependent (χ^2 = 58.08, df =16, p <0.001), in that respondents who consumed more food generated more waste, and vice versa. However, mean increases in overall food purchase differed significantly for respondents in different baseline income brackets (F-value = 4.8, p-value = 0.0001), for respondents who experienced income loss (F-value = 2.9, p-value = 0.04), and for respondents whose household size was altered during the pandemic (F-value = 6.0, p-value = 0.003). Post-hoc comparison of ANOVA results showed significant pair-wise differences in food purchasing occurred for respondents in the highest three baseline income brackets (above $80,000 per year) compared to respondents in the lowest income bracket (less than $20,000 per year) and for those who experienced temporary income loss relative to those with no income impacts. Mean food purchases were also significantly lower for respondents who had a smaller number of people in their household during COVID-19 compared to those with no change or an increased household size. Full results of these ANOVA and Tukey's HSD tests are provided in the SI (Tables S2-S4). No other significant differences were observed among demographic groups or location within NYS regions.

Results were more varied when considering specific types of food purchased or wasted. Canned goods, frozen foods, meat, and fresh fruits and vegetables all saw relative increases in purchas-
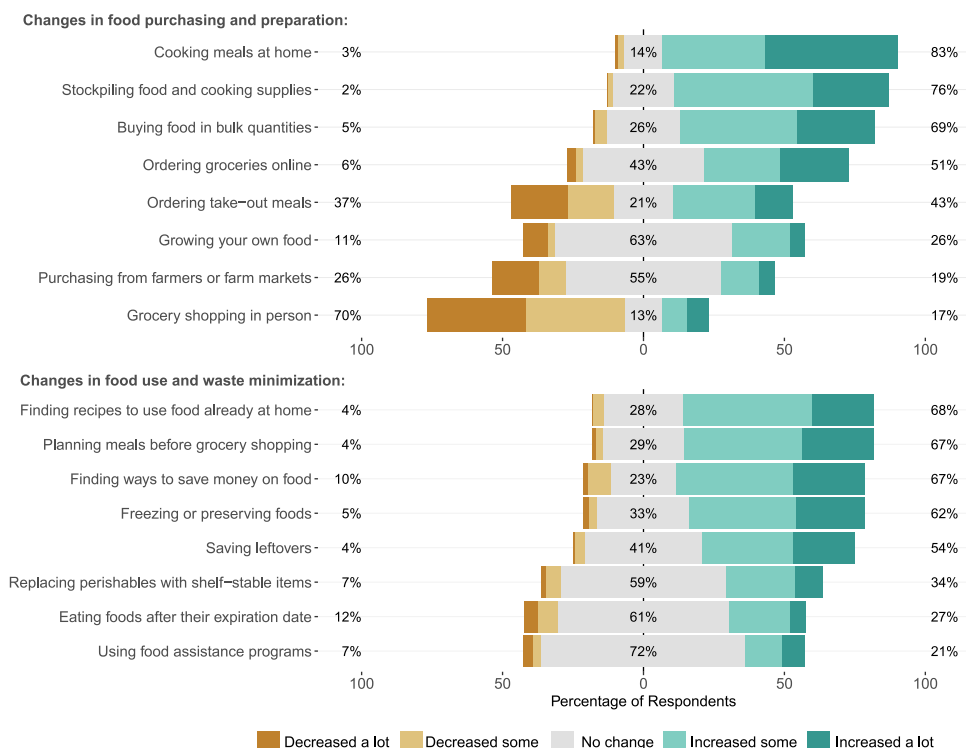
Fig. 1. Relative change in behaviors related to food provisioning (top) and use (bottom) during COVID-19. Results are presented relative to the "no change" scenario shown at the center of the graph. The total percentage of respondents who increased or decreased the behavior to any degree is reported at the right and left of each bar, respectively.
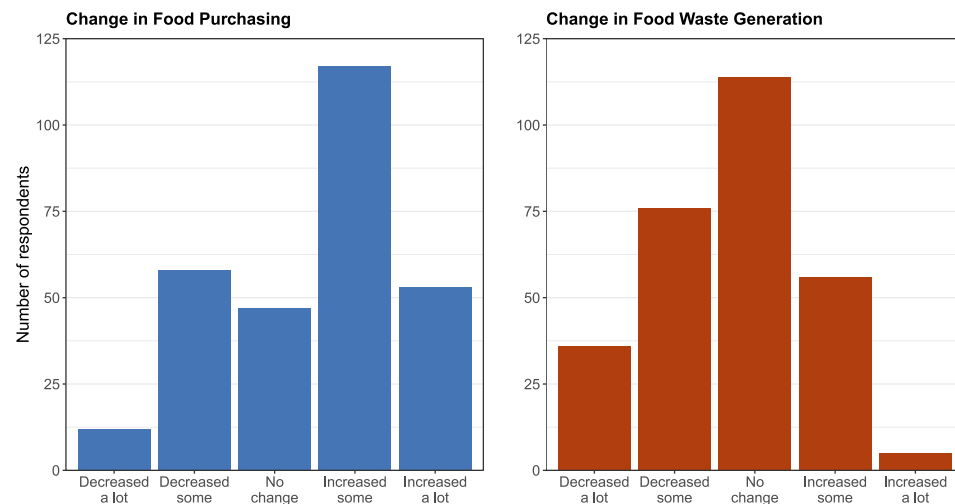

Fig. 2. Overall change in food purchase (left) and food waste generated (right) perceived by respondents during COVID-19. Changes in food purchasing and food waste were strongly interdependent ($\chi^2 = 58.08$, df =16, p <0.001) and also indicate that food purchasing behavior was more elastic in response to the pandemic than food waste generation.

ing, while minimal changes were reported for dairy products and single-serve pre-packaged foods (Fig. 3). Specific types of food waste also had variable outcomes. Waste from unused ingredients, uneaten leftovers, and spoiled or expired food items declined to the greatest degree, with minimal overall change to waste from failed recipes and vegetable trimmings. These results are consistent with the findings of Jribi et al. (2020), who demonstrated that vegetables were among the highest categories of food wasted during COVID-19 for Tunisian households. However, the majority of consumers reported no observed change in many wasted food outcomes. A case study on Toronto, Canada residents also found that

the majority of respondents reported no difference in the amount organic waste collected during the pandemic (Ikiz et al., 2021). It may be that increased preparation waste from a greater frequency of cooking at home was offset by an increased tendency towards behaviors associated with food conservation and frugality (Fig. 1). Increased time spent cooking may also have led to consumers learning and improving food preparation, cooking, and preservation skills (Amicarelli and Bux, 2020).

The underlying relationships between behaviors and food waste outcomes were explored by identifying latent constructs within the data and then testing correlations between these constructs and
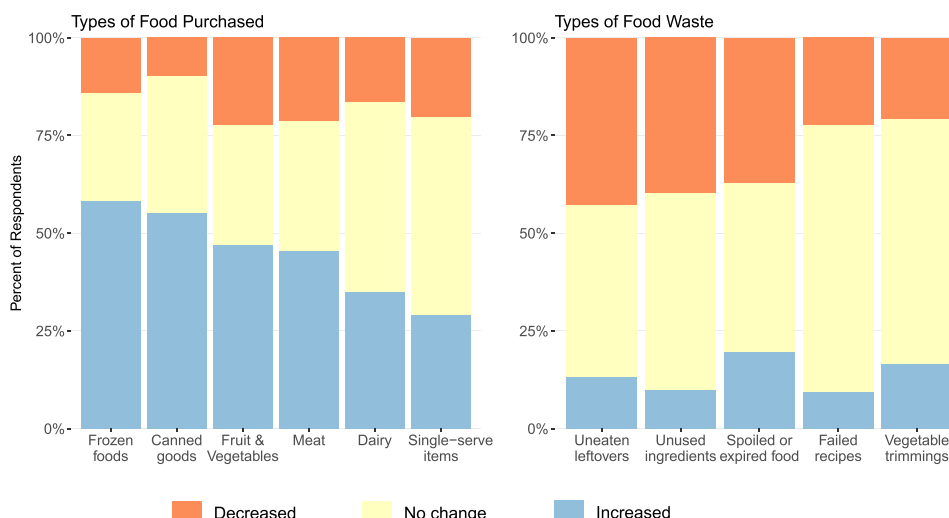
Fig. 3. Relative changes in specific kinds of food purchased (left) or wasted (right) during COVID-19.

Table 1

Exploratory factor analysis demonstrating the underlying relationships between surveyed behaviors and beliefs and the most important factors driving these behaviors. The initially surveyed variables and their loadings on each factor are provided for all factors.

Behaviors and beliefs	Factor loading	Factor
Planning meals before grocery shopping	0.72	Efficient food use
Saving leftovers	0.71	
Finding ways to save money on food	0.66	
Finding recipes to use food at home	0.56	
Freezing or preserving foods	0.49	
Cooking meals at home	0.46	
More time thinking about food use	0.40	
Eating foods after their expiration date	0.32	
Stockpiling food and cooking supplies	0.76	Self- sufficiency
Buying food in bulk quantities	0.72	
Replacing perishables with shelf-stable items	0.39	
Ordering take-out meals	-0.33	
Worry that food would run out	0.86	Food insecurity
Worry the grocery would not have food needed	0.58	
Felt financial strain due to higher food prices	0.52	
COVID-19 threat to population health	0.86	Health concerns
COVID-19 threat to household health	0.76	
Concern about exposure via food purchases	0.41	
COVID-19 threat to household finances	0.96	Economic impacts
Household income loss due to COVID-19	0.63	
Ordering groceries online	0.99	Shopping mode
In-person grocery shopping	-0.34	
Buying meal subscription boxes	0.62	Alternate provisioning
Growing your own food	0.57	
Purchasing from farmers	0.42	

observed changes in food purchase and waste. Factor analysis identified seven underlying constructs, with the first two providing the greatest insight into the underlying data structure (additional detail on EFA results is provided in the SI Table S5). The first factor, which captured "efficient food use," included behaviors associated with increased cooking, planning meals, and efforts to preserve and use foods already available to minimize excess and avoid additional shopping trips (Table 1). The second factor related to "self-sufficiency" and was associated with stocking up in preparation for COVID-19, included behaviors such as purchasing food in bulk, choosing shelf-stable options, and stockpiling food and cooking supplies. Notably, ordering take-out meals had a negative loading for this factor. Additional factors were identified from the underlying data, including ones that appeared to measure "food insecurity," "economic impact," "health concerns," and "shopping mode." A final factor, related to "alternate provisioning," included behav-

iors such as growing food, purchasing meal subscription boxes, and buying fruits and vegetables directly from farmers or farm markets.

The ultimate influence of these underlying constructs was analyzed via post hoc correlation of factor scores with food purchase and waste composites. The efficient food use factor had a significant positive correlation with total food purchased during COVID-19 and a significant negative correlation with total food wasted (Fig. 4). The self-sufficiency factor also had a significant positive correlation with respondent observations of food purchased during COVID-19 but no significant association with food waste generation. These relationships suggest a complex interplay between reported behaviors and outcomes. On one hand, consumers sought to avoid frequent shopping by both efficient use of food and shifting purchase behaviors towards items with a longer shelf life. These behaviors, combined with increased cooking at home, and in some cases, with increased number of people to feed, all contributed to
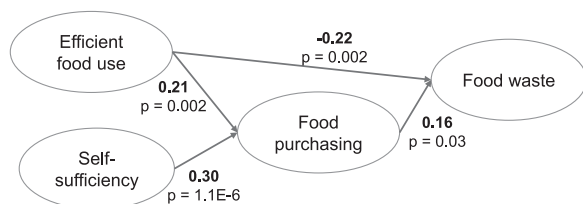
Fig. 4. Post-hoc correlation structure of associations between underlying behavioral constructs and food purchase and waste outcomes. Associations are reported as Spearman rank correlation coefficients (rho) along with adjusted p-values (Holm correction) for the significant correlations between factor scores and composite outcomes.

Fig. 5. Potential perseverance in efficient food use behaviors. Percentages represent those individuals that plan to continue the behavior in the future, relative to the total number who increased the frequency of that behavior during COVID-19. The dashed line at the top of the graph represents the total sample size.

elevated levels of food purchasing. In turn, food purchasing had a significant and positive correlation with food waste generation. In other words, the more food that entered the household, the more waste was ultimately generated. On the other hand, the same efficiency-oriented behaviors also led to waste minimization. Notably, the activities most strongly linked with reduced waste are those that are widely recommended to consumers in efforts to curb household food waste pre-pandemic as well (Diaz-Ruiz et al., 2018; Hebrok and Boks, 2017; Schmidt and Matthies, 2018). This disruption proved that these strategies can be effective for resource minimization, but unfortunately came at the cost of significant impact to human health and well-being.

In general, the majority of the remaining factors listed in Table 1 had positive associations with food purchasing and negative associations with food waste generation, but none of these correlations were significant. Prior to the pandemic, food waste minimization intent was shown to be negatively correlated with consumer beliefs about health risks from food waste (Abdelradi, 2018; Barone et al., 2019), but elevated concern about virus exposure from shopping during the pandemic may have outweighed these fears. As noted earlier, some aspects of the underlying correlative structure of the data, such as associations between food purchasing and economic and food insecurity factors, were particularly strong for those respondents reporting the greatest degree of concern over food prices, economic losses, and food insecurity. However these relationships were not significant for the entire population of respondents. Such results suggest a need for greater study of these behaviors specific to groups of individuals who experienced different impacts from the pandemic.

4.3. Implications for future resource management

It is clear that efficient food use activities are effective at reducing household food waste. However, it is unclear whether consumers will continue these behaviors after the immediate threat of COVID-19 has passed. Ideally, lessons learned from pandemic disruptions to food supply chains can be used to inform sustainable strategies for resource management in the future. Respondents had the opportunity to indicate activities they had done during COVID-19 that they planned to continue in the future. This response set was filtered to focus on those individuals who increased the frequency of three key activities related to efficient food use during the pandemic: meal planning before grocery shopping, freezing or preserving food, and using leftovers. When these individuals were queried about future plans, between 60-75% stated that they were likely to continue these three behaviors beyond the pandemic (Fig. 5). While strength of this commitment was not specifically assessed, these behavioral changes might be considered to be relatively "easy" compared to others analyzed. They also have co-benefits of saving money, which was closely connected to efficient food use in the underlying factor analysis.
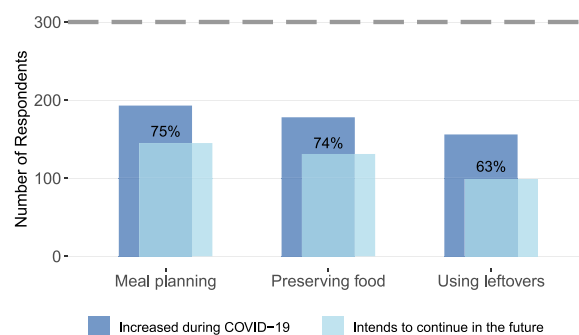
Facilitating permanence in these behavioral intentions will likely depend on situational factors that enable an individual to enact their stated plans. For example, waste minimization behaviors have been linked with an individual's available time (Khan et al., 2019), sense of control (Russell et al., 2017), responsibility for food preparation (Graham-Rowe et al., 2015), and support in overcoming difficulties (Zhang et al., 2015). Evidence from the pandemic supports the idea that additional time at home and opportunity to develop skills in food preparation and preservation may contribute to efficient food use and less waste generation (Amicarelli and Bux, 2020). As traditional work modes are re-established and time at home declines, consumers who gained experience in meal planning and food preservation during the pandemic (Fig. 5) may become catalysts for behavioral change if their knowledge can be harnessed and shared more broadly. Intent to perform sustainable behaviors has been shown to correlate with social influence, including knowledge of others who perform similar behaviors and perceived social pressure to conform (Cialdini et al., 1990; de Leeuw et al., 2015; Graham-Rowe et al., 2015; Huffman et al., 2014; Rivis and Sheeran, 2003). While emphasizing moral norms and social cohesion has been shown to increase behavioral intent in some cases (Nguyen et al., 2015; Zhang et al., 2015), they may be less effective in this U.S. context, where moral appeals for mask wearing and distancing have clashed against political ideologies during the pandemic.

Experiences from COVID-19 may also help shape the way that food waste is managed in the future. Respondents were queried about their typical methods to handle or discard food waste prior to the pandemic and whether this mode of waste management changed due to COVID-19. The vast majority of respondents typically dispose of their food waste in municipal solid waste (MSW) streams (Fig. 6). However, almost 30% use an alternative method, such as home composting, instead of or in addition to disposing food waste in the trash. About 10% of respondents indicated that they started or increased home composting or the use of a residential compost collection service during the pandemic (Fig. 6). While not directly assessed, these increases may have also been due to additional time spent at home and focused on food-related activities, as past research has shown that time and convenience are key factors in consumers adopting household waste separation and recycling behaviors (Khan et al., 2019).

However, the results of Fig. 6 show that increased food waste diversion behaviors were reported at a far lower rate that efficient food use behaviors discussed above, potentially because the added time and complexity were too great of challenges to overcome or because these are behaviors that are largely controlled by external factors. In this regard, a subset of respondents (approximately 5%) indicated that they stopped or paused composting dur-
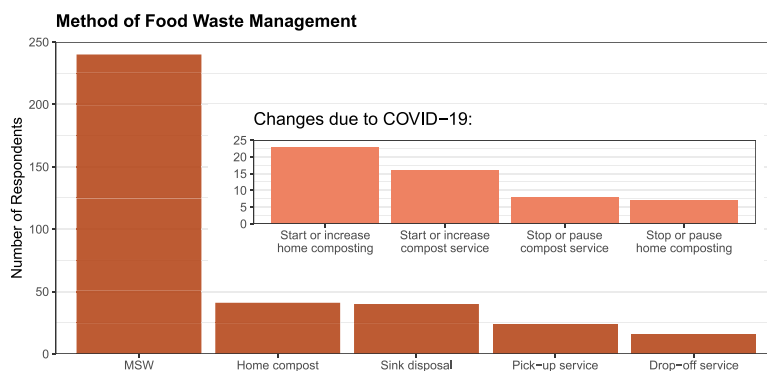
Fig. 6. A relative ranking of the various pathways used for food waste management prior to COVID-19 and changes to waste management practices as a result of the pandemic (inset figure). Note that respondents were allowed to make multiple responses in the survey.

ing the pandemic. Analysis of free text responses associated with this question showed that many of these changes were in response to external factors, such as their municipality suspending curbside food waste collection during the initial phases of pandemic closures (BioCycle, 2020). These findings underscore the essentiality of workers in the waste sector, the need to overcome misperceptions of virus exposure from waste handling (Brown, 2020), and the importance of resilient food waste management systems that can accommodate sudden disruptive shifts (Sharma et al., 2020).

One additional implication of these waste management results is the need for expanded capacity to collect, transport, and treat household food waste even during natural or human-induced disruptions. The emerging business model of distributed collection and small, independent household food waste composting services could potentially fill a critical niche in the waste management ecosystem (Franchetti, 2016). Not only are such firms likely to be more agile than municipal- or regional- scale services (Armington et al., 2018), they may also help "nudge" households towards food waste management by providing containers into which individuals can separate their food waste and contactless pick-up that addresses convenience and exposure concerns (Bernstad, 2014). However, there is a need to study consumer willingness to participate in such services, both during and beyond the pandemic, as well as to understand what broader economic and policy challenges such companies face in their startup and operation.

Beyond direct food waste impacts, the pandemic also highlighted the potential for ripple effects in other waste systems. Respondents were queried about changes in their use of disposable plastic and paper products associated with food provisioning and consumption (see SI Figure S2). The largest increase was in use of paper kitchen products, such as paper towels or cleaning wipes (45%). In the other categories – use of shopping bags, drink bottles, and plastic containers and utensils – the majority of respondents reported no change, with other responses spread relatively evenly between increased and decreased usage. There was a strong and significant positive correlation between ordering takeout meals and the use of plastic containers and utensils. Several respondents noted the NYS plastic bag ban, a policy that began to take effect just prior to the U.S. pandemic outbreak. Their free text responses noted scenarios such as having recently switched to reusable grocery bags but being prevented from using them by grocery stores concerned about virus transmission or cross-contamination. In fact, the state did halt the plastic bag ban during the pandemic but has since resumed its implementation (Mercado, 2020). More positively, a slightly greater fraction of respondents indicated decreased use of plastic drink bottles, likely due to the additional time at home and less purchases of 'on the go' convenience food and drink.

While direct policy interventions at the level of household food consumption are unlikely, broader consideration should be given to policy that can strengthen and support resource and waste management across the entire food supply chain (Schanes et al., 2018). One example can be seen in the mismatch between food excesses and shortages. While some food providers found themselves with a food surplus (Yaffe-Bellany and Corkery, 2020), consumers, as indicated in this study, expressed concern about being able to obtain food that they wanted or needed. One potential solution is in enabling upstream food producers to quickly pivot to redirect supply using mobile technology (Schanes et al., 2018) or applications that connect surplus to new consumers (Maria et al., 2019). While such a strategy responds to calls for greater food supply chain resiliency to changing markets (Aldaco et al., 2020), companies may be hesitant to expose themselves to greater risk and liability. Thus, a related need is for policy that expands liability protection for companies who donate usable food (Evans and Nagele, 2018).

It is likely that policy interventions at other points in the food supply chain can similarly enable greater systemic resilience. For example, consumers noted an increased willingness to eat food after its 'expiration date.' However, date labels on food in the U.S. do not follow a federal standard and their meaning varies widely across product and state, often leading to confused consumers who unknowingly discard safe and edible food (Thyberg and Tonjes, 2016). Thus, policy efforts aimed at standardizing food labels and educating consumers about label meaning and food safety (Neff et al., 2019) have the potential to minimize food waste during the pandemic and beyond (Maria et al., 2019). At the other end of the supply chain, policies aimed at food waste recycling and landfill diversion may also play an indirect role in addressing disruptions observed during the pandemic. In the past several years, some U.S. states and municipalities have passed laws requiring donation, recycling, or other forms of landfill diversion for food and organic wastes (Bolden et al., 2019). These efforts are anticipated to eventually expand food waste treatment infrastructure and capacity while simultaneously generating ancillary resources, such as biogas and electricity from waste-to-energy systems (Ebner et al., 2018). Realizing the potential of such systems can be supported by further policies that set forth economic incentives for firms to produce bio-products from organic waste (De Clercq et al., 2017) or provide capital grants to lower upfront infrastructure costs (Shahid and Hittinger, 2021).

4.4. Limitations and extensions

This work provides an initial case study that examines COVID-19 impacts within a specified region of the U.S., to control for potential variability associated with state-level pandemic responses. However, this narrow geographic focus potentially limits the broad

generalizability of findings outside New York State. The NYS data could potentially be representative of outcomes expected of a very rapid disruption, due to the initial severity of the outbreak and immediacy of the public health response in the state. A related limitation is any sampling bias introduced by the use of Internet-based surveys. For example, respondent ages skewed younger than the NYS age distribution, with underrepresentation of adults over 65 years old. Future study is required to understand how these trends compare to regions that saw a more gradual change in conditions (Qian et al., 2020) or with fundamentally different production supply chains and underlying consumer motivations and demographics (Funk et al., 2021).

An additional consideration is that behavioral outcomes are measured solely through respondents' self-reported recall of changes to food purchase and waste generation. While self-reported behavior is not an ideal proxy for actual food waste measurement, it is a pragmatic strategy when directly observing behavior is not feasible (Russell et al., 2017). Nonetheless, ongoing research is needed to develop high-quality, objective measures of food waste outcomes (Quested et al., 2020) and then deploy them to measure continued change over time. Longitudinal study of consumers can also provide insight into permanence of behavioral adaptations that influence reduced resource consumption and waste production. There is now a critical opportunity to design and then study the effect of interventions that can support a continued shift towards food provisioning, use, and conservation practices that alleviate food insecurity, support the economic recovery of consumers and businesses, reduce pressures to supply chains, and simultaneously reduce wasted food.

The broad spectrum of benefits possible through ongoing behavior change and system adaptation underscores the importance of a systems perspective on assessing food loss and waste. This study focused primarily on direct food flows and behaviors that might influence the magnitude and composition of those flows. However, food consumption and waste do not take place in isolation, and are in fact linked with interacting material systems and sustainability issues. For example, an increased interest in cooking and food preservation techniques, such as canning, led to a US-wide shortage in the Mason jars and lids used to safely can and store foods (Gray, 2020). Similarly, findings reported here and in past work (Schmidt and Matthies, 2018) show the potential for freezing foods and saving leftovers to minimize food waste. However, freezers and other appliances also experienced significant supply shortages during the pandemic (Selyukh, 2020). An important future research direction will be the application of methods like material flow analysis and life cycle assessment to model potential ripple effects of wasted food flows and potential management pathways (Aldaco et al., 2020) and create proactive insight to avoid unintended consequences.

5. Conclusions

This study documented a unique U.S. case study of COVID-19 impacts on household-scale food provisioning, use, and waste behaviors and evaluated the associated changes to overall food purchases, food waste generation, and wasted food management methods. Findings demonstrate that increased adoption of behaviors associated with efficient use and conservation of food correlate with reduced waste generation. We posit that added time and thought spent by consumers on food-focused activities during the pandemic may have allowed new habits and household routines to develop. We also show that the vast majority of respondents who started or increased activities including preserving food, using leftovers, and meal planning before grocery shopping intend to continue these behaviors in the future. A major opportunity for future research is longitudinal study of whether this behavioral in-

tent persists over time and ultimately translates into food waste minimization actions.

Findings also emphasize the importance of and opportunities for enhancing food waste management pathways for both immediate sustainability gains and long-term resilience to disruptions. Only about 30% of respondents manage their food waste through composting or other routes beside landfill disposal, a rate that is comparable to the national average for food waste management. Just a small fraction of respondents increased waste diversion behaviors during COVID-19, either by starting or increasing composting at home or by using residential composting services. This increase was much smaller than what was observed for food use behaviors discussed above. Food waste separation and composting may be limited by consumer perceptions that they are unsanitary, complex and time consuming, or too dependent on factors outside their control, such as available space and access to composting infrastructure. Future research is needed on policy and business models that can enable consumer participation in food waste management and facilitate ongoing sustainable behavior change. While the devastating impacts of COVID-19 still persist globally, innovative solutions offer hope for rebuilding resilient systems in the future.

Declaration of Competing Interest

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

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Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.spc.2021.04.012.

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