COVID-19 PANDEMIC, FOOD BEHAVIOUR AND CONSUMPTION PATTERNS

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COVID-19 PANDEMIC, FOOD BEHAVIOUR AND CONSUMPTION PATTERNS

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Editorial: COVID-19 pandemic, food behaviour and consumption patterns

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Editorial on the Research Topic
COVID-19 pandemic, food behaviour and consumption patterns

With already 600 million confirmed cases of COVID-19 and over 6 million recorded deaths, the Coronavirus Disease 2019 (COVID-19), detected in Wuhan (China) in late 2019, is nowadays one of the most pressing global challenges facing humanity. In addition to significantly impacting health systems, the COVID-19 pandemic disrupted food systems from farm to fork, with consequences for food and nutrition security at all levels (global, national, local, and individual). While a growing corpus of research examines the pandemic's disruption of food supply networks, the implications regarding food environments and consumer behavior are still widely overlooked, particularly in developing countries. Accordingly, this Research Topic intends to offer insight into the pandemic's influence on food buying behavior, nutrition, and eating habits and the consequences of these changes. It includes 10 papers on various issues (diet, food security, food affordability, food safety, shopping habits, food waste, etc.) and geographical areas (Oman, Jordan, Saudi Arabia, Italy, Canada, and India).

Regarding the influence of the pandemic on diet and food choices, in their study in Oman, Ben Hassen et al. highlighted a significant change in the attitude and behavior of respondents regarding food and health, such as a shift to healthier diets, an increase in the consumption of local products, buying more groceries online; and a reduction of food waste. Further, Vetrani et al. examined the impact of the lockdown on eating habits in individuals in Italy with type 1 diabetes (T1D) on a hybrid artificial pancreas (HAP). They reported that Italian patients with T1D on HAP altered their eating choices during the lockdown by consuming less animal protein and more carbohydrates. This increase in whole grain and low-glycemic index items did not affect blood glucose control.

Additionally, in their longitudinal study, Alshahrani et al. assessed the impact of the COVID-19 pandemic on body weight and body mass index (BMI) in Saudi Arabia. They pointed out that about one-quarter (23%) of their sample had gained 5% or more of their pre-2020 weight. Females saw more weight increases from pre-2020 to post-2020. These data highlight COVID-19's negative externalities in terms of its influence on infections and other health disorders that affect population health.

Furthermore, Nielsen et al. showed that COVID-19 affected food purchases in Quebec, Canada. In-store food purchases were lowest during the lockdown (once a week or less), then rose to pre-pandemic levels. During the lockdown, concerns regarding grocery store virus exposure and disinfection/disposal of food packaging peaked. Frequent usage of no-contact grocery methods was linked to public transit, walking or cycling.

In developing countries, the impact of the pandemic on food security was significant. Padmaja et al. studied the pandemic's effects on food security and coping methods in Hyderabad, India. The findings showed over 40% of families interviewed observed food security decline during the pandemic. It also showed that food security was strongly linked to a family's main income earner's sector of activity. The surveyed households adopted different consumption-smoothing strategies, including borrowing from official and informal sources and liquidating savings. Along the same line of inquiry, Jeyakumar et al. studied food availability, accessibility, and affordability during the first wave of the pandemic in selected districts of Chhattisgarh in India. Of the 63% non-tribal population, a more significant percentage experienced income loss (13.4%) and worried about not having sufficient food (40%). Non-tribal areas reported more food shortages (34%) and hunger (15%) than tribal areas. To overcome the pandemic's consequences, immediate and vulnerable-focused interventions must be addressed.

Regarding food safety, Osaili et al. evaluated food safety knowledge, attitudes, and practices (KAP) amongst university students in Jordan and changes in food-related behaviors during the COVID-19 pandemic. They concluded that university students in Jordan have insufficient food safety knowledge. They recommended that the basics of food safety be taught through short courses/lectures. Further, Luo et al. analyzed the relevant literature on food safety in the food supply chain and assessed its present state, hot spots, and development patterns. They concluded that future food supply chain management might become an important topic, particularly when traceability management and the blockchain are linked.

Regarding virus transmission, Rafieepoor et al. investigated the presence of SARS-CoV-2 virus RNA along the food production and retail chain in Tehran (Iran), from wastewater to water used for irrigation and harvested and marketed vegetables. The results revealed that SARS-CoV-2 was prevalent in retail food and could potentially contaminate agricultural water and products. This research showed that although SARS-CoV-2 RNA was identified on minimally washed and raw foods, there was no indication of a public health risk.

Finally, according to Maffetone and Laursen, the COVID-19 pandemic was a predictable and avoidable disaster. It should serve as a wake-up call to public health and healthcare professionals, politicians, and citizens. While many reactive measures to the pandemic were implemented, preventative efforts were overlooked in the years before COVID-19. They recommended implementing proactive lifestyle changes with basic, safe, and affordable dietary improvements that may lead to a healthier population.

The results of the studies presented in this Research Topic confirm that the consequences of COVID-19 vary by country, based not only on the epidemiological situation but also, among other factors, on the baseline socio-economic situation and level of resilience to shocks. Furthermore, since there is no widely available literature on modern pandemics other than SARS, these studies help to provide a better understanding of future shocks and crises and their potential impact. Current and future research will serve as a foundation for organizational and government readiness and preparedness for future public health shocks, including new pandemics.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

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

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Food Safety Knowledge, Attitudes, and Practices Among Jordan Universities Students During the COVID-19 Pandemic

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Objective: This study aimed to evaluate food safety knowledge, attitudes and practices (KAP) amongst university students in Jordan and changes in food-related behaviors during the COVID-19 pandemic. Correlation between food safety KAP scores and general characteristics of university students was also evaluated.

Methods: A cross-sectional study was conducted where an Internet-based questionnaire was distributed through social media platforms. The sample consisted of 1,739 respondents from 29 Jordanian universities. The participants completed a 58-item questionnaire covering demographical characteristics and different food safety aspects which were namely "COVID-19 food-related attributes," "food cooking and storage," "personal hygiene." "cross-contamination prevention/disinfection procedures." and "restaurant hygiene." Descriptive statistics, Chi square tests and binary logistic analysis were used to assess the data.

Results: The sample consisted of 67.2% females with a mean age of 21.3 ± 1.8 years. The average overall score of the tested aspects was 14.1/34.0 which corresponds to 41.3% of the questions being answered correctly. The percentage of correct answers of "COVID-19 food-related attributes," "food cooking and storage," "cross-contamination prevention/disinfection procedures," "personal hygiene" and "restaurant hygiene" was 56.8, 36.6, 28.4, 44.6. and 36.9%, respectively. A significant ($P < 0.05$) association between respondents' food safety KAP scores and gender, marital status, university degree, employment status, self-rating of food safety knowledge, and the source of food safety information.

Conclusion: University students in Jordan had insufficient KAP scores which is a concerning trend during the pandemic. Teaching fundamentals of food safety in the form of short courses/ lectures is recommended.

Keywords: knowledge, attitude and practice, coronavirus, cross-contamination, sanitation, cooking, personal hygiene

INTRODUCTION

Outbreaks associated with food pose a great threat to public health. As per the World Health Organization (WHO), on an annual basis, about 600 million cases and 420,000 deaths are associated with the consumption of contaminated food and water (1). Foodborne outbreaks affect 48 million Americans, 4 million Canadians and 2.4 million Britons each year (2–4). A recent food poisoning outbreak in Jordan (Ain Al-Basha region) associated with contaminated Shawerma resulted in 700 infections and two deaths. The Shawerma was reported to be infected with *Enterococcus Faecalis* and *Campylobacter* (5).

Food can get contaminated during various stages of production, distribution, and storage (1). Measures commonly recommended to combat foodborne outbreaks include frequent/ correct technique of hand washing, appropriate cleansing of kitchen surfaces, storing food at suitable temperatures and the separation of raw and cooked food (6, 7).

The advent of COVID-19 has been reported to impact people's food preparation/ eating habits, consumer food safety awareness, food and hygiene related attitude and food purchasing behavior (8–11). The primary mode of transmission of the virus has been reported to be through person to person contact and via respiratory droplets generated by coughing or sneezing. Untrue to common belief, the COVID-19 virus is not foodborne (12). However, the entire affair revolving around food could act as a vehicle for transfer, for example, an infected individual could transfer the virus on to the food package, the utensils, table tops, cash, machinery or even via a simple handshake (13).

A previous study has reported that young adults (18 to 29 years old) are more likely to take the concept of food safety lightly (14). This could be because (with a probable exception of personnel whose predominant occupation revolves around food), this section of the population usually do not possess appropriate training/certifications (14). An area of concern is that it is this section of the population who tend to work in food service establishments (part- or full-time job) during their course of study. Moreover, they tend to cook for themselves and their colleagues (roommates/ friends etc.). They are also more likely to attend parties and take the seriousness of the pandemic lightly because of their belief of higher immunity in young adults (15). Hence, it is highly possible that they act as a vehicle for the transfer of this virus.

Multiple studies pertaining to food safety knowledge amongst different population strata have been conducted previously in Jordan (16–19). However, none of them have assessed the impact of the COVID-19 pandemic in university student's food safety knowledge, attitudes, and practices (KAP). Therefore, the present study aimed to (i) evaluate food safety KAP among Jordan universities students during the COVID-19 pandemic, (ii) determine the changes in food-related behaviors during the COVID-19 pandemic, and (iii) assess the correlation between food safety KAP scores and general characteristics of university students.

MATERIALS AND METHODS

Study Design

A cross-sectional study was performed from March 2021 to April 2021 to assess food safety knowledge, attitudes, and practices amongst Jordan universities students during the COVID-19 pandemic. Any student currently studying at a Jordanian University ($n = 29$) above 18 years was considered to be eligible to take part in the study regardless of gender, academic year, full time/ part time or academic program. The total number of students in all public and private universities (inclusive of all degrees) at the beginning of the academic year of 2020–2021 was announced to be 322,349. The universities are spread throughout the country thereby increasing the representativeness of the sample.

Questionnaire

The questionnaire was designed by adapting some existing questions from validated and reliable questionnaires used in prior studies pertaining to food safety (10, 16, 20–28). All authors went through the questionnaire in-tandem to discuss the questions that need to be included in the study. The questions were revised to remove the ambiguity and ensure that they were short and clear. This was done to avoid self-reported bias such as social desirability and acquiescent responding (29). The questionnaire was translated from English to Arabic. It was tested by four bilingual academicians specialized in food safety, for its understandability. The final questionnaire consisted of 58 items (**Supplementary Material**) starting with a cover page which explained the nature and purpose of the study besides the confidentiality statement. The Cronbach alpha coefficient value (used to check questionnaire reliability) was observed to be 0.774. The questionnaire was composed of four sections; demographic information (13 items), food safety knowledge (12 items), attitudes (7 items) and practices (26 items) during COVID-19. A combination of multiple-choice, true-false-not sure, and Likert-scale questions were used in the questionnaire. The questionnaire covered the following food safety aspects: "COVID-19 food-related attributes," "food cooking and storage," "personal hygiene," "cross-contamination prevention/disinfection procedures," and "restaurant hygiene." The total score of students' knowledge, attitudes and practices was calculated by the summation of correct answers from each aspect. Each correct answer was given 1 point while incorrect and not sure answers were given a score of 0. Finally, the practice part consisted of questions pertaining to behavioral changes during the COVID-19 pandemic where the answer choices were "Less than before," "About the same" and "More than before", respectively. The final questionnaire draft was then piloted amongst students ($n = 30$). This involved completing the survey using different computers or phones at different locations. No further adjustments on the questions were needed as per the feedback.

Data Collection

The data were collected via an Internet-based link (Google Forms). The invitation link was primarily distributed via

students' groups on social media platforms namely Facebook and Twitter. The link was shared by the researchers, as well as willing participants—who forwarded it to other potential participants from the same or other universities (snowball approach).

On the first page of the questionnaire, participants had been informed that their participation was purely on a voluntary basis and their consent was taken prior to starting the questionnaire. The participants were given all information deemed necessary about the study on the consent form. They were informed of their right to withdraw from the survey at any time. There was no possibility of placing any undue pressure on the respondents as the survey had to be completed via an online link. All responses were kept confidential. The study and the protocol were approved by the Department of Nutrition and Food Technology (#26/2021) and Deanship of Graduate Studies (#7/2021) at Jordan University of Science and Technology.

Data Analysis

All survey responses were exported from the Google Forms platform into SPSS Version 26.0 (SPSS Inc., USA) for analysis. Descriptive statistics of means, standard deviation, variation ratio, frequencies and percentages were used for variables as appropriate. Chi-square test was conducted to explore the difference between categorical variables. Binary logistic analysis was used to assess the contributing factors affecting students' knowledge, attitudes and practices (KAP) scores. A p-value < 0.05 was considered to be significant. A cut-off point of 50% was used to calculate the total participant score and a sufficient KAP score was considered when the participant correctly answered more than 50% of the questions.). A score of <50% was considered as inefficient knowledge, attitude and practice.

RESULTS

Demographic Characteristics

A total of 1,739 students from 29 private and public universities in Jordan participated in this study. The sample consisted of 67.2% females with a mean age of 21.3 ± 1.8 years (**Table 1**). More than half (57.8%) of the participants studied at public universities. Most of the participants lived with their family (89.1%), did not work (77.4%), and helped in preparing food (83.6%). Only 12.0% of the participants rated themselves to have "excellent" knowledge of food safety. The main sources of food safety information were reported to be the internet (43.2%) (**Table 1**).

TABLE 1 | Demographic characteristics of university students ($n = 1739$).

Character	Frequency (%)
Age [Mean, (range)]	21.3 (18–25)
Gender	
Female	1168 (67.2%)
Male	571 (32.8%)
Marital status	
Single	1630 (93.7%)
Married	109 (6.3%)
University type	
Public university	1006 (57.8%)
Private university	733 (42.2%)
College	
Humanities	559 (32.1%)
Scientific*	675 (38.8%)
Health**	505 (29.0%)
University degree	
Bachelors	1604 (92.2%)
Masters	131 (7.5%)
Doctorate	4 (0.2%)
Year of study	
First year	339 (19.5%)
Second year	297 (17.1%)
Third year	392 (22.5%)
Fourth year	513 (29.5%)
Fifth year	139 (8.0%)
Sixth year	59 (3.4%)
Living with	
Family	1550 (89.1%)
Roommate	80 (4.6%)
Alone	109 (6.3%)
Employment	
Do not work	1346 (77.4%)
Full time work	182 (10.5%)
Part time work	211 (12.1%)
Monthly expenses	
<100 JD (1 JD = 1.41$)	845 (48.6%)
100–300 JD	703 (40.4%)
>300 JD	191 (11.0%)
Self-rating of food safety knowledge	
Excellent	208 (12.0%)
Very good	625 (35.9%)
Good	768 (44.2%)
Weak	122 (7.0%)
Very weak	16 (0.9%)
Source of food safety information	
Courses/workshops	289 (16.6%)
Family	388 (22.3%)
Friends	26 (1.5%)
Healthcare professional	85 (4.9%)
Social media	167 (9.6%)
Internet	752 (43.2%)
Others***	32 (1.8%)

(Continued)

Overall Food Safety Knowledge, Attitudes, and Practices Score of University Students During the COVID-19 Pandemic

The overall food safety KAP score of university students during the COVID-19 pandemic was calculated by the summation of correct answers (34 questions) in the tested food safety aspects: "COVID-19 food-related attributes," "food cooking and storage," "personal hygiene," "cross-contamination prevention/disinfection procedures," and "restaurant hygiene." The average overall KAP score of the tested aspects was 14.1/34.0 which translates to 41.3% of the questions being

TABLE 1 | Continued

Character	Frequency (%)
Preparing/helping in preparing food	
Yes	1453 (83.6%)
No	286 (16.4%)

*Scientific college include: engineering, biological sciences, IT and agriculture.
**Health college include: medicine, dentistry, pharmacy and nursing.
***Others include: dietitian, private sport trainer, self-information and experience.

answered correctly (**Figure 1**). The food safety aspect with the highest percentage of correct answers was for "COVID-19 food-related attributes" (56.8%) while the aspect with the lowest percentage of correct answers was "cross-contamination prevention/disinfection procedures" (28.4%).

COVID-19 Food Related Attributes

Query statements and responses of the COVID-19 food related attributes are presented in **Table 2**. More than 75% of the respondents possessed the knowledge that the COVID-19 virus flourishes in the nose and mouth of the infected person and it could be transmitted upon coughing or sneezing. A good number of participants (70%) correctly believed that the vaccine solitarily would not be protective against the COVID-19 infection, without compliance to general safety measures (masks, gloves etc.). More than half (62.4%) of the participants correctly believed that COVID-19 does not grow in food; however, only 27.0% believed that it cannot be transmitted through it. A similar number (28.8%) knew that COVID-19 virus could not be found in drinking water (**Table 2**).

Food Cooking and Storage KAP During the COVID-19 Pandemic

Regarding the appropriate temperature for killing viruses such as COVID-19 during cooking, only 33.2% knew the correct answer (**Table 3**). And, about 33.5% believed that cooling food in a refrigerator or keeping it in the freezer was ineffective in inhibiting or killing COVID-19. Only 17.0% knew that the best way to check for meat readiness was with the help of a food thermometer. However, the majority of our respondents (89.9%) believed that the number of people involved in food preparation should be reduced in an event where a family member is infected with COVID-19. Moreover, majority (90.4%) of the students did not wash the animal products like eggs before storing them in the refrigerator.

Cross-Contamination Prevention/Disinfection Procedures KAP During the COVID-19 Pandemic

In general, the results indicated very low KAP score with respect to cross-contamination prevention and disinfection procedures (28.4%) amongst the students. A very small percentage of the participants (19.8%) were aware about washing of vegetables under running water prior to usage (**Table 4**). Approximately, 58.1% of the respondents agreed that using the same chopping board to cut vegetables (post raw meat cutting) resulted in cross-contamination. A quarter of the participants (25.4%) falsely believed that using salt, vinegar, pepper or lemon juice was effective in destroying COVID-19 on food-contact surfaces. However, only 42.0% of our respondents knew the correct procedure for cleaning the kitchen surfaces. Less than quarter of our respondents disposed empty shopping bags (19.0%) and disinfected food packages prior to use (23.0%). A lower percentage (11.5%) of our participants used separate sponges for the dishes and the sink.

Personal Hygiene KAP During the COVID-19 Pandemic

In terms of personal hygiene, due to the pandemic, all the respondents recorded not using a mobile phone while preparing food (OR = −0.013, CI = −0.061–0.035), and not using bare hands (OR = −0.133, CI = −0.194-−0.071) while sharing a dish with several people (a common Arab custom), in other words all the respondents used a spoon while sharing a dish with several people (**Table 5**). As a response to the pandemic, approximately, 90% of our respondents knew that washing hands after handling raw food would aid in reduction of microbial transfer. About half of our respondents (51.8%) agreed that it is was necessary to wash hands after touching the face during food preparation in an effort to prevent spread of the virus. About 44% of our respondents reported washing their hands after touching the outer bags and covers, upon returning home (52.4%), prior to food preparation (43.5%), and eating during the COVID-19 pandemic (51.3%). However, only 36.2% of our participants knew the appropriate duration of handwashing. Approximately, 74 and 78% of our respondents did not agree that hand sanitizers could replace hand washing and knew the best way to dry hands post washing (using a tissue), respectively (**Table 5**). Only 15.2% of our respondents reported wearing gloves when touching raw food.

Restaurant Hygiene Behavior in Response to COVID-19

Regarding restaurant hygiene during the COVID-19 pandemic, 35.0% of the university students checked tables and chairs (if they were sanitized) before sitting, 38.9% checked the bathroom (for sanitization) before using it, 39.6% paid attention to the safety measures taken by workers at restaurants, such as the use of masks, gloves and physical distancing, and 34.2% observed whether the restaurant followed social distancing protocols for visitors (**Table 6**).

Behavioral Changes During the COVID-19 Pandemic

The results regarding food-related practices during COVID-19 pandemic suggest clear changes in student behaviors. As shown in **Figure 2**, 79.5 and 70.8% of the participants reported reduced eating and gathering with friends and family members, respectively during the COVID-19 pandemic. Moreover, 78.0% of respondents reported dining out less than before. In this study about half (42.4%) of the students shifted toward buying groceries online and only 28.9% of participants paid their bills by credit card more than that before the pandemic. In our study, buying from a large shopping mall or a small grocery store stayed approximately the same while comparing the pre

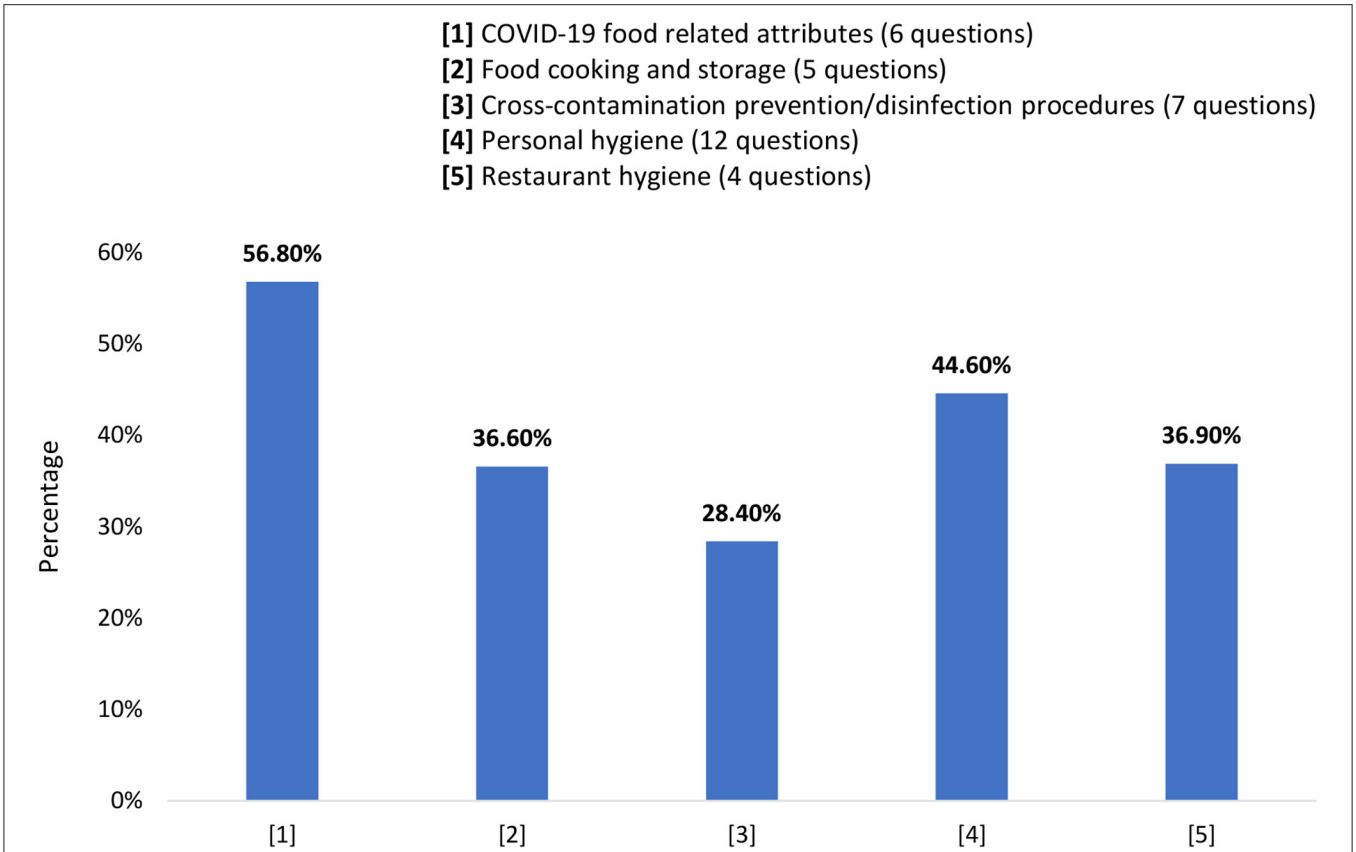

FIGURE 1 | Food safety knowledge, attitudes and practices scores among university students during COVID-19 pandemic (n = 1,739).

TABLE 2 | Query statements and responses of "COVID-19 food-related attributes" aspect.

Question type*	Query statement	Frequency (%)
K	COVID-19 can be found in the nose and mouth of infected person	1325 (76.2%)
K	A person infected with COVID-19 virus without symptoms can transmit the virus when coughing or sneezing to others	1328 (76.4%)
K	COVID-19 virus cannot be found in drinking water	500 (28.8%)
A	I do not think COVID-19 virus can be transmitted through food	470 (27.0%)
A	I do not think COVID-19 virus grows in food	1086 (62.4%)
A	I do not think COVID-19 vaccine will protect me from getting infected when eating outside the home (with friends or in restaurants) without complying to the general safety measures	1218 (70.0%)

Knowledge (K), Attitude (A), or Practice (P).

and post pandemic periods. However, 69.2% of our participants reduced the frequency of their shopping visits while another 48.1% reduced the time spent during shopping because of the pandemic (**Figure 2**).

The Association Between Overall Food Safety Knowledge, Attitudes, and Practices Scores and General Characteristics of University Students During the COVID-19 Pandemic

In this study, no significant ($P \geq 0.05$) association was observed between overall food safety knowledge, attitudes, and practices (KAP) score of university students during the COVID-19 pandemic and age, university type, college, studying year, living status and the enrollment in a food preparation course (**Table 7**). Significant associations ($P < 0.05$) were found between respondents' food safety KAP scores and gender, marital status, university degree, employment status, self-rating of food safety knowledge, and the source of food safety information. The current study found that females (18.0%) had higher food safety KAP scores than males (5.6%). In other words, 18.0% of all female participants answered more than half of the questions correctly. In the current study, being a female was not only significantly associated with higher food safety KAP scores but also was a predictor that effected KAP results. Married students

TABLE 3 | Query statements and responses of "food cooking and storage" aspect.

Question type*	Query statement	Frequency (%)
K	The appropriate temperature for killing viruses such as COVID-19 virus during cooking is 70 °C	578 (33.2%)
K	The best way to check that poultry is sufficiently cooked is through checking with a thermometer	295 (17.0%)
A	I do not think that cooling food in refrigerator or keeping it in the freezer is effective in inhibiting or killing COVID-19 virus	582 (33.5%)
A	I think that number of people involved in preparing food should be reduced in the event where a family member is infected with COVID-19 virus	1563 (89.9%)
P	During COVID-19 pandemic, I do not wash animal products such as eggs before storing them in the refrigerator	1572 (90.4%)

**Knowledge (K), Attitude (A), or Practice (P).*

TABLE 4 | Query statements and responses of "cross-contamination prevention/disinfection procedures" aspect.

Question type*	Query statement	Frequency (%)
K	The correct way to wash vegetables is to wash them with running water	345 (19.8%)
K	At home, the proper procedure when cutting vegetables on a cutting board that was previously used for cutting raw meat is to use another board	1010 (58.1%)
K	The proper procedure for cleaning kitchen surfaces is that surfaces are washed with a detergent, rinsed with water, and then wiped with a sterile solution	730 (42.0%)
A	I do not think that using salt, vinegar, pepper or lemon juice is effective in removing germs such as COVID-19 virus from food-contact surfaces	442 (25.4%)
P	During COVID-19 pandemic, I dispose all of shopping bags after emptying their contents	331 (19.0%)
P	During COVID-19 pandemic, I disinfect food packaging or boxes before use	400 (23.0%)
P	During COVID-19 pandemic, I use a separate dishwasher sponges for both dishes and sink	200 (11.5%)

**Knowledge (K), Attitude (A), or Practice (P).*

in this study scored a higher KAP ($P < 0.05$) than single students; more than one third of the married participants answered more than 50% of the questions correctly while less than a quarter of the single participants got correct answers. The current study showed that there was a direct relationship ($P < 0.05$) between the educational level and KAP scores. Higher education program (Masters) students had a higher score than their undergraduate counterparts (2.6 vs. 21% respectively). Students who work in part time jobs had higher ($P < 0.05$) KAP scores compared to full time and unemployed students. This study showed a strong association ($P < 0.05$) between self-rated food safety knowledge and KAP scores. Those who rated themselves to have higher knowledge indeed got higher KAP scores. Majority of the students in this study agreed that their major source of food safety information was the Internet (43.2%) followed by family (22.3%). In this study taking courses/workshops and consulting a healthcare professional about food safety information were significantly associated with higher ($P < 0.05$) food safety KAP scores.

Logistic regression results (**Table 8**) showed that male respondents had a lower Odds ratio compared to females (0.5) (*P*-value < 0.05). This analysis indicated that males were 0.5 times less likely to have good KAP scores than females. Moreover, in this study, unemployed and full-time employee students were 0.6 times less likely to have good KAP scores in comparison with part time employee students. This finding was unique to our study and has not been observed in previously published work to the best of our knowledge.

DISCUSSION

This study aimed to investigate the level of KAPs of Jordan universities students during COVID-19 pandemic. Gaps in food safety knowledge, attitudes and practices were identified in this population, as the participants were found to have insufficient scores of overall food safety KAP. This level of food safety knowledge amongst university students has been previously reported (14, 16, 22, 23, 30). A meta-analysis reported overall KAP scores regarding COVID-19 to be 78.9, 79.8, and 74.1, respectively (31).

COVID-19 transmission route is reported to be either by person to person contact or via droplet transfer upon sneezing and coughing (12), the majority of our participants knew the way of COVID-19 transmission. In Saudi Arabia, it was reported that 94.8% of the participants knew that COVID-19 spread could be via the transfer of respiratory droplets upon coughing or sneezing, and only a small number (14.9%) knew that infected people with no fever could transmit the virus to others (32). While, amongst the South East Asian consumers, about half of the respondents (50.3%) were unaware that asymptomatic infected food handlers could transmit COVID-19 (33). The respondents of this study wrongly knew that food and water were vehicles for virus transfer. Official records report that there is no evidence that people can be infected with COVID-19 via food or water consumption, as it is a respiratory disease. Moreover, COVID-19 cannot multiply in foods (as correctly thought by our respondents), as the viruses need a human or an animal

TABLE 5 | Query statements and responses of "personal hygiene" aspect.

Question type*	Query statement	Frequency (%)
K	While preparing food, hands should be washed after touching the face	900 (51.8%)
K	Washing hands after handling raw food reduce the transmission of food-related germs	1562 (89.8%)
K	20 seconds is sufficient to wash hands	630 (36.2%)
K	The best way to dry my hands after washing them is to use a tissue paper	1347 (77.5%)
A	I do not think that using hand sanitizers should replace washing hands with soap and water to get rid of germs	1278 (73.5%)
P	During COVID-19 pandemic, I wash my hands before eating	892 (51.3%)
P	During COVID-19 pandemic, I do not use hands to eat directly without a spoon while sharing the dish with several people	1739 (100%)
P	During COVID-19 pandemic, I wash my hands after touching the outer bags and covers	765 (44.0%)
P	During COVID-19 pandemic, I wash my hands when I get home	911 (52.4%)
P	During COVID-19 pandemic, I wash my hands before preparing food	756 (43.5%)
P	During COVID-19 pandemic, I do not use my mobile phone while preparing food	1739 (100%)
P	During COVID-19 pandemic, I wear gloves when touching raw (uncooked) food	265 (15.2%)

**Knowledge (K), Attitude (A), or Practice (P).*

TABLE 6 | Query statements and responses of "restaurant hygiene" aspect.

Question type*	Query statement	Frequency (%)
P	When going to a restaurant, I check the disinfection procedures for tables and chairs before sitting during COVID-19 pandemic	608 (35.0%)
P	When going to a restaurant, I check the disinfection procedures in the bathroom before using it during COVID-19 pandemic	676 (38.9%)
P	When going to a restaurant, I check the sanitation and safety measures of workers, such as masks, gloves and physical distancing during COVID-19 pandemic	689 (39.6%)
P	When going to a restaurant, I make sure that the restaurant applies the condition of social distancing between visitors during COVID-19 pandemic	595 (34.2%)

**Knowledge (K), Attitude (A), or Practice (P).*

host to grow (34). A large number of participants believed that the vaccine alone will not be protective against getting infected without complying to safety measures, CDC and WHO also recommend following safety precautions at public places even after being fully vaccinated (35, 36).

With regards to food cooking and storage during the COVID-19 pandemic, KAP score about appropriate cooking temperature for killing viruses was relatively low. South East Asian population showed that (41.2%) of participants believed that cooking at a temperature of >70°C destroyed the coronavirus (33). It is documented that coronavirus is a thermolabile virus and it is susceptible to traditional cooking temperatures (70°C) (37). However, when talking about refrigeration and freezing one third of our participants believed that these cooling techniques is not effective against COVID-19 virus. This proportion is lower than previously published studies where 64 and 52% of university students in Lebanon and Jordan knew that freezing does not kill harmful germs in food, respectively (16, 22). The authors expected respondents to cook meat well as a response to the belief that the heat would kill the virus present in the meat. Hence, it was expected that they use a thermometer to check for meat wellness. Contrary to the assumption, students demonstrated a low knowledge about using a food thermometer as an accurate way of determining whether meat are cooked enough to prevent food poisoning. Previous studies also testify to this premise; university students were reported to have limited knowledge about the suggested use of food thermometer for such a purpose (16, 22, 23, 38). Our results showed a good attitude toward food preparing situations which harmonizes with the general recommendation from WHO to limit the number of persons involved in food preparation during COVID-19 pandemic (12). Mishandling of food can occur at any stage during preparing and storage, for example, not washing the eggs is encouraged as washing could make them more porous and would result in microbial transfer to the internal section of the egg (39). The authors expected the respondents to wash animal products like eggs prior to storage as a precautionary measure to combat the virus, but surprisingly the majority of students did not.

Surfaces contaminated with COVID-19 may act as vehicles for spread of the virus. The virus could be present on chopping boards, knives etc. More than half of the students knew that they should use different chopping boards for vegetables and meat. This is in accordance with previous studies (23, 38, 40). Students displayed poor knowledge regarding cross contamination prevention and disinfection procedures. For instance, the respondents have a poor knowledge about the correct way to wash vegetables, where running water is expected to aid in washing away the virus. The majority of respondents have wrong information about the use of salt, vinegar, pepper and lemon juices as cleaning items. Such measures have officially been reported to be ineffective (34). Cleaning surfaces with detergent, water and then a disinfectant would be the most appropriate way

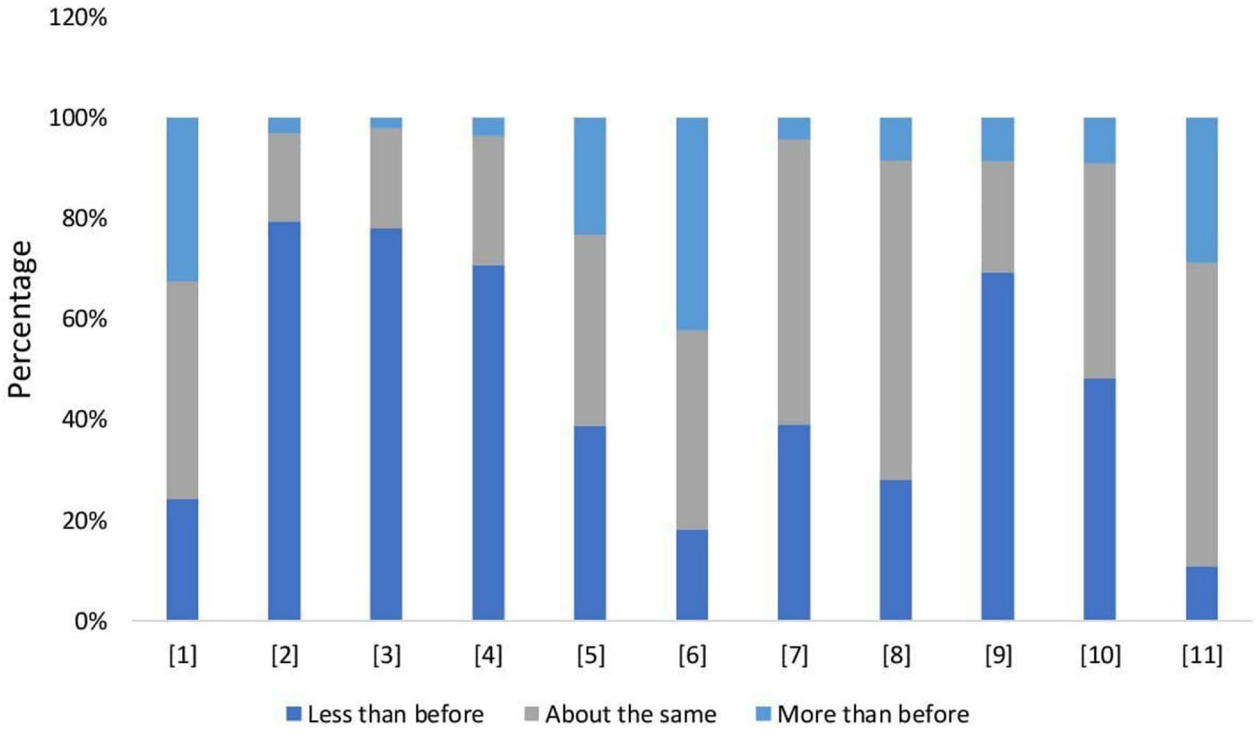

FIGURE 2 | Changes of food-related behaviors during COVID-19 pandemic (n = 1,739).

for reducing the presence of the virus on kitchen surface tops. The authors expected students to dispose/disinfect shopping bags/ other food packaging to prevent virus transfer from outside to homes. Most of the respondents did not dispose empty shopping bags and disinfect food packaging, a similar pattern was observed in Jordanian participants where only 15.2% of the reported disposing of all boxes, packages, and covers of food while 13.4% reported always disinfecting food packaging prior to home storage (10). In contrast, about 40% of the consumers in Indonesia and Malaysia washed or wiped food jars and cans before using them (33), and 71.9% of United Arab Emirates residents sanitized or cleaned groceries before storing them (41). A higher percentage of our participants have insufficient knowledge on the proper use of reusable kitchen sponges as they reported using them for multiple purposes such as dishes and sink. This finding contrasts with a previous study that showed that a high percentage (74%) of female students in university dormitories used different sponges for cleaning utensils and the sink (26).

Unexpectedly, our university students exceeded other populations in not using their mobile phones while preparing food, and not using hand in a one-dish shared meal. Our results differ considerably from another study which reported 81.4% of the respondents used their cellphone during food preparation, cooking and packaging (42). It is expected that consumers sans a pandemic would use their cell phones during food preparation for various purposes (checking recipes, posting food pictures etc.); however, as the cellphone/ spoon could have remnant virus on its surface, if not disinfected, the respondents seem to exercise caution, which is encouraging. The majority of the respondents agreed that washing hands regularly and after touching the face and raw foods is important in preventing COVID-19 spreading. Similarly, Italian undergraduate students agreed that handwashing, wearing masks and avoiding close contacts were good protective measures to prevent the spread of COVID-19 (43). Only half of the respondents wash their hands before eating, and the same percentage wash their hands after returning home. It is not only handwashing but rather the time spent doing this activity that is equally important. In North Central Nigeria, majority (82.3 %) of respondents agreed that handwashing should last from a minimum of 20 s to 1 minute (44). Less than half of our participants knew how long they should wash their hands. This is a matter of grave concern as handwashing is one of the best front-line approaches to combat the virus. The respondents need to be educated about the correct handwashing technique/ time. In a multi-country study, 36.3% of Jordanian

TABLE 7 | Association between food safety knowledge, attitudes, and practices scores and general characteristics of university students.

Character	Good KAP*	Poor KAP	*P*-value**
Age	411 (23.6%)	1328 (76.4%)	$P = 0.168$
Mean ± SD	21.39 ± 1.80	21.22 ± 1.76	
Gender			
Male	98 (5.6%)	473 (27.2%)	$P < 0.001$
Female	313 (18.0%)	855 (49.2%)	
Marital status			
Single	372 (21.4%)	1258 (72.3%)	$P = 0.002$
Married	39 (2.2%)	70 (4.0%)	
University type			
Public	235 (13.5%)	771 (44.3%)	$P = 0.752$
Private	176 (10.1%)	557 (32.0%)	
College			
Humanities	125 (7.2%)	434 (25.0%)	$P = 0.117$
Scientific	150 (8.6%)	525 (30.2%)	
Health	136 (7.8%)	369 (21.2%)	
University degree			
Bachelors	365 (21.0%)	1239 (71.2%)	$P = 0.003$
Masters	46 (2.6%)	85 (4.9%)	
Doctorate	0 (0.0%)	4 (0.2%)	
Year of study			
First	88 (5.1%)	251 (14.4%)	$P = 0.625$
Second	66 (3.8%)	231 (13.3%)	
Third	95 (5.5%)	297 (17.1%)	
Fourth	114 (6.6%)	399 (22.9%)	
Fifth	37 (2.1%)	102 (5.9%)	
Sixth	11 (0.6%)	48 (2.8%)	
Living with			
Family	372 (21.4%)	1178 (67.7%)	$P = 0.404$
Roommate	14 (0.8%)	66 (3.8%)	
Alone	25 (1.4%)	84 (4.8%)	
Employment			
Do not work	299 (17.2%)	1047 (60.2%)	$P = 0.004$
Full time work	43 (2.5%)	139 (7.9%)	
Part time work	69 (4.0%)	142 (8.2%)	
Monthly expenses <100 JD	190 (10.9%)	655 (37.7%)	$P = 0.533$
100–300 JD	175 (10.1%)	528 (30.4%)	
>300 JD	46 (2.6%)	145 (8.3%)	
Self-rating of food safety knowledge			
Excellent	64 (3.7%)	144 (8.3%)	$P < 0.001$
Very good	181 (10.4%)	444 (25.5%)	
Good	152 (8.7%)	616 (35.4%)	
Weak	12 (0.7%)	110 (6.3%)	
Very weak	2 (0.1%)	14 (0.8%)	
Source of food safety information			
Courses/workshops	103 (5.9%)	186 (10.7%)	$P < 0.001$
Family	73 (4.2%)	315 (18.1%)	
Friends	1 (0.1%)	25 (1.4%)	
Healthcare professional	28 (1.6%)	57 (3.3%)	
Social media	35 (2.0%)	132 (7.6%)	
Internet	165 (9.5%)	587 (33.8%)	
Others*	6 (0.3%)	26 (1.5%)	

(Continued)

TABLE 7 | Continued

Character	Good KAP*	Poor KAP	*P*-value**
Preparing/helping in preparing food			
Yes	355 (20.4%)	1098 (63.1%)	$P = 0.077$
No	56 (3.2%)	230 (13.2%)	

**Good KAP score: >50% of the questions were answered correctly.*
***Significance level at P <0.05.*

TABLE 8 | Predictors of food safety KAP using logistic regression analysis.

Character	OR (CI)	*P*-value*
Gender		
Male	0.464 (0.343–0.629)	$P < 0.001$
Female	Reference	
Marital status		
Single	0.815 (0.332–2.002)	$P = 0.655$
Married	Reference	
Employment		
Do not work	0.637 (0.407–0.995)	$P = 0.048$
Full time work	0.588 (0.429–0.805)	$P = 0.001$
Part time work	Reference	
Self-rating of food safety knowledge		
Excellent	Reference	
Very good	2.303 (0.498–10.663)	$P = 0.286$
Good	2.451 (0.544–11.041)	$P = 0.243$
Weak	1.46 (0.324–6.569)	$P = 0.622$
Very weak	0.786 (0.156–3.968)	$P = 0.77$
Source of food safety information		
Courses/workshops	Reference	
Family	2.202 (0.799–6.066)	$P = 0.127$
Friends	1.226 (0.445–3.377)	$P = 0.693$
Healthcare professional	0.278 (0.029–2.628)	$P = 0.264$
Social media	2.16 (0.722–6.466)	$P = 0.169$
Internet	1.5 (0.519–4.331)	$P = 0.454$
Others	1.451 (0.536–3.923)	$P = 0.464$

**Significance level at P <0.05.*

community washed their hands after returning home before the COVID-19 pandemic, this percentage increased to 53% during COVID-19 (10). This is still a low number considering the perilous behavior of this virus. A large number of participants have a good knowledge about the effectiveness of hand sanitizers but agreed with the need for hand washing. This is in accordance with the WHO recommendations which highlight that hand sanitizers should not replace washing hands with water and soap (12). It is possible that the virus transfers from the contaminated food surface to the respondent's hand which could then infect the person via oral orifices. The respondents were hence expected to use gloves while handling raw foods. It was noted that only a small number ($n = 265$) wore gloves when dealing with raw foods. On similar lines, 98.4% Philippine food handlers who were engaged in an online food business, reported that they did not use gloves when handling raw food during the COVID-19 pandemic (42). However, it is agreed upon that although gloves are an important hygienic measure, they cannot replace hand washing. Hands need to be washed prior to wearing gloves and also after their removal (45).

Approximately more than one third of the participants checked restaurants hygienic measures such as tables, chairs and toilet sanitization, as well as workers' safety precautions. CDC recommends the use of masks for both employees and customers (46). It is obvious that costumers would be more confident about going to restaurants, if the restaurant management followed hygienic/sanitizing practices besides mandating workers to wear masks and maintain social distancing (25). More than half (57.4%) of the consumers in Indonesia and Malaysia always choose to dine in restaurants that followed social distancing rules, and 37.6% always sanitized the utensils and tables before eating at restaurants (33). Most (93%) of the customers in the study

expected some safety precautions by restaurants, such as hand sanitizers at the door, staff adherence to masks and gloves, social distancing and reduced costumer serving capacity (47). Such measures along with toilet disinfection, surface sanitization and ventilation limit the spread of the COVID-19 virus (48).

Indeed, there have been a noted change in students' behavior toward gatherings, eating with family and friends during COVID-19. In Qatar, people reported eating more with immediate family members during COVID-19 (20). The author highlighted a shift toward eating meals at home rather than restaurants and a significant increase in home food deliveries during the COVID-19 pandemic. A similar trend was seen in Netherlands too during the pandemic lockdown, with 29.5% of the participants using meal delivery services more frequently than usual (49). It was reported that young, educated adults, tended to use internet services like online grocery shopping and meal delivery more frequently compared to their older counterparts (20). A shift toward using an online grocery delivery is shown in the results, however, more than half of the participants did not use credit cards as a safe payment method. Payment by credit card was expected to be preferred as cash could act as a vehicle for virus exchange.

Students reported shopping from either small grocery stores or large supermarkets as before but they reduced their time and frequency of shopping. However, in an Italian community, a shift toward shopping from small grocery stores due to the pandemic was observed. This may be because small grocery stores are less crowded than large supermarkets and hence are preferred by consumers (50). During the pandemic, Spanish consumers showed a significant reduction in the frequency of shopping; however, no significant change in the food shopping location was recorded (51).

Regarding the relationship between the KAP scores and demographic characteristic, this study shows that gender, marital status, university degree, employment status, self-rating of food safety knowledge, and the source of food safety information have a significant association. Female respondents outnumbered their male counterparts in KAP scores, this result might be related to the fact that traditionally in Jordan females play a central role in food preparation, kitchen work, cleaning, as well as the cultural trend of mothers passing their food related experience to daughters. A study of university students in Indiana showed that females had a higher food safety knowledge mean score (7.41) than males (7.04) (52). However, a Greek study showed that both genders had the same knowledge level about food safety issues (23). While, female and male Lebanese university students showed an equal knowledge level about food safety; however, female students had better food safety practices (22). Students identified as married in this study obtained higher KAP scores than single students. This is probably because married couples need to take charge of housekeeping and food preparation. In contrast, in Kuwait, single students were observed to get higher scores in food handling practices compared to their married counterparts. This could probably because in the country, married couples traditionally live in an extended family home and they tend to hire domestic helpers who aid in food preparation (53).

Higher education programs students reported higher KAP scores, this can be attributed to the greater amount of knowledge of these students by their readings, studying and experience. Part-time jobs have been considered as one of the factors influencing students KAP scores. Their work experience may have contributed to this observation. This factor was also another predictor of food safety KAP results in the present study.

Higher self-rated food safety knowledge levels correspond with higher KAP scores. A similar observation amongst college and university students in the United States was observed that the lower the self-rated food safety knowledge level, the lower was the knowledge mean scores (54). Common major sources of food safety knowledge among participants are internet and family, these were also the main sources of information in a study (40). However, another study reported that people tended to trust healthcare professionals more about COVID-19 related information (55). Food safety information from courses/workshops and healthcare professionals also correspond with higher KAP scores. Swedish university students who reported food safety education as their primary source of knowledge answered a higher number of food safety knowledge questions correctly (40). On the other hand, being informed by family about food safety was related to poorer food preparation safety knowledge (23, 38).

The present study was limited to students who have access to social media since it was conducted online.

CONCLUSION

University students in Jordan have insufficient scores in terms of overall food safety knowledge, attitudes and practices, a matter of great concern especially during the COVID-19 pandemic. However, results of this study report positive behavioral changes due to the pandemic with study participants increasing the adoption of hygienic practices. Fundamentals of food safety should be implemented in university curricula to better educate young adults.

STUDY STRENGTH AND LIMITATIONS

A current very important topic related to COVID-19 and food safety has been addressed in this manuscript. As the sample size was high, the generalizability of the results was at a good level. However, the findings of the study confer to the Jordanian students alone. Perhaps students from other countries would rate differently. Moreover, the survey questions pertaining to "practices" are subject to recall. Errors in recollection in terms or practice may have resulted in bias.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and the protocol were approved by the Department of Nutrition and Food Technology (#26/2021) and Deanship of Graduate Studies (#7/2021) at Jordan University of Science and Technology. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TO, AA-N, and AT contributed to conception and design of the study. TO and AT contributed to manuscript writing. All authors contributed to manuscript revision, read, and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.729816/full#supplementary-material

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Dietary Changes During COVID-19 Lockdown in Adults With Type 1 Diabetes on a Hybrid Artificial Pancreas

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In this retrospective analysis, we examine the impact of the lockdown of the coronavirus pandemic (COVID-19) on eating habits in individuals with type 1 diabetes (T1D) on a hybrid artificial pancreas (HAP). Dietary composition before and during lockdown was assessed by 7-day food records of 12 participants with T1D on HAP (three men and nine women, ages 38 ± 13 years, HbA1c 6.8 ± 0.3%, M ± SD). Continuous glucose monitoring (CGM) metrics and lifestyle changes (online questionnaire) were also assessed. Compared to prelockdown, reported body weight tended to increase during lockdown with no changes in total energy intake. Participants significantly decreased animal protein intake (−2.1 ± 3.7% of total energy intake, $p = 0.048$), but tended to increase carbohydrate intake (+17 ± 28 g/day, $p = 0.052$). These changes were induced by modifications of eating habits at breakfast and lunch during weekdays. Patients consumed more cereals (+21 ± 33 g/day, $p = 0.038$), whole grain (+22 ± 32 g/day, $p = 0.044$), and sweets (+13 ± 17 g/day, $p = 0.021$), and less animal protein sources (−42 ± 67 g/day, $p = 0.054$). Participants showed a more regular meal timing and decreased physical activity. Blood glucose control remained optimal (time-in-range 76 ± 8 vs. 75 ± 7% before lockdown), and daily total insulin infusion increased (42 ± 10 vs. 39 ± 12 I.U., $p = 0.045$). During the lockdown, patients with T1D on HAP modified dietary habits by decreasing animal protein and increasing carbohydrate intake. This increase, mainly concerning whole grain and low-glycemic-index products, did not influence blood glucose control.

Keywords: type 1 diabetes, diet, eating habits, diet composition, glucose control, COVID-19, lockdown, hybrid artificial pancreas

INTRODUCTION

The coronavirus pandemic (COVID-19) yielded a lockdown period in many countries to limit the spread of the virus. In Italy, it started on March 9, 2020, and lasted until May 3, 2020. Lockdown rules did not allow leaving home except for specific reasons (health, work, and shopping for basic needs) with a withdrawal of all non-essential services. Such measures translated into self-isolation and social distancing deeply affecting the lifestyle and behaviors of individuals.

These lifestyle changes, concerning physical activity, stress, and nutrition, and the lack of access to outpatient diabetes clinics, apart from interacting with their diabetes team by teleconsulting, were likely to adversely affect blood glucose control in patients with type 1 diabetes (T1D). However, in a large cohort of patients with T1D, an improvement in blood glucose control during lockdown was observed, which was related to lifestyle changes, including more regular eating habits, evaluated by a qualitative online questionnaire (1).

The possible role of dietary changes on this improvement is not known. Diet composition is a key determinant of blood glucose control in individuals with T1D (2, 3), over specific features of the patient (physical activity, insulin doses, illness, stress, pain, dehydration, and menstrual period) (4). Moreover, it has been shown that the time spent in the optimal range of blood glucose concentration after meals, especially lunch and dinner, strongly predicts daily blood glucose control (5).

Foods containing fiber and/or those with a low glycemic index induce a better metabolic profile (6, 7). In addition, others food components, such as fats and proteins, can affect blood glucose control (8, 9). Quantitative and qualitative changes in eating habits are linked to several factors that could have acted during the lockdown. First, food access and availability can drive the food choices of an individual (10), whereas emotional conditions, i.e., stress, sadness, fear, and anxiety are known to influence dietary patterns and quality of the diet (11).

Changes in eating behaviors during the pandemic have been reported in the general population (12–14) and also in patients with T1D (15). As expected, increased consumption of comfort foods, in particular sweets, was reported. To the best of our knowledge, no studies reporting nutritional composition are available so far.

Therefore, hypothesizing that changes in diet composition could also have contributed to the observed improvement in glucose control, we evaluated the effects of COVID-19-related confinement on dietary habits and nutritional composition in individuals with T1D treated with a hybrid artificial pancreas (HAP).

MATERIALS AND METHODS

This retrospective analysis was conducted in compliance with the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) statement checklist (16).

Participants

Individuals with T1D with a HAP (MiniMed 670G®) attending the Diabetes Outpatient Clinic of Federico II University Hospital (Naples, Italy) and regularly filling in food records during their follow-up were screened for eligibility. All patients with a 7-day food record completed both before (January–February 2020) and during (March–April 2020) lockdown were included in this study. For the use of her/his data, each participant gave informed consent following the approval of the Ethical Committee of the Federico II University.

Methods

Patients were provided with a 7-day food diary along with instructions including descriptive information for identifying foods eaten and guidelines for calculating portion size for various foods. They were asked to record all foods and drinks consumed, including dressing, reporting portions by household measures (cup, spoons, etc.) or weight, and providing as many details as possible (i.e., cooking methods and brands names). Food records were discussed with a skilled dietitian to check potential mistakes and missing information. Energy intake and dietary composition and food group consumption were calculated using the MetaDieta software (Meteda s.r.l., Ascoli-Piceno, Italy).

Qualitative lifestyle data were collected through a not-validated online questionnaire (1), evaluating changes between before and during the lockdown in physical activity (type and frequency), eating habits (food amount, meal timing, and the number of snacks), and body weight (**Supplementary Table S1**).

Blood glucose control was evaluated by the following metrics obtained through subcutaneous continuous glucose monitoring (CGM) (17): time-in-target range (TIR) (3.9–10.0 mmol/L), time-above-target range (TAR, >10.0 mmol/L and >13.9 mmol/L), time-below-target range (TBR, <3.9 mmol/L and <3.0 mmol/L) which were expressed as a percentage (%) of all CGM

TABLE 1 | Daily energy intake and dietary composition obtained through 7-day food records completed before and during the lockdown in the type 1 diabetes (T1D) study participants ($n = 12$).

	Before lockdown	During lockdown	*P*
Energy (kcal)	1,302 ± 317	1,347 ± 337	0.477
Protein (g)	61 ± 12	56 ± 12	0.229
(% TEI)	19 ± 3	17 ± 2	0.045
-Animal (g)	40 ± 9	34 ± 7	0.132
(% TEI)	13 ± 3	10 ± 3	0.048
-Plant (g)	20 ± 6	19 ± 6	0.689
(% TEI)	6.1 ± 1	6.3 ± 1	0.146
Carbohydrate (g)	159 ± 35	177 ± 50	0.052
(% TEI)	48 ± 5	51 ± 5	0.119
-Sugar (g)	44 ± 16	46 ± 16	0.627
(% TEI)	14 ± 4	13 ± 5	0.965
-Starch (g)	104 ± 26	115 ± 41	0.144
(% TEI)	33 ± 5	34 ± 6	0.303
Fat (g)	46 ± 10	48 ± 15	0.757
(% TEI)	33 ± 4	32 ± 5	0.724
-SFA (g)	13 ± 3	13 ± 5	0.658
-MUFA (g)	22 ± 5	20 ± 4	0.621
-PUFA (g)	5.8 ± 1.7	6.2 ± 2.0	0.667
Cholesterol (mg)	192 ± 51	155 ± 52	0.091
Fiber (g)	15 ± 6	15 ± 5	0.813
Alcohol (g)	0.5 ± 1.1	0.3 ± 0.9	0.679
Glycemic index (%)	54 ± 6	55 ± 7	0.475
Glycemic load	86 ± 24	97 ± 33	0.064

M ± SD. MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; TEI, total energy intake.

readings, mean glucose, and glycemic variability which was expressed by the coefficient of variation (CV%).

Statistical Analysis

Data were expressed as mean ± SD unless otherwise stated. Differences between before and during lockdown were assessed by a paired sample *t*-test or Wilcoxon signed-rank test when parameters were not normally distributed. Normal distribution was checked using the Shapiro–Wilk test. A two-side $p < 0.05$ was considered significant. The statistical analysis was performed according to standard methods using the SPSS software version 25 (SPSS/PC; SPSS, Chicago, IL, USA).

RESULTS

All patients with T1D with a HAP were screened for eligibility ($n = 22$). Ten patients were excluded due to: no filling of 7-day food records before lockdown, incomplete dietary data registration, daily energy intake <800 kcal, or problems with the CGM sensor. Therefore, 12 participants (three men and nine women, aged 38 ± 13 years, BMI 25 ± 4 kg/m^2, HbA1c 6.8 ± 0.3%, and diabetes duration 19 ± 9 years) met the inclusion criteria and were included in the analysis. On average, food records were completed 28 ± 9 days after the beginning of lockdown.

Dietary Composition

Dietary energy intake did not differ significantly between before and during lockdown (**Table 1**). During the lockdown, participants decreased protein intake (17 ± 2% of daily total energy intake vs. 20 ± 3% before lockdown, $p = 0.045$), particularly animal protein (10 ± 3% of daily total energy intake vs. 13 ± 3% before lockdown, $p = 0.048$) (**Table 1**). In addition, a non-significant increase in carbohydrate amount was observed (177 ± 50 g/day vs. 159 ± 35 g/day before lockdown, $p = 0.052$) (**Table 1**). These changes were mainly triggered by modifications of dietary habits during weekdays, as shown in **Table 2**, with the reduction in total and animal protein intakes being significant on weekdays but not on weekends.

During the lockdown, dietary composition mainly changed at breakfast and lunch, whereas no significant changes were detected at dinner (**Table 3**). At breakfast, fat intake significantly increased during the lockdown, while animal protein and cholesterol decreased (**Table 3**). At lunch, patients consumed more carbohydrates and less protein, particularly animal proteins, while decreasing cholesterol intake and the glycemic index of the meal (**Table 3**).

TABLE 2 | Daily energy intake and dietary composition on weekdays and weekends obtained through 7-day food records completed before and during the lockdown in the T1D study participants ($n = 12$).

	Weekdays			Weekend		
	Before lockdown	**During lockdown**	***P***	**Before lockdown**	**During lockdown**	***P***
Energy (kcal)	1,259 ± 204	1,299 ± 360	0.638	1,311 ± 369	1,339 ± 278	0.831
Protein (g)	64 ± 11	56 ± 13	0.077	58 ± 18	57 ± 11	0.850
(% TEI)	20 ± 3	17 ± 3	0.022	18 ± 5	17 ± 2	0.542
-Animal (g)	43 ± 10	33 ± 10	0.026	35 ± 14	38 ± 6	0.611
(% TEI)	14 ± 3	10 ± 3	0.010	9 ± 6	10 ± 5	0.532
-Plant (g)	20 ± 5	20 ± 7	0.721	21 ± 8	17 ± 7	0.105
(% TEI)	6 ±1	6 ± 2	0.866	5 ± 3	4 ± 3	0.062
Carbohydrate (g)	156 ± 34	175 ± 53	0.065	171 ± 55	179 ± 56	0.614
(% TEI)	47 ± 5	51 ± 7	0.106	49 ± 8	50 ± 7	0.741
-Sugar (g)	43 ± 16	46 ± 17	0.484	49 ± 20	47 ± 17	0.804
(% TEI)	13 ± 5	14 ± 6	0.784	14 ± 4	13 ± 4	0.554
-Starch (g)	102 ± 27	112 ± 44	0.193	112 ± 38	117 ± 43	0.650
(% TEI)	32 ± 6	34 ± 7	0.261	29 ± 14	28 ± 15	0.837
Fat (g)	46 ± 8	47 ± 17	0.920	48 ± 21	49 ± 12	0.925
(% TEI)	33 ± 4	31 ± 6	0.453	33 ± 8	33 ± 7	0.989
-SFA (g)	13 ± 3	13 ± 6	0.968	13 ± 3	15 ± 1	0.396
-MUFA (g)	22 ± 4	20 ± 5	0.340	22 ± 10	22 ± 6	0.998
-PUFA (g)	6 ± 2	6 ± 2	0.875	6 ± 2	6 ± 3	1.000
Cholesterol (mg)	201 ± 70	148 ± 61	0.070	179 ± 98	164 ± 61	0.693
Fiber (g)	16 ± 5	15 ± 6	0.918	16 ± 8	13 ± 6	0.309
Alcohol (g)	0.4 ± 1	0.3 ± 1	0.841	0.8 ± 2	0.1 ± 0.2	0.214
Glycemic index (%)	54 ± 6	54 ± 6	0.600	54 ± 5	56 ± 11	0.534
Glycemic load	84 ± 24	93 ± 35	0.117	93 ± 38	100 ± 38	0.496

M ± SD. MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; TEI, total energy intake.

TABLE 3 | Energy intake and dietary composition of breakfast, lunch, and dinner obtained through 7-day food records completed before and during the lockdown in the T1D study participants ($n = 12$).

	Breakfast			Lunch			Dinner		
	Before lockdown	During lockdown	*P*	Before lockdown	During lockdown	*P*	Before lockdown	During lockdown	*P*
Energy (kcal)	172 ± 96	175 ± 130	0.771	556 ± 187	541 ± 196	0.569	534 ± 242	574 ± 261	0.256
Protein (g)	12 ± 8	16 ± 3	0.350	29 ± 13	24 ± 13	0.015	31 ± 15	27 ± 14	0.122
(% TEI)	20 ± 7	22 ± 4	0.803	18 ± 7	16 ± 6	0.039	22 ± 9	19 ± 9	0.088
-Animal (g)	7.9 ± 3.2	7.3 ± 4.4	0.200	14 ± 13	11 ± 12	0.046	21 ± 14	18 ± 12	0.138
(% TEI)	17 ± 9	11 ± 9	<0.001	10 ± 8	7 ± 7	0.019	15 ± 9	13 ± 10	0.293
-Plant (g)	1.4 ± 2.1	1.3 ± 2.3	0.841	12 ± 6	11 ± 6	0.210	7.7 ± 4.6	7.6 ± 4.8	0.833
(% TEI)	2.9 ± 4.3	3.6 ± 7.6	0.543	8.2 ± 3.3	8.2 ± 3.6	0.972	5.7 ± 3.3	5.7 ± 3.0	0.934
Carbohydrate (g)	31 ± 16	33 ± 19	0.092	71 ± 23	73 ± 26	0.544	64 ± 32	74 ± 43	0.077
(% TEI)	54 ± 10	55 ± 16	0.771	49 ± 13	53 ± 13	0.040	44 ± 17	48 ± 16	0.105
-Sugar (g)	14 ± 8	15 ± 10	0.091	16 ± 12	14 ± 12	0.120	16 ± 11	20 ± 13	0.060
(% TEI)	30 ± 9	31 ± 6	0.671	11 ± 12	11 ± 9	0.694	12 ± 14	11 ± 9	0.563
Fat (g)	9.1 ± 7.0	12 ± 8.6	0.032	23 ± 12	21 ± 12	0.181	21 ± 13	22 ± 16	0.918
(% TEI)	25 ± 7	29 ± 10	0.034	33 ± 10	31 ± 11	0.291	34 ± 14	32 ± 13	0.389
-SFA (g)	2.5 ± 2.0	2.8 ± 3.1	0.290	4.7 ± 3.7	4.3 ± 4.1	0.527	5.6 ± 4.9	6.3 ± 6.1	0.407
-MUFA (g)	2.1 ± 1.7	2.3 ± 1.7	0.425	11 ± 5	9 ± 5	0.063	10 ± 6	9 ± 6	0.203
-PUFA (g)	0.8 ± 0.7	1.0 ± 0.8	0.069	3.0 ± 2.0	2.5 ± 1.7	0.070	2.6 ± 1.8	2.8 ± 2.9	0.682
Cholesterol (mg)	24 ± 20	19 ± 18	0.092	69 ± 80	46 ± 61	0.041	110 ± 121	82 ± 96	0.151
Fiber (g)	1.7 ± 1.6	2.2 ± 2.1	0.126	7.8 ± 4.6	6.8 ± 4.0	0.124	6.7 ± 4.4	6.7 ± 3.9	0.950
Glycemic index (%)	48 ± 14	49 ± 14	0.692	51 ± 11	48 ± 10	0.023	58 ± 14	62 ± 14	0.340
Glycemic load	16 ± 9	29 ± 6	0.115	36 ± 13	35 ± 16	0.827	38 ± 23	45 ± 32	0.077

M ± SD. MUFA, monounsaturated fatty acids; PUFA, polyunsaturated fatty acids; SFA, saturated fatty acids; TEI, total energy intake.

Consumption of food groups is shown in **Figure 1**. During the lockdown, the patients significantly increased the consumption of cereals (177 ± 64 vs. 156±48 g/day before lockdown, $p = 0.038$, **Figure 1A**). This corresponded to an increase in whole grain products (157 ± 61 vs. 135±45 g/day, $p = 0.044$) with no changes in refined cereals (20 ± 23 vs. 22 ± 22 g/day, $p = 0.728$). The intake of pasta and rice increased during lockdown (404 ± 158 vs. 321 ± 165 g/week before lockdown, $p = 0.038$), whereas bread consumption did not change (463 ± 370 vs. 465 ± 281 g/week before lockdown, $p = 0.970$). The overall consumption of animal-derived products tended to decrease (247 ± 86 vs. 315 ± 83 g/day before lockdown, $p = 0.054$) with no major changes in the individual main sources of protein (**Figure 1B**). During the lockdown, the intake of sweets significantly increased (29 ± 26 vs. 16 ± 18 g/day before lockdown, $p = 0.021$, **Figure 1D**), and it mainly included chocolate and pastries (84 ± 7 1 vs. 24 ± 53 g/week before lockdown, $p = 0.079$). No changes were observed for other main food groups (**Figures 1C,D**).

Blood Glucose Control

No significant differences were observed in the control of blood glucose between before and during the lockdown in TIR (75 ± 7 and 76 ± 8%, $p = 0.652$), TAR (26 ± 7 and 28 ± 9%, $p = 0.608$), TBR (3.8 ± 3 and 4.2 ± 3%, $p = 0.746$), and mean glucose (8.70 ± 1.0 and 8.36 ± 0.5 mmol/L, $p = 0.420$), respectively, with a tendency to reduced glycemic variability (CV%) during lockdown (30 ± 5 vs. 33 ± 4 before lockdown, $p = 0.145$).

Daily total insulin doses increased significantly during lockdown (42 ± 10 vs. 39 ± 12 I.U. before lockdown, $p = 0.045$), mainly due to an increase in basal infusion (23 ± 8 vs. 21 ± 7 I.U., $p = 0.120$).

Lifestyle Changes

Data on lifestyle changes are reported in **Supplementary Table S2**. During the lockdown, seven participants reported a slight increase in body weight (+2 kg), three reported weight loss (−3 kg), and two reported no change at all. Ten participants reported a reduction in total physical activity. Eating habits were characterized by a more regular meal pattern in seven patients and no increase in snacking (no changes in 10 participants and a decrease in two participants).

DISCUSSION

We describe the impact of total lockdown on dietary habits in patients with T1D on a hybrid artificial pancreas. Our results indicate that lockdown for COVID-19 induced small but relevant modifications in dietary habits. In brief, a reduction of protein, particularly animal protein, and an increase in carbohydrate intake were detected. As confirmed by the evaluation of food groups consumption, these changes were mainly due to a reduction in the intake of overall animal sources of protein and an increase in the intake of whole grain cereals. They are partially in line with the current nutritional recommendations for a healthier dietary pattern in patients with T1D to achieve good blood glucose control (2, 3). On the other hand, during the lockdown, patients increased the consumption of sweets

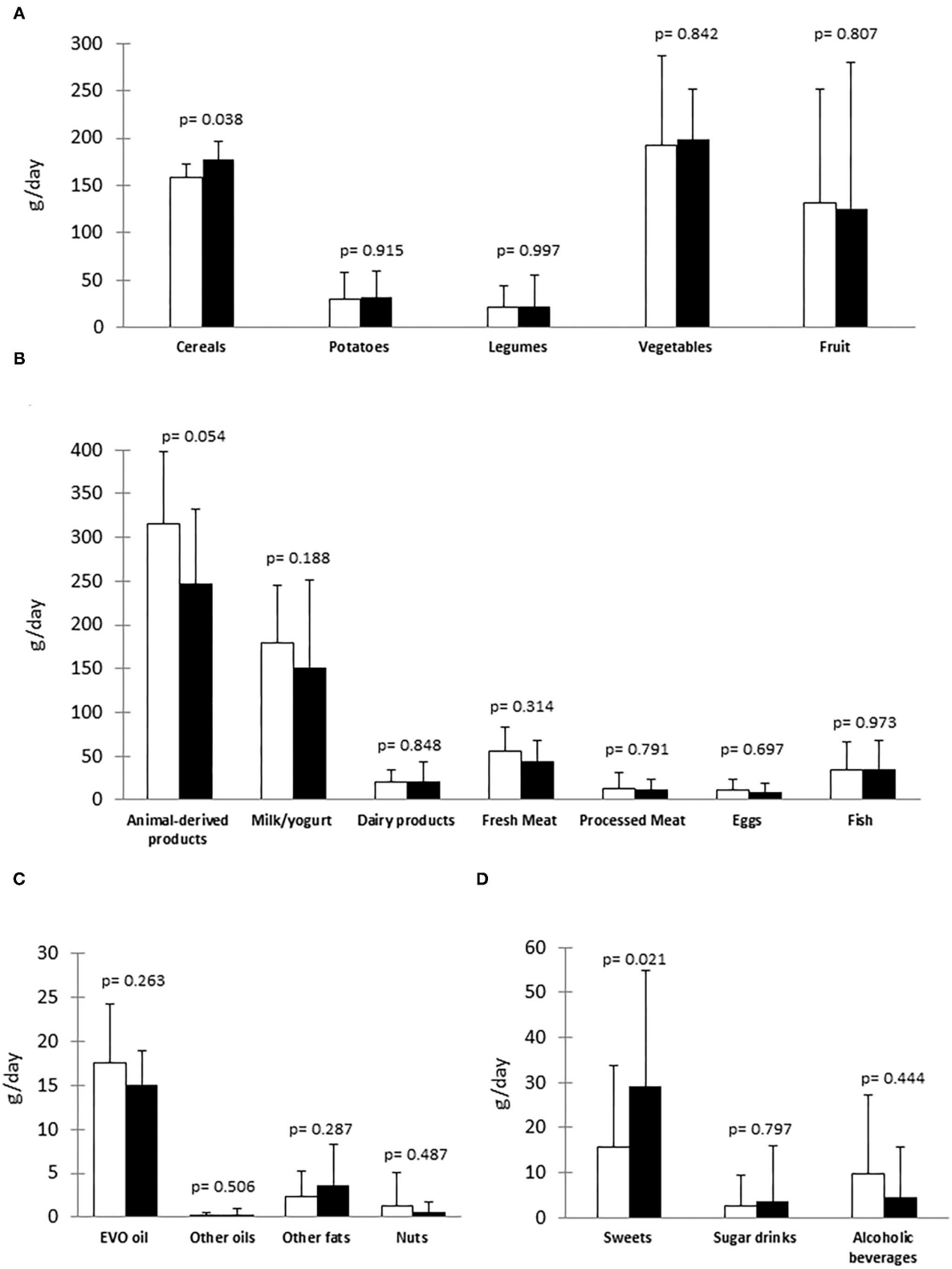

FIGURE 1 | Food groups consumption before lockdown (White column) and during lockdown (Black column) in the type 1 diabetes (T1D) study participants ($n = 12$). **(A)** Main sources of carbohydrate/fiber; **(B)** Main sources of protein; **(C)** Main sources of fat; **(D)** Other food and beverages. EVO oil, extra-virgin olive oil.

(mainly chocolate and pastries) around dinner time by 13 g. It is of note that these changes were in line with those observed in the general Italian population (14) and in patients with diabetes (15).

During the lockdown, eating habits were characterized by a more regular meal timing and snacking pattern that are considered as key features of a healthier dietary pattern, especially in individuals with T1D (18). We hypothesize that these changes in dietary habits were mainly related to the increased time spent at home which induced patients to consume cooked meals (i.e., meals including pasta and rice) rather than sandwiches or toasts, which would have resulted in higher consumption of foods containing animal protein. This is in line with the higher amount of carbohydrates consumed at lunch from foods with a lower glycemic index.

During confinement, participants slightly increased their body weight, likely due to the reduced physical activity, while the changes in daily energy intake were not statistically significant. In this cohort of patients with T1D on a HAP, blood glucose control did not change significantly during the lockdown, as it was expected considering the high performances of this insulin infusion system in keeping blood glucose in the optimal range. Furthermore, a trend to reduced glucose variability was observed. It is important to underline that blood glucose control was maintained through an increased basal insulin infusion, which is in line with impairment of insulin sensitivity due to decreased physical activity.

Our study has some strengths, particularly in relation to the use of the weighted 7-day food records that represent the gold standard for evaluating eating habits at an individual level (19). Additionally, lockdown for COVID-19 provided a unique opportunity to evaluate the effects of home confinement in a free-living T1D population on HAP.

A limitation of this study is the small sample size, which may have reduced its statistical power, impeding to detection of possible changes. Another limitation is the possible underreporting that is common to all types of food recordings. However, we compared intraindividual changes and, therefore, the same potential mistakes could be expected on both occasions. In addition, food records were discussed with a skilled dietitian to check for potential errors. A further limitation includes lifestyle changes that were investigated by a simple non-validated questionnaire. This questionnaire had been specifically structured to retrieve information related to the unique context of the lockdown (1). As for generalizing the results of this study to a wider T1D population, it must be considered that they refer to a cohort living in Italy, characterized by specific nutritional habits and only concern patients on a hybrid artificial pancreas.

In conclusion, our results show that during lockdown for COVID-19, Italian patients with T1D on a HAP changed some of their eating habits with no major effects on blood glucose control. Overall, they experienced a more regular eating pattern that also included a potentially healthy reduction in the intake of animal protein sources and increased consumption of meals containing foods with a lower glycemic index. Therefore, increasing good quality carbohydrate sources may not lead to worsening glycemic control.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Ethics Committee Federico II. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

CV, IC, GA, and LB contributed to the design of the study and the analysis and interpretation of data. CV, IC, and LB wrote the first draft of the report. GR, AAR, and GA provided relevant intellectual contributions to the development of the report. SD, MP, AR, and RD collected and analyzed the data. GA is the guarantor of this study, had full access to all the data in the study, takes responsibility for the integrity of the data, and the accuracy of the data analysis. All authors provided substantial contributions to the acquisition of data, critically revised the report, and gave final approval of the version to be submitted for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.752161/full#supplementary-material

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The Impact of COVID-19 Pandemic on Weight and Body Mass Index in Saudi Arabia: A Longitudinal Study

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The COVID-19 pandemic has had a major impact on various health conditions. The objective of this study was to assess the impact of the COVID-19 pandemic on body weight and body mass index (BMI) in Saudi Arabia. We used electronic health records obtained from a healthcare system representing five hospitals in three different regions in the Kingdom to examine the change in weight utilizing a longitudinal design. The study included all adults who had visited outpatient clinics in two different time points, pre-2020 (years 2018 and 2019 prior to COVID-19) and post-2020 (the year 2021). Weight and BMI changes in percentages were described. Also, bivariate chi-square test, paired *t*-test, and multivariable multinomial logistic regression model were used for the analyses. A total of 165,279 individuals were included in the study. On average, a significant weight gain of 0.33 kg (95% CI: 0.29–0.36) was observed in our study. Approximately 10% of the population had shifted to either overweight or obese BMI classes during the study period, as 4.8% of those with normal BMI pre-2020 had shifted to overweight or obese classes at post-2020, and 5.1% of those who were overweight had shifted to obese class. Also, 23.1% of the population had gained 5% or more of their pre-2020 weight, while 17% had lost 5% or more. Young individuals were over three times more likely to gain 5% or more than older individuals (OR: 3.34; 95% CI: 3.12–3.56). Females had 24% higher odds to gain 5% or more of their pre-2020 weight than males (OR: 1.24; 95% CI: 1.21–1.27). Diabetics were 27% more likely to lose 5% or more than non-diabetics (OR: 1.27; 95% CI: 1.23–1.31). Our findings provide insights into the impact of COVID-19 on weight and population health. Further investment in interventions for weight management is warranted during similar circumstances such as lockdowns due to infection waves or new variants. Future studies are also needed to explore the modifications that have occurred during the pandemic in the weight-related lifestyle factors such as dietary choices and physical activity levels.

Keywords: COVID-19 pandemic, weight change, body mass index, obesity, Saudi Arabia

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INTRODUCTION

The prevalence of obesity has been increasing in most countries over the past five decades (1), rendering this a global phenomenon and a major public health concern. As per the WHO report, over 1.9 billion are overweight, and 650 million individuals are obese (2). The recent World Health Survey in Saudi Arabia (KSAWHS) indicated that the prevalence of overweight and obesity in 2019 was 38 and 20%, respectively, in the Kingdom (3).

On the 11th of March 2020, COVID-19, an acute respiratory syndrome caused by SARS-CoV-2, was declared a global pandemic by the World Health Organization (WHO) (4). Worldwide, around 261 million cases were reported; of which, there were approximately 5.2 million deaths (5). In Saudi Arabia, approximately 550,000 cases and 8,800 deaths were documented (6). Many countries worldwide have enforced lockdowns and strict measures to reduce the spread of the virus, and they may reinforce these measures again due to new variants (7), while the world is anxiously awaiting updates on the Omicron variant (8). Saudi Arabia had imposed both partial curfews and full 24-h lockdowns between March 23-June 21, 2020, which included the holy month of Ramadan and Eid Al-Fitr (9). The measures applied to reduce the infection transmissibility include social and travel restrictions and even complete lockdowns involving a full closure of recreation centers and gyms (10).

As a result of the COVID-19 pandemic, many lifestyle habits may be unintentionally affected by lockdowns and "stay-at-home" instructions. Some important but undesirable consequences of staying at home may include weight gain, physical inactivity, and social isolation (11). The former is of particular concern, given that weight gain during adulthood is associated with a higher risk of chronic diseases (12). Further, stress and anxiety from the pandemic may be associated with health issues, including poor dietary choices and weight gain (13, 14). Several studies across the globe reported weight gain during the COVID-19 lockdowns (15–21). In the United States, two studies found that the proportion of those who have gained weight during the pandemic ranged between 22 and 27.5% (15, 16). Furthermore, results from a longitudinal study including two-time points indicated an increase of 0.62 kg from the "peak-lockdown" to "post-lockdown" periods in the United States (17). In addition, the weight gain in Europe during the pandemic ranged between 1.5 and 3 kg (18, 19). Also, an average of 0.5 kg weight increase had been observed in China (21). In Saudi Arabia, the proportion of those who reported a weight gain of 2–4 kg during the pandemic was 27.3%, with a significant increase in the proportion of those who reported "highly increased" weight during the pandemic as compared to before the pandemic (22). Such impact of the COVID-19 pandemic on weight will influence future disease burden and population health.

Risk groups of weight gain during the pandemic have been previously investigated (23–26). For example, women and youth were more likely to gain weight during the pandemic, particularly during the lockdowns (23, 24). Also, comorbidities such as hypertension and diabetes were explored for their potential association with weight change during the pandemic (25, 26). Interestingly, those with diabetes were more likely to lose weight during the pandemic, which may have been mediated by an improvement in the glycemic control (26).

Indeed, lockdowns and "stay-at-home" instructions present new obstacles to maintaining a healthy lifestyle. As of yet, the impact of the COVID-19 pandemic on weight in Saudi Arabia remains unclear. Therefore, this retrospective longitudinal study aims to compare the weight of patients visiting the National Guard Health Affairs (NGHA) in Saudi Arabia before 2020 and after 2020. The year 2020 was used as an "intervention-like" period between the two-time points (pre-2020 and post-2020), mainly because 2020 was the year in which lockdown and most restriction measures were applied in the Kingdom. This study also explores the potential risk groups associated with weight gain in our population.

METHODS

Study Design

This is a longitudinal study based on retrospective data obtained from the patient's medical records at the National Guard Health Affairs (NGHA), Saudi Arabia. All data were retrieved from BESTcare, the hospital's electronic health system. This health system covers ∼700,000 individuals receiving free full-healthcare services in five hospitals around the main three regions of Saudi Arabia (Central, Western, and Eastern). Data retrieved from the BESTCare system were grouped into two primary time points: "pre-2020," which included data from 2018 to 2019, and "post-2020," which included data from 2021. We identified 2020 as the intervention-like period as that it included lockdown or restriction measures. Thus, no data were collected from 2020.

Study Population and Sample Size Calculation

The inclusion criteria were ≥17-year-old adults who visited any outpatient clinic in the health system. Weight and height measurements are routine practices for any patients visiting any of NGHA clinics taken by registered nurses. The study included measurements taken during any patient's visits in 2018, 2019, and 2021. Individuals with a history of cancer were excluded as we believe their prognosis may affect their anthropometric measurements, including weight. The final analytical sample included 165,279 subjects with two weight measurements (one during pre-2020 and another during post-2020). Assuming a mean difference of 0.2 kg between pre-and post-2020 and a standard deviation of 10 kg with a type I error of 0.05 and 80% statistical power, the sample size needed would have been 19,625 subjects (Power analysis **Supplementary Table S1** in Supplementary Material); hence we believe that we have considerably sufficient power in the study with the final analytical sample of 165,279 subjects. This study was reviewed and approved by the Institutional Review Board (IRB) at King Abdullah International Medical Research center (KAIMRC).

Measurements

Anthropometric measurements, including body weight in kilograms (kg) and height in centimeters (cm), were collected

TABLE 1 | Characteristics of the study population based on the weight change status ($N = 165,279$)[a].

Variable	Level	Total	≥5% Weight loss	<5% change	≥5% Weight gain	*P*-value[b]
Age groups, *n* (%)	17–25	23,429 (14.2)	4,160 (14.8)	10,741 (10.9)	8,528 (22.4)	<0.001
	26–45	71,328 (43.2)	12,200 (43.3)	38,373 (38.8)	20,755 (54.5)	
	46–64	48,734 (29.5)	7,783 (27.6)	34,680 (35.0)	6,271 (16.5)	
	≥65	21,788 (13.2)	4,016 (14.3)	15,223 (15.4)	2,549 (6.7)	
Gender, *n* (%)	Female	101,320 (61.3)	18,030 (64.0)	58,301 (58.9)	24,989 (65.6)	<0.001
	Male	63,959 (38.7)	10,129 (36.0)	40,716 (41.1)	13,114 (34.4)	
Marital status, *n* (%)	Married	113,693 (68.8)	19,626 (69.7)	70,631 (71.3)	23,436 (61.5)	<0.001
	Unmarried	41,606 (25.2)	6,957 (24.7)	21,779 (22.0)	12,870 (33.8)	
	Other/Unknown	9,980 (6.0)	1,576 (5.6)	6,607 (6.7)	1,797 (4.7)	
Geographic region, *n* (%)	Central	94,558 (57.2)	16,389 (58.2)	56,926 (57.5)	21,243 (55.8)	<0.001
	Western	35,306 (21.4)	5,842 (20.8)	20,811 (21.0)	8,653 (22.7)	
	Eastern	35,415 (21.4)	5,928 (21.1)	21,280 (21.5)	8,207 (21.5)	
Diabetes, *n* (%)	Yes	54,545 (33.0)	10,170 (36.1)	36,487 (36.9)	7,888 (20.7)	<0.001
	No	110,734 (67.0)	17,989 (63.9)	62,530 (63.2)	30,215 (79.3)	
Hypertension, *n* (%)	Yes	42,967 (26.0)	7,492 (26.6)	29,886 (30.2)	5,589 (14.7)	<0.001
	No	122,312 (74.0)	20,667 (73.4)	69,131 (69.8)	32,514 (85.3)	
Dyslipidemia, *n* (%)	Yes	56,642 (34.3)	9,362 (33.3)	39,897 (40.3)	7,383 (19.4)	<0.001
	No	108,637 (65.7)	18,797 (66.8)	59,120 (59.7)	30,720 (80.6)	
Stroke, *n* (%)	Yes	2,807 (1.7)	671 (2.4)	1,683 (1.7)	453 (1.2)	<0.001
	No	162,472 (98.3)	27,488 (97.6)	97,334 (98.3)	37,650 (98.8)	
COVID infection, *n* (%)	Yes	8,707 (5.3)	1,556 (5.5)	5,256 (5.3)	1,895 (5.0)	0.005
	No	156,572 (94.7)	26,603 (94.5)	93,761 (94.7)	36,208 (95.0)	

[a]*Data are presented as frequency and percentages (%).* [b]*Derived from Chi-square test.*

in each visit for each patient during the period of interest. Body mass index (BMI) was calculated as kg/m^2. Based on the definition of WHO, we classified BMI classes as underweight (BMI $<$ 18.5 kg/m^2), normal weight (BMI $=$ 18.5–24.9 kg/m^2), overweight (BMI $=$ 25–29.9 kg/m^2), and obese (BMI $\geq$ 30 kg/m^2) (2). Implausible BMI values were excluded ($<$12 or $>$45).

Covariates

Several demographic and clinical variables were retrieved, including age (17–25, 26–45, 46–64, ≥65), gender (male and female), marital status (married, unmarried, other/unknown), and geographic region (central, western, eastern). The patient's medical history of comorbidities was also obtained. We identified comorbidities including diabetes, hypertension, dyslipidemia, stroke, and COVID-19 infection based on the International Statistical Classification of Diseases and Related Health Problems (ICD-10) code (27).

Statistical Analysis

Descriptive statistics were reported as frequency and percentages. Bivariate chi-square test was used to measure the association between several variables and percent weight change. The percent weight change was calculated by subtracting the weight at post-2020 from the weight at pre-2020 then dividing the difference by the weight at pre-2020. The change was then categorized as follows: weight gain ($\geq$+5%), unchanged weight ($<$ +5% and $>$-5%), and weight loss ($\leq$-5%). The mean difference between average weight at pre-2020 and average weight at post-2020 was tested using a paired *t*-test. In addition, a multivariable multinomial logistic regression model was used to evaluate predictors associated with the percent weight change between pre-and post-2020. The multivariable logistic regression model included the following covariates: baseline age ($>$65 as the reference), gender (males as the reference), marital status (unmarried/unknown individuals as the reference), geographic region (central as the reference), and medical history including diabetes, hypertension, and dyslipidemia. Model assumptions of paired *t*-test and multinomial logistic regression were evaluated. All analyses were conducted using Stata software for statistical analysis version 15 (STATA Corp., College Station, TX).

RESULTS

A total of 165,279 subjects were included in the study; of which, 43.2% aged 26–45, 61.3% were females, 68.8% were married, 57.2% resided in the Central region, 33% were diabetics, 26% were hypertensive, 34.3% had dyslipidemia, 1.7% had a history of stroke, and 5.3% had a previous COVID-19 infection (**Table 1**). The characteristics of the study participants included in the study based on their weight change status were also reported in **Table 1**.

TABLE 2 | Change in BMI and weight pre- and post-2020[a].

		Mean	S.D.[b]	95% C.I.	
BMI change (kg/m^2)	Post-2020	29.74	6.8	29.71	29.78
	Pre-2020	29.60	6.9	29.57	29.64
	Diff	0.14	2.9	0.12	0.15
Weight change (kg)					
Overall	Post-2020	76.67	18.1	76.58	76.76
	Pre-2020	76.34	18.4	76.25	76.42
	Diff	0.33	7.4	0.29	0.36
Male					
	Post-2020	80.91	18.4	80.77	81.06
	Pre-2020	80.72	18.9	80.57	80.86
	Diff	0.19	7.9	0.13	0.25
Female					
	Post-2020	73.99	17.4	73.88	74.09
	Pre-2020	73.57	17.6	73.46	73.68
	Diff	0.41	7.1	0.37	0.46
Weight change within BMI classes (kg)					
Normal BMI	Post-2020	60.75	10.1	60.64	60.85
	Pre-2020	58.74	8.3	58.65	58.82
	Diff	2.01	6.3	1.94	2.07
Overweight	Post-2020	72.99	10.3	72.90	73.09
	Pre-2020	72.29	8.8	72.21	72.37
	Diff	0.70	6.1	0.64	0.75
Obese	Post-2020	89.33	15.7	89.21	89.44
	Pre-2020	90.27	14.9	90.16	90.37
	Diff	−0.93	7.8	−0.99	−0.88

[a]*Derived from paired t-test to test for the mean difference from pre-2020 to post-2020.*
[b]*Standard Deviation.*

Those who gained 5% or more of their pre-2020 weight at post-2020 were likely to be 26–45 years old (54.5%), females (65.6%), married (61.5%), and residents of the central region (55.8%). As for comorbidities, individuals without diabetes, hypertension, or dyslipidemia had the highest percentages of weight gain by 5% or more of their pre-2020 weight with 79.3, 85.3, and 80.6%, respectively. Patients who have been diagnosed with stroke and COVID-19 had the lowest proportions of demonstrating weight gain with 1.2 and 5%, respectively (**Table 1**).

The BMI and weight changes from pre-2020 to post-2020 **(Table 2)** showed an average increase of 0.14 kg/m^2 in the BMI (95% CI: 0.12–0.15) and an average increase of 0.33 kg in weight (95% CI: 0.29–0.36). Across gender, weight increased by an average of 0.19 kg (95% CI: 0.13, 0.25) among males, and 0.41 kg (95% CI: 0.37, 0.46) among females. During the study period, those with normal BMI had gained an average of 2.01 kg (95% CI: 1.94–2.07), while overweight individuals had gained an average of 0.7 kg (95% CI: 0.64–0.75). In contrast, obese individuals had lost an average of 0.93 kg (95% CI:−0.99,−0.88) (**Table 2**).

There were also increases from pre-2020 to post-2020 in the proportions of those who were overweight (29.7 vs. 30.4%) and obese (44.7 vs. 45.1%). In contrast, there was a decrease in the proportion of those who had a normal BMI pre-2020 as compared to post-2020 (22 vs. 21.4%) (**Figure 1**).

Approximately 10% of the population had shifted to either overweight or obese classes during the study period, as 4.8% of those with normal BMI pre-2020 had shifted to overweight or obese classes at post-2020, and 5.1% of those who were overweight had shifted to obese class (**Figure 2**). Comparing the change in BMI class between pre-2020 and post-2020, there were 13.5% who had shifted to upper BMI class (including those who were underweight to normal weight) during the study period and 8.9% who had shifted to lower BMI class, while 77.6% remained in their same pre-2020 BMI class (**Figure 3A**). Similarly for the change in weight, there were 23.1% had gained 5% or more of their pre-2020 weight at post-2020, and 17% had lost 5% or more of their pre-2020 weight, while around 60% had <5% or no change in their pre-2020 weight at post-2020 (**Figure 3B**).

Results from the multinomial logistic regression model suggested that youth (17–25) were over three times more likely to gain 5% or more of their pre-2020 weight during 2020 than the elderly (>65 years) (OR: 3.34; 95% CI: 3.12–3.56). Moreover, those who aged 26–45 years were over two-fold more likely to gain 5% or more of their pre-2020 weight during 2020 than the elderly (>65 years) (OR: 2.37; 95% CI: 2.24–2.50). Furthermore, females had 24% higher odds of gaining 5% or more of their pre-2020 weight during 2020 than males (OR: 1.24; 95% CI: 1.21–1.27). On the other hand, diabetic individuals were 27% more likely to lose 5% or more of their pre-2020 weight during 2020 than non-diabetics (OR: 1.27; 95% CI: 1.23–1.31) (**Table 3**).

DISCUSSION

This present study found that close to a quarter (23%) of our population have gained 5% or more of their pre-2020 weight. The average weight gain from pre-2020 to post-2020 was higher for females. These findings underline the negative externalities of COVID-19 in terms of its impact not only on infections but to other health conditions that impact population health.

Our findings are consistent with previous findings from different regions worldwide (15–21). In the United States, Zachary et al. (15) and Flanagan et al. (16) found that approximately 22 and 27.5%, respectively, of their samples had gained weight during the lockdown, which are comparable to our findings. Although their study was cross-sectional using a survey, Zachary et al. (15) collected data on an ordinal scale of multiple intervals of weight change, which may have reduced the amount of information error. Flanagan et al. (16) have used a validated instrument to collect their data, which may have enhanced the internal validity of their results. However, women were overrepresented in their study (80%); hence, the weight gain may have been slightly overreported. Further, Bhutani et al. (17) conducted a longitudinal study on weight change from the "peak-lockdown" to "post-lockdown" periods in the United States, in which they found an increase of 0.62 kg. This is relevant to

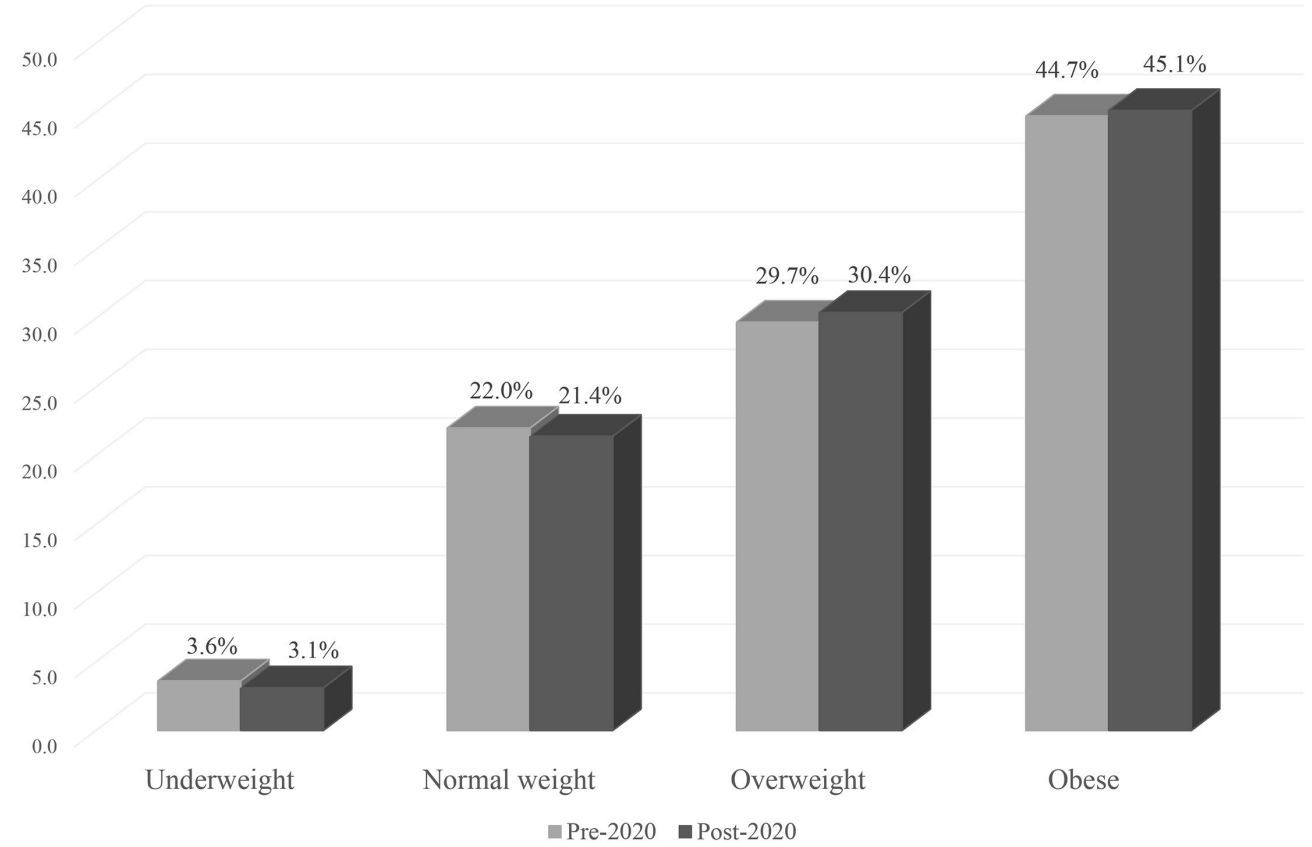

FIGURE 1 | Changes in BMI classifications from pre-2020 to post-2020.

our study because we also used longitudinal data from two-time points, "pre-2020 and post-2020." However, the average weight gain difference between Bhutani et al. study and ours may be explained by the timing of data collection. They collected their baseline data during the lockdown period, while we used retrospective data from pre-2020 as baseline data. Besides, they used self-report data, which may have overestimated the weight gain in their study.

In Europe, Sidor et al. (18) reported that 30% of their sample had gained 3 kg during the COVID-19 quarantine in Poland. Furthermore, Pellegrini et al. (19) reported a 1.5 kg increase in their population average weight 1 month after the lockdown period in Italy These increases were larger than what we found in our study, which can be attributed either to the periods of their data collection (e.g., during or soon after the lockdown periods) or to a potential measurement error due to self-report weight information. In our study, on the other hand, we used longitudinal data from two time points, and the measurements were taken by registered nurses in the NGHA clinics, which should have minimized the amount of measurement error. Also in Europe, Micheletti Cremasco et al. (20) found an average weight gain of 0.4 kg which is relatively comparable to our finding. Although they collected their data soon after the lockdown, their study was cross-sectional, relying on the individual's perception of gaining weight, which could have been prone to a measurement error.

In China, Zhu et al. (21) conducted a cross-sectional study early during the pandemic and found an average gain weight of 0.5 kg, which was slightly higher than that in our study. Although they gathered a broad list of related dietary and lifestyle factors, the cross-sectional design accompanied by the self-report information may have overestimated the weight gain.

In Saudi Arabia, Abdulsalam et al. (22) found a significant increase in the proportion of those who reported "highly increased" weight during the pandemic as compared to before the pandemic (23.5 vs. 12.3%). They also found that the proportion of those who reported a weight gain of 2–4 kg during the pandemic was 27.3%, which is considerably higher than that in our study. This can be attributed to the large proportion of those aged 19–29 years in their sample (55%), whereas this age group represents roughly around 15% in our study. Nonetheless, this age group in our study has over three-fold higher odds of gaining 5% or more of their pre-2020 weight as compared to the elderly (>65 years old), which could be relevant to Abdulsalam et al. (22) findings.

Multiple factors may have led to weight gain during the pandemic such as physical inactivity, sedentary behaviors, and screen time (28–30). Access to physical activity resources, including recreation places, gyms, and sports, have been limited

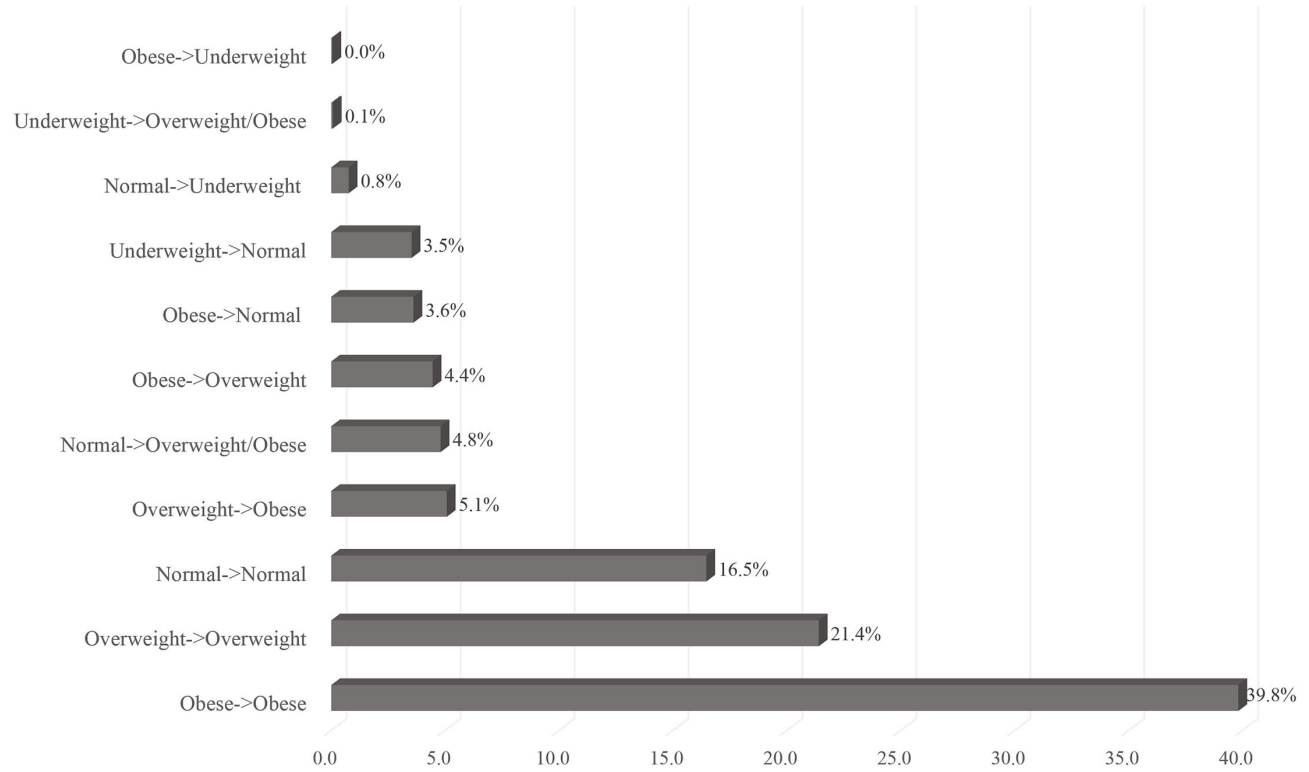

FIGURE 2 | Shift in BMI classifications from pre-2020 to post-2020.

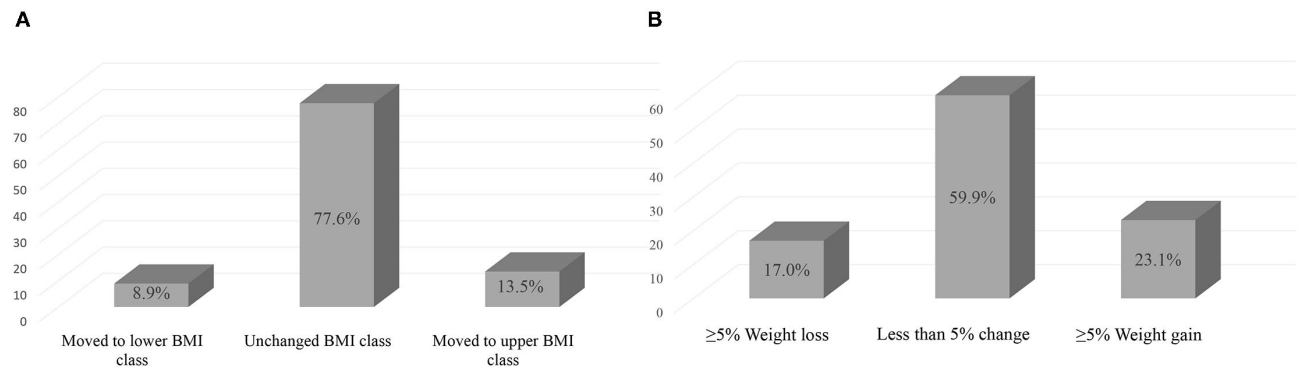

FIGURE 3 | Changes in **(A)** BMI classification and **(B)** weight from pre-2020 to post-2020.

(31). The positive association of physical inactivity and sedentary lifestyle with weight has been well established (32). In addition, dietary habits could be another potential factor contributing to weight gain during the pandemic (28). Adverse changes in eating habits such as overeating, additional meals, snacking, and sweets have been observed during the pandemic (19, 23). Furthermore, it has been reported that individuals consumed less fruits and vegetables and more canned food during lockdown periods (15, 18).

In Saudi Arabia, the proportion of people who spent 6 h or more a day watching TV or working on computers before the pandemic had significantly increased during the pandemic as compared to before the pandemic (36.2 vs. 12.5%) (22). Further, the proportion of individuals with poor dietary habits had significantly increased during the pandemic as compared to before the pandemic (27.3 vs. 17.6%) (22). Regarding the level of physical activity in the Kingdom, the proportion of those who engaged in 3–4 h/week of physical activity before the pandemic had significantly dropped during the pandemic (16.9 vs. 11.9%) (22). The lockdown period in Saudi Arabia was imposed on March 23, 2020, and lasted until June 21, 2020, which included the holy month of Ramadan, followed by the Eid Al-Fitr holiday.

TABLE 3 | Multinomial logistic regression of predictors of 5% weight change among the study population[a].

Variable		≥5% Weight loss vs. <5% change[b]	≥5% Weight gain vs. <5% change[b]
Age group	17–25	1.52 (1.42–1.63)	3.34 (3.12–3.56)
	26–45	1.23 (1.18–1.30)	2.37 (2.24–2.50)
	46–64	0.86 (0.82–0.90)	1.00 (0.94–1.05)
	>65	Ref	Ref
Gender	Female	1.24 (1.20 (1.27)	1.24 (1.21–1.27)
	Male	Ref	Ref
Marital	Married	1.07 (1.03–1.12)	1.07 (1.03–1.10)
	Unmarried/Other/Unknown	Ref	Ref
Region	Western	0.95 (0.91–0.98)	1.03 (0.99–1.06)
	Eastern	0.96 (0.92–0.99)	0.96 (0.93–0.99)
	Central	Ref	Ref
Diabetes	Yes	1.27 (1.23–1.31)	0.91 (0.88–0.94)
	No	Ref	Ref
Hypertension	Yes	1.02 (0.98–1.06)	0.95 (0.91–0.99)
	No	Ref	Ref
Dyslipidemia	Yes	0.79 (0.77–0.82)	0.64 (0.62–0.66)
	No	Ref	Ref

[a]*Data are presented as Odds Ratio (OR) and 95% Confidence Interval (CI).* [b]*Change of <5% is the reference category for the dependent variable (weight change).*

The consumption of high-caloric foods enriched with sweets and salts resulting in weight gain has been observed during the holy month of Ramadan in Saudi Arabia (33). Moreover, weight gain has been previously investigated during holidays, as Yanovski et al. (34) assessed weight change during the holiday season (November-January). They found an average weight gain of 0.37 kg during the holiday seaso. This finding is very similar to our study, which the average weight gain was 0.33 kg.

Another factor that may have played a role in weight change during the pandemic is the impact on mental health. This may have contributed to or even exacerbated poor eating habits and weight gain, as reported by several studies (35–37). Levels of stress, anxiety, depression, and other mental disorders have been increased during the COVID-19 pandemic (14). Mason et al. (13) reported that eating to cope with stress is common among young adults explaining the higher likelihood of gaining weight among youth in our study. These dietary choices—triggered by mental stressors—combined with physical inactivity and sedentary lifestyle may have contributed to weight gain in our study.

Our study also found that females have higher odds of gaining weight. This may be explained by women's response to stress by poor dietary behaviors, as Tourkmani et al. (38) suggested. Additionally, we found that people with diabetes have higher odds of losing weight in our study. A possible explanation may be related to the teleconsultation offered to people with diabetes to reduce COVID-19 associated risks. A study conducted in Saudi Arabia found that telemedicine during the pandemic had improved glycemic control among those with uncontrolled type 2 diabetes (38). Improved glycemic control during the pandemic has also been reported by other studies (26, 39). Such improvement may be accompanied by other lifestyle components such as a healthy diet and physical activity.

On the other hand, we found that 17% in our study have lost 5% or more of their pre-2020 weight. That estimate is comparable to findings previously reported by other research groups (15, 17, 18). In particular, Zachary et al. (15) found approximately 19% of their participants had lost weight during the "self-quarantine," which is also relatively comparable to our study as we found 17% of the population who had lost 5% or more of their pre-2020 weight. This could perhaps be related to those who benefited from the working at home policy to increase their physical activity levels and/or prepare their healthy meals.

Interestingly, we observed approximately 2 kg weight loss among obese individuals in our study, whereas Flanagan et al. (16) found that the percentage of obese individuals who had gained weight during the lockdown was higher than that of those with normal weight (33 vs. 27%) (16). Such a discrepancy between Flanagan et al. study (16) and ours may be attributed to the time frame of the data collection. That is, Flanagan et al. (16) collected their data using a survey during the lockdown period in the United States, while we used longitudinal data—before 2020 and after 2020— retrieved from medical records. Furthermore, the lockdown period in Saudi Arabia was lifted on June 21, 2020 (6 months before the post-2020 data was collected), which perhaps was an opportunity for obese individuals in our study to lose more weight after the lockdown.

In this present study, we used longitudinal data collected from the patient's charts. Such type of data may ensure higher validity and reliability as compared to self-reported data using surveys. However, our study has some limitations. First, the data represents those who visited the hospital in 2021. Therefore, we are unable to generalize the findings to the underlying population. However, measuring weight and height is a standard procedure in all routine appointments; hence, we have no reason to believe that our population differs substantially from the Saudi population. Second, we did not collect data on dietary behaviors or physical activity, nor did we assess the psychological disorders of the population during the pandemic. Finally, the lockdown period represented only 3 months of 2020; hence, we may have missed the potential weight fluctuations during the rest of the year. However, we believe that the lockdown effect would have resulted in more weight gain if we had assessed the weight change only during the lockdown period. Also, even though the lockdown period was only for 3 months, many organizations had continued the working-from-home policy, and many other recreation centers and gyms had remained closed.

Consequently, the level of physical activity may have been similar to the lockdown period.

IMPLICATIONS

Obesity is a major public health issue and associated with multiple chronic diseases and a considerable economic burden (40, 41). According to the World Health Survey in Saudi Arabia (KSAWHS), the prevalence of overweight and obesity in 2019 in the Kingdom were 38% and 20%, respectively (42). Given that the Saudi population is approximately 34 million according to the Saudi General Authority for Statistics (3), these percentages can be translated as there are approximately 13 million overweight and 7 million obese individuals in the country. Hence, if we add the increased percentage of those who were overweight pre-2020 and shifted into the obese class (5.1%) during the pandemic in our study to the current percentage in the country, it means that there would be approximately additional 357,000 obese individuals post-2020. This burden would ultimately contribute to the existing health and economic burden of obesity in Saudi Arabia.

CONCLUSION

Our study provides insights into the effect of the COVID-19 pandemic on weight and obesity in Saudi Arabia. Utilizing a longitudinal design with data retrieved from medical records, we estimated the weight change from before 2020 to after 2020. We found that people tended to gain weight during the pandemic, which will negatively impact population health. Proper interventions should be considered during similar circumstances—such as lockdown due to infection waves or new variants—especially for those at higher risk of complications due to obesity. Future studies should shed light on the most relevant factors associated with weight gain during the pandemic, including dietary choices and physical activity levels.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because it must be requested from the corresponding author and they may be available upon reasonable request. Requests to access the datasets should be directed to Suliman Alghnam, ghnams@ngha.med.sa.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Institutional Review Board (IRB) at King Abdullah International Medical Research Center (KAIMRC). Written informed consent from the participants' legal guardian/next of kin was not required to participate in this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SA and SMA conceived the research question and study design. SA and NT facilitated data collection. SA analyzed the data. SMA, AFA, NT, SSA, and AA-M wrote the original draft of the manuscript. SMA, NA-S, and SA reviewed and edited the manuscript. All authors contributed to the article and approved the submitted version.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.775022/full#supplementary-material

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Longitudinal Patterns of Food Procurement Over the Course of the COVID-19 Pandemic: Findings From a Canadian Online Household Survey

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Introduction: Consumer food procurement during the COVID-19 pandemic has been understudied. This investigation aimed to longitudinally evaluate food procurement patterns, concern of virus exposure in grocery retailers, and food access challenges over the pandemic among a sample of households in Quebec, Canada.

Methods: Online surveys were collected at three time points of the pandemic: first wave in spring 2020 (lockdown period), summer 2020 (deconfinement period), and second wave in winter 2021 (curfew period). Respondents were the household's primary grocery shopper ($n = 491$). Non-parametric tests and multivariable logistic regression were conducted to compare responses over time and to evaluate characteristics of respondents who regularly used no-contact grocery methods (store pick-up or home delivery).

Results: Frequency of in-store grocery shopping was lowest during the lockdown (once per week or less), and significantly increased over time to resemble pre-pandemic frequency. Concern of virus exposure in grocery retailers and disinfection/discarding of food packaging was highest during the lockdown, but significantly decreased over time. At all time points, use of public transit, walking or cycling for grocery shopping was associated with regular use of no-contact grocery methods (curfew odds ratio (OR): 3.13 (95% confidence interval 1.60, 6.14). Age (60 years+) was associated with regular use during the lockdown [OR: 2.27 (1.13, 4.59)].

Conclusion: Among our sample, frequency of in-store grocery shopping was lowest and concern of virus exposure in stores was highest during the lockdown period. No-contact grocery use was associated with transportation mode and potentially with personal risk perception (age).

Keywords: food procurement, online grocery, risk perceptions, COVID-19 pandemic, online survey

INTRODUCTION

The COVID-19 pandemic has had profound societal impacts that have disrupted activities of everyday life, such as food procurement. Lockdowns, loss of income, and disruptions in food supply chains have impacted consumer food access and food security globally, with severe ramifications amongst the world's poorest (1). The World Food Program (WFP) estimates that the number of people experiencing food crises due to the pandemic could double around the world if appropriate action is not taken (2); however, the pandemic's impact on global food security is considered to stem from issues related to consumer food access rather than food availability (3). Therefore, investigations into ways in which individuals organized themselves around the basic act of procuring food over the course of the pandemic are important to inform strategies for food retailers and consumers in the event of future public health emergencies. India, South Africa, and the United Kingdom were observed to have had sharp decreases in in-person grocery shopping during the beginning of the pandemic, potentially a result of these countries' strict and sudden lockdown implementations (4), and the global use of no-contact grocery methods (ordering online or by phone) have increased dramatically during the pandemic (5–7). Despite the rapid increase in no-contact grocery methods including store pick-up and home delivery, few investigations have evaluated consumer experiences with these methods and other outcomes related to food procurement. Therefore, this investigation used online surveys to longitudinally examine household grocery shopping frequency and method (in-store vs. no-contact), concerns over virus exposure in grocery stores and through grocery products, food access challenges, and indicators of food insecurity over the course of the COVID-19 pandemic among a convenience sample of households in the province of Quebec, Canada.

Quebec is the largest Canadian province by area and second largest by population with 8,164,361 residents (2016 Census) (8). During the first wave of the pandemic, Quebec had the highest numbers of COVID-19 cases in Canada and a provincial lockdown period was in effect during spring 2020 where non-essential services were closed. Face mask use became mandatory in all indoor public spaces, including food retailers, in summer 2020 (9). COVID-19 prevalence fell that summer only to rise again during fall 2020 and through winter 2021 (second wave) (10). To control the spread of the virus during the second wave, the province instituted a curfew that required individuals to be at their home (or in a small perimeter surrounding their home for dog walking) between the hours of 8 pm−5 am in the areas with highest COVID-19 prevalence (9:30 pm−5 am in areas with lower prevalence). Retailers including grocery stores closed at 7:30 pm, but delivery of take-out food was permitted during curfew hours. Our data collection occurred between spring 2020—winter 2021, capturing the lockdown period of the first wave, deconfinement period, and curfew period of the second wave. A third wave occurred in spring 2021, but this investigation had been completed prior to its onset.

Abbreviations: COVID-19, coronavirus disease 2019.

We previously reported results from our first survey conducted during the lockdown where we observed a reduction in the frequency of in-store grocery shopping and an increase in the use of online grocery shopping compared to before the pandemic (11). Concern of virus exposure in grocery stores and disinfecting/discarding food product packaging were also prevalent. This present investigation reports on changes to these outcomes that were re-evaluated at two additional time points: summer 2020 when restrictions eased (deconfinement period) and during the second wave in winter 2021 (curfew period). The primary outcomes of interest were changes in the frequency of grocery shopping (in-store and no-contact) and characteristics of regular users of no-contact grocery methods. We evaluated the following two hypotheses: (1) In-store grocery shopping frequency would be lowest at the lockdown period and return to pre-pandemic patterns by the end of the investigation, reflecting consumer adaptation to the public health situation over time; and (2) Sociodemographic characteristics of regular users of no-contact grocery methods would be stable across time points, reflecting consumer preference for this grocery method (12). Other outcomes of interest included changes in concern of virus exposure in grocery stores and from grocery products, methods of meal preparation, and food access challenges (including during self-isolation). These were considered exploratory analyses given characteristics of our sample and lack of existing literature upon which to form hypotheses for each outcome. Findings from this research are anticipated to assist in informing retail and public health considerations around food access in the event of future public health emergencies.

METHODS

Survey Overview and Timeline

An open online household survey investigation with three time points over ∼1-year was conducted *via* the platform SurveyMonkey. Recruitment was facilitated prior to the first survey through a radio broadcast, digital advertising in online media outlets, a social media campaign, and through professional networks. Informed consent was collected at the time of participation in the first survey, where respondents could also provide consent to be contacted for the follow-up surveys. Those who provided consent for recontact were e-mailed when the follow-up surveys were available for completion. Two e-mail attempts were made for the second survey and three attempts for the final survey, ∼1 week apart, after which respondents were considered lost to follow-up. An incentive was added to the final survey to attempt to retain participation (random draw for a $20 electronic gift card to participating local retailers), but no incentive was provided for the first or second survey. The survey respondent was the household member who was primarily responsible for grocery shopping. Each survey required 15–20 mins to complete.

Responses to the first survey (lockdown) were collected between May 20—June 4, 2020. This survey retrospectively probed for information beginning from March 13, 2020 (the start of the lockdown) and some items enquired about 2019 (methods of meal preparation, household food situation). Respondent

postal codes were collected and linked to the Statistics Canada Postal Code Conversion File (August 2018 release) to determine region of residence and assign urban and rural classifications. The second survey (deconfinement) was collected between August 15–30, 2020, capturing information when the province had re-opened and the prevalence of COVID-19 was low. The third and final survey (curfew) was collected between February 15—March 14, 2021, during the second wave of the pandemic when the provincial curfew was in effect. A total of 1,955, 658, and 621 individuals completed the lockdown, deconfinement, and curfew surveys, respectively. Analyses for the present investigation were conducted on the sample of users that completed all three surveys to ensure that comparisons were made on the same group of individuals.

Survey Development

The longitudinal surveys consisted of between 16 and 19 items, depending on the number of follow-up questions that applied, most of which were repeated at each time point (survey questions are presented in the **Supplementary Tables 1–3**, as well as in respective Tables/Figures). In addition, eight sociodemographic questions that were collected on the first survey (lockdown) were considered in the present analyses. The surveys were developed by the research team, comprised of investigators from nutrition science and consumer science, and were available in English and French. Face validity and pilot testing were conducted with a pilot sample of eight community-dwelling participants to correct any leading questions or unclear wording. French translations were back translated to English and tested among bilingual ($n = 4$) and francophone ($n = 4$) individuals to ensure comprehension in mother tongues. Responses from the first survey were analyzed and assessed to inform decisions for any modifications to survey items (addition/removal of questions) for the follow-up surveys.

Study Outcomes

This investigation evaluated four themes: grocery shopping frequency and methods, concern of virus exposure and mitigation behaviors, methods of meal preparation, and food access challenges (including during 14-day self-isolation). The first theme contained our primary outcomes of interest. Frequency of in-store grocery shopping and frequency of using no-contact grocery methods were assessed at all time points using a 7-point scale: daily or more, 4–6 times per week, 2–3 times per week, once per week, 1–3 times per month, less than once per month, or never. Completeness of no-contact grocery methods was assessed at all time points as a proxy for reliability of the service, using a 4-point scale evaluating whether the grocery order contained: everything that was ordered, almost everything, some products not included, or many products not included. The wait time for no-contact grocery orders to arrive was also evaluated at all time points using a 4-point scale: 1–3 days, 4–7 days, 8–13 days, or 2 weeks or more. We evaluated the sociodemographic characteristics of regular users of no-contact grocery methods, defined as frequency of use of at least once per week, using sociodemographic data from the lockdown (baseline) time point and no-contact grocery use responses from all time points.

The remaining themes were evaluated in exploratory analyses and included concern of virus exposure in grocery stores and mitigation strategies, methods of meal preparation, and food access challenges (including during self-isolation). Readers are directed to **Supplementary Table 2** for the list of specific questions and response options for these themes, beginning from item 6. Note that the lockdown survey items regarding food product availability were not repeated on the deconfinement survey due to improvement of the public health situation leading to easing of restrictions. Thus, it was considered unlikely that food products would be less available at that time and the questions were removed to reduce survey completion time. The items were included on the curfew survey when COVID-19 prevalence had increased, and public health restrictions tightened. Two and four items from the Household Food Security Survey Module were included on the lockdown and follow-up surveys, respectively, to evaluate indicators of food insecurity (13). All time points included an item on household food situation (item 12) and an adapted question on skipping meals/reducing food intake as a form of food rationing (item 13 a and b), a coping strategy to conserve one's food supply that is a potential indicator of vulnerability to food insecurity (14). Food rationing behavior was defined as any of the following reasons for reducing food intake: food not lasting between grocery trips, unable to afford to buy more food, or saving food for other household members. Results from the lockdown survey revealed common reports of skipping meals for non-income related reasons (such as loss of appetite due to stress, or health consciousness). Therefore, two income-related food insecurity items were added to the follow-up surveys to specifically evaluate income-related vulnerability (items 14–15). The present investigation was not designed to assess the prevalence of food insecurity, but these questions were used to evaluate the potential for vulnerability to food insecurity over the course of the investigation. Ethics approval was obtained from the McGill University Faculty of Agriculture and Environmental Sciences Research Ethics Board (#20-05-021). As per ethics requirements, all survey items were optional to respond to. Thus, minor variations in sample sizes across questions occur due to non-response.

Statistical Analyses

Statistical analyses were conducted with SPSS version 24 and all p-values were two-sided with alpha level of 0.05. Descriptive statistics were calculated to obtain frequencies (%) of responses for each item. Changes in repeated survey items were analyzed using non-parametric tests. Specifically, categorical data that were binary in nature and repeated on all three surveys were analyzed using Cochran's *Q*-test to determine whether an overall significant difference across time points was evident. Significant results were further assessed with the McNemar test to evaluate comparisons of time point pairings (lockdown vs. deconfinement, and deconfinement vs. curfew). The Friedman test was used to compare responses to ordinal items from all three time points to determine whether an overall significant difference was evident. Similarly, significant results were further assessed with the Wilcoxon signed-rank

test to evaluate comparisons of the same above-described time point pairings. Some multiple-choice survey items included an "Other (please specify)" free text response option. These free text responses were analyzed using content analysis with two researchers involved in coding and content extrapolation using an inductive approach (15). MT read free text responses several times and developed a codebook, which DEN reviewed. MT assigned codes and suggested content themes, which DEN reviewed. Discordant themes were discussed and 100% consensus was achieved.

Multivariable binary logistic regression was conducted to identify sociodemographic characteristics of respondents who regularly used no-contact grocery methods at each study time point (yes/no dependent variable). Adjusted odds ratios were examined from a single model for each time point that included the following socio-demographic factors as independent variables: age [under 60 (reference), 60 years and older] [this cut-off was evaluated because being 60 years of age or older is a risk factor for severe illness from COVID-19 (16)], gender [female (reference), male], marital status [married (reference), single, divorced/separated/widowed], total household income [under $50,000 (reference), $50,000-$100,000, over $100,000], children under the age of 18 years residing in the household [no (reference), yes], household size [single individual (reference), 2 individuals, 3 or more individuals], primary mode of transportation when grocery shopping [car (reference), public transit/walking/cycling], baseline concern over the COVID-19 pandemic [low (reference), medium, high], and urban/rural region of residence [large population center (reference), small and medium population center, rural].

RESULTS

A total of 491 respondents completed all three surveys (47% of those who consented to be contacted for the follow-up surveys). Response rates for each survey item were high, with the lowest rate being 97%. The respondents resided in 15 of the 18 administrative health regions of the province, with approximately half residing in Montreal (**Supplementary Material**). **Table 1** displays characteristics of these respondents. At baseline, the majority of respondents were moderately to extremely concerned about the pandemic (88%). Most respondents resided in urban areas with a mean ± standard deviation household size of 2.6 ± 1.4, that is similar to the average household size in Quebec (2.3 individuals) (8). The most common response for total household income among our sample ($50,000–$99,999) aligned with the median total household income of Quebec economic families ($79,378 from Census 2016), defined in the Canadian Census as a group of two or more persons who live in the same dwelling and are related to each other by blood, marriage, common-law union, adoption or a foster relationship (8). Thus, the present sample appears similar in demographic composition to Quebec families living in urban regions. Characteristics of this sample of respondents align with those of the full set of the lockdown (baseline) survey respondents (11). **Supplementary Table 4** presents the distribution of respondents across the province's 18 administrative health regions.

TABLE 1 | Baseline characteristics of respondents.

Characteristic	n (%)[†]
Age group (years)	
18–39	153 (31%)
40–59	216 (44%)
60 and older	122 (25%)
Total	491
Gender	
Female	445 (91%)
Male	44 (9%)
Preferred to specify	2 (<1%)
Total	491
Language	
French	271 (55%)
Total	491
Total household income	
<$20,000	18 (4%)
$20,000–$49,999	69 (14%)
$50,000–$99,999	190 (39%)
$100,000–$149,999	119 (25%)
$150,000–$199,999	52 (11%)
≥$200,000	36 (7%)
Total	484
Marital status	
Never married	92 (19%)
Married/Common-law	334 (68%)
Separated/Divorced	53 (11%)
Widowed	10 (2%)
Total	489
Urban vs. rural residence	
Large population center	369 (78%)
Medium population center	27 (6%)
Small population center	28 (6%)
Rural	48 (10%)
Total	472
Household size	
Single individual	109 (23%)
2	179 (37%)
3 or more	195 (40%)
Mean ± standard deviation	2.6 ± 1.4
Total	483
Mode of transportation for grocery shopping	
Car	381 (78%)
Public transit, walking, cycling	109 (22%)
Total	490
Baseline concern over pandemic	
Low (Not at all + Slightly concerned)	61 (12%)
Medium (Moderately concerned)	162 (33%)
High (Very + Extremely concerned)	268 (55%)
Total	491

[†] *Percentages may not total to 100% due to rounding.*

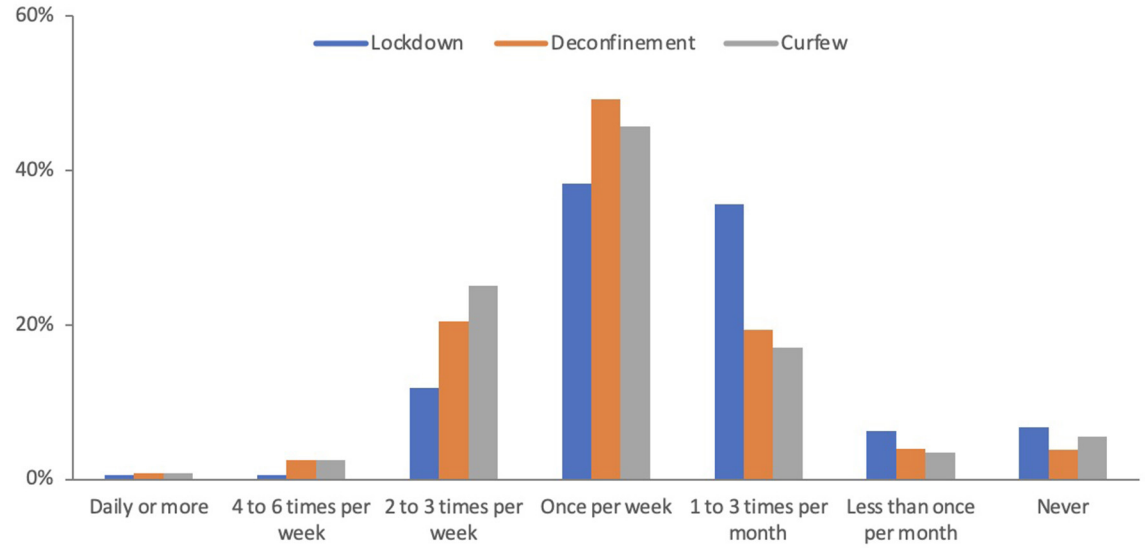

FIGURE 1 | Grocery shopping frequency over the COVID-19 pandemic. "Overall, between *(time period)*, how often did you/your household delegate physically go into astore to shop for groceries?" Wilcoxon signed-rank test: Lockdown vs. Deconfinement $p < 0.001$, Deconfinement vs. Curfew $p = 0.537$.

Grocery Patterns and Use of No-Contact Methods

Figure 1 presents patterns of in-store grocery shopping frequency across time points. During the lockdown period in the first wave of the pandemic, most respondents selected that they went in-store grocery shopping either once per week (38%) or one to three times per month (36%). Some respondents (11%) reported never shopping for groceries in-store during the lockdown period. The frequency of grocery shopping significantly changed across the time points (Friedman test $p < 0.001$). Specifically, the frequency increased at the deconfinement time point and remained similar at the curfew time point, where most respondents indicated that they went in-store shopping once per week (46%) or 2–3 times per week (25%). At all time points, most respondents (>50%) indicated that only one member of the household was responsible for grocery shopping (**Supplementary Table 5**). However, the proportion of respondents who reported that grocery shopping was done by more than one member of the household increased and the proportion who reported never going in-store grocery shopping decreased after the lockdown period (in both cases, the change remained stable between deconfinement and curfew) (**Supplementary Table 5**). Relatedly, the frequency of no-contact grocery use significantly differed across the time points (Friedman test $p < 0.001$). It decreased between the lockdown period and deconfinement, and remained stable thereafter (**Figure 2A**). **Figures 2B,C** present responses for the completeness and wait time for no-contact grocery methods that significantly differed across the time points (Friedman test $p < 0.001$). During the lockdown period, slightly over half of the respondents reported that some or many items were missing when they received their orders. The proportion of respondents reporting missing items significantly decreased over time, indicating an improvement in completeness of no-contact grocery methods after the lockdown period. Similarly, during the lockdown period, roughly 40% of participants reported having to wait 4 or more days for their no-contact grocery order. Wait time significantly decreased between the lockdown and deconfinement, thereafter remaining stable with nearly 90% of respondents reporting a wait time of 3 days or less.

The most consistent characteristic of regular users of no-contact grocery methods was usual mode of transportation for grocery shopping (**Table 2**). Those who used public transit, walking, or cycling were significantly more likely to use no-contact methods regularly compared to those who used a car. Being aged 60 years or older, compared to under 60, was a significant predictor during the lockdown period, but not at the other time points. Higher total annual household incomes were significantly associated with regular no-contact grocery use, compared to the lowest income category, during the lockdown period only. Gender, marital status, children residing at home, household size, and baseline concern about the COVID-19 pandemic were not significant predictors of regular no-contact grocery use at any time point.

Concern Over Virus Exposure and Mitigation Behaviors

During the lockdown, roughly 90% of respondents reported that they were "a bit worried" (54%) or "very worried" (34%) about being exposed to the COVID-19 virus when in-store grocery shopping (**Figure 3**). Worry significantly differed across time points (Friedman test $p<0.001$). Specifically, worry decreased between the lockdown and deconfinement, with roughly 70% of participants reporting being "a bit" (59%) or

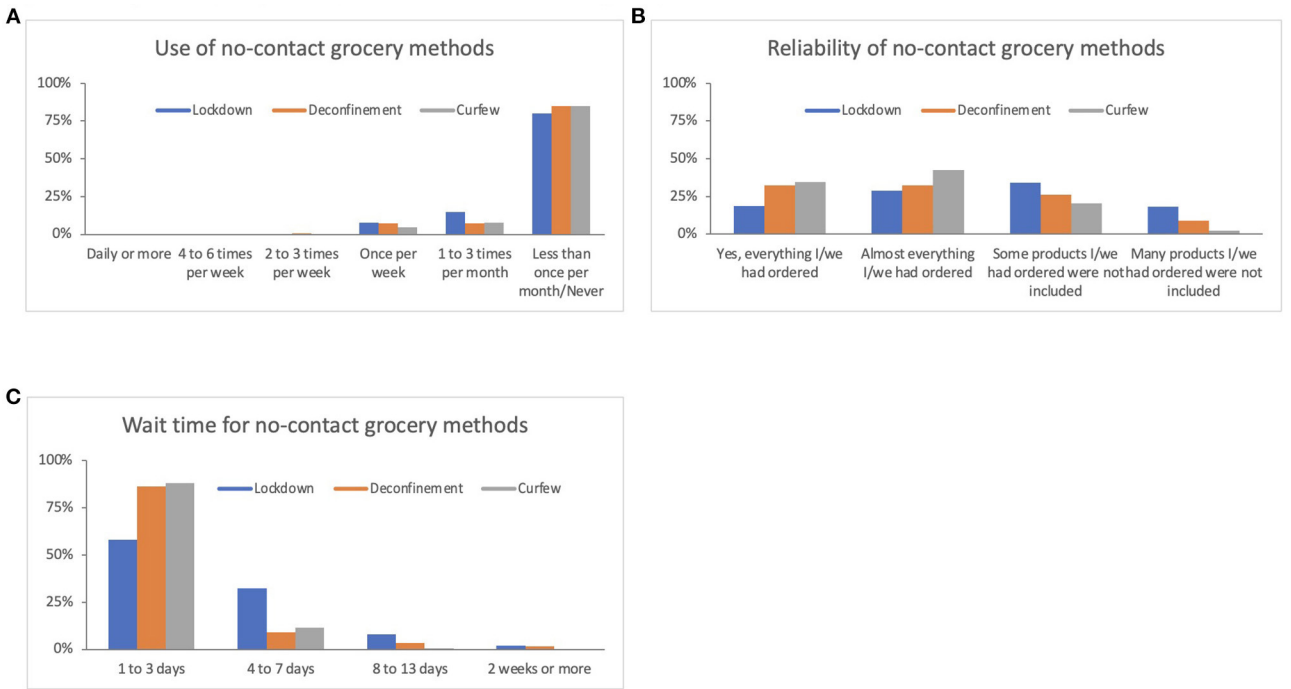

FIGURE 2 | Changes in use, completeness, and wait time for no-contact grocery methods. **(A)** "Between *(time period)* how often did your household utilize grocery pick-up or home delivery?" Wilcoxon signed-rank test: Lockdown vs. Deconfinement $p < 0.001$**,** Deconfinement vs. Curfew $p = 0.318$. **(B)** "If you used grocery pick-up or delivery, were all the products your household ordered included in what you received?" Wilcoxon signed-rank test: Lockdown vs. Deconfinement $p < 0.001$**,** Deconfinement vs. Curfew $p = 0.005$. **(C)** "If you used grocery pick-up or delivery, on average, after placing your order how long did you have to wait to receive your groceries?" Wilcoxon signed rank-test: Lockdown vs. Deconfinement $p < 0.001$**,** Deconfinement vs. Curfew $p = 0.260$.

"very" (14%) worried during deconfinement. This remained stable at the curfew time point. In-store virus mitigation behaviors that significantly changed across time points included wearing gloves, a face mask, and disinfecting the shopping cart handle (Cochran *Q*-test all $p < 0.001$), (**Figure 4**). Wearing a face mask significantly increased from 61 to 92% between lockdown and deconfinement (face masks became mandatory in indoor public settings in July 2020), thereafter remaining stable. Reports of wearing gloves while shopping and disinfecting the shopping cart handle significantly decreased between the lockdown and the follow-up points (from 18 to 3%, and 52 to 38%, respectively). The most common selected strategies of using hand sanitizer in store and attempting to keep a physical distance from other shoppers remained stable across time points (∼90% each). Utilizing self check-out and avoiding wait lines to enter a store also remained stable over time, but were reported by a smaller proportion of respondents (∼30%).

During the lockdown, 46% of respondents reported that they "disinfected packaging with wipes/spray" and 42% "threw away unnecessary packaging" (**Figure 5**). Analysis of free text responses at this time point revealed two additional measures: washing produce (fresh fruits and vegetables) with soap, vinegar, or diluted bleach and leaving non-perishable items in a "quarantine space" for hours to days before using. As a result, these behaviors were added as response options to the subsequent surveys. The prevalence of all grocery handling strategies significantly decreased after the lockdown and deconfinement periods to ultimately only 12 and 8% of respondents reporting disinfecting packaging and washing packaging with soap, respectively, at the curfew time point (Cochran *Q*-test all $p < 0.001$). Reports of discarding unnecessary packaging and leaving items in a quarantine space were reported by 23 and 13% of respondents, respectively, at the curfew time point.

Methods of Meal Preparation

Household mode of meal preparation was assessed before (2019), during and after the lockdown (**Table 3**). A significant increase in the frequency of cooking meals at home was reported during the lockdown compared to 2019. However, the frequency of cooking meals significantly decreased between the lockdown and deconfinement and then remained stable until the curfew period. The frequency of ordering prepared food significantly increased between deconfinement and the curfew period, with a greater proportion of respondents reporting ordering take-out food once per week or more often. The frequency of reporting eating at a sit-down restaurant had significantly decreased between 2019 and deconfinement (the only time point during this study when in-restaurant dining was permitted with capacity limits and distancing requirements).

TABLE 2 | Characteristics of regular users of no-contact grocery methods (n = 463).

Characteristic	Lockdown OR (95% CI)	Deconfinement OR (95% CI)	Curfew OR (95% CI)
Age			
Under 60 years old	Reference	Reference	Reference
60 years and older	**2.27 (1.13, 4.59)**	1.34 (0.65, 2.79)	1.91 (0.96, 3.83)
Gender			
Female	Reference	Reference	Reference
Male	0.54 (0.17, 1.66)	1.09 (0.40, 2.95)	0.78 (0.27, 2.22)
Marital status			
Married	Reference	Reference	Reference
Single	2.32 (0.90, 5.99)	0.47 (0.16, 1.38)	0.78 (0.27, 2.21)
Divorced/separated/widowed	0.95 (0.36, 2.51)	0.79 (0.30, 2.07)	0.65 (0.23, 1.80)
Total annual household income			
<$50,000	Reference	Reference	Reference
$50,000–$99,999	**3.06 (1.12, 8.35)**	1.34 (0.54, 3.29)	0.70 (0.29, 1.70)
$100,000+	**4.82 (1.65, 14.03)**	1.72 (0.65, 4.57)	1.19 (0.47, 2.98)
Children residing at home			
No	Reference	Reference	Reference
Yes	1.63 (0.85, 3.16)	1.12 (0.56, 2.27)	1.13 (0.57, 2.24)
Household size			
Single individual	Reference	Reference	Reference
2	1.99 (0.78, 5.04)	0.54 (0.21, 1.36)	2.24 (0.87, 5.79)
3 or more	2.30 (0.78, 5.04)	0.97 (0.34, 2.77)	1.56 (0.50, 4.89)
Mode of transportation for grocery shopping			
Car	Reference	Reference	Reference
Public transit, walking, cycling	**3.75 (1.92, 7.33)**	**5.10 (2.60, 10.00)**	**3.13 (1.60, 6.14)**
Baseline concern about COVID-19 pandemic			
Low	Reference	Reference	Reference
Medium	1.21 (0.43, 3.42)	2.31 (0.70, 7.64)	1.37 (0.41, 4.62)
High	1.85 (0.70, 4.88)	3.03 (0.97, 9.49)	2.96 (0.96, 9.15)
Urban/rural			
Large+Medium Urban	Reference	Reference	Reference
Small Urban	0.50 (0.11, 2.25)	0.71 (0.16, 3.18)	0.29 (0.04, 2.25)
Rural	0.75 (0.27, 2.07)	0.36 (0.08, 1.58)	0.28 (0.06, 1.22)

OR, odds ratio; CI, confidence interval.
Bolded values are statistically significant ($p < 0.05$).

Food Access Challenges

During the lockdown period, few respondents indicated that they were unable to obtain enough food products for their household's need. While food access did not appear to be problematic, canned or frozen fruits and vegetables and grain products had the highest reports of not obtaining enough (8 and 6%, respectively). Nevertheless, the proportion of respondents who reported that they were able to purchase enough of the products to completely meet their household's needs significantly increased between the lockdown and curfew period (**Supplementary Figure 1**). The shift was a result of fewer respondents selecting that they were able to "mostly" meet their needs (8–23%), and more selecting "completely" (55–89%) at the curfew time point. At both time points, the top selected factor for not obtaining enough was that products were not available in stores, but the proportion of respondents who selected this was markedly higher during the lockdown period (**Supplementary Table 6**).

As compared to 2019, during the lockdown period, a 17% decrease was observed in respondents reporting that their household had enough of the kinds of foods they wanted to eat (**Table 4**). This was a result of more participants reporting that although they had enough to eat, it was not always the kinds of foods that were wanted. This changed over time, with significantly greater participants reporting always having enough of the kinds of food they wanted at each time point after the lockdown period, ultimately exhibiting a proportion at the curfew period that was very similar to that of 2019.

Between 10 and 15% of respondents reported that they skipped meals or reduced their food intake across the study time points (**Supplementary Table 7**). Reasons related to food rationing behavior were highest during the lockdown period (up to 25%), but significantly decreased over time (to 14%). While some participants, particularly during the lockdown, reported reducing food intake because food did not last in between grocery trips, assessment of free text responses revealed that this was linked to efforts to reduce the frequency of grocery shopping rather than due to income-related food challenges. Indeed, assessment of the free text responses revealed more common explanations for reducing food intake across the study time points, which were health consciousness considerations (e.g., food intake reduced due to reduced physical activity), inconvenience around food preparation (e.g., irregular schedule, unwillingness to cook), and stress/anxiety/mental health affecting appetite. Similarly, the food insecurity module items included on deconfinement and curfew surveys revealed very low reports of income-related challenges with food and this pattern was stable between the time points (**Supplementary Table 7**).

During the lockdown period, 11% of respondents indicated that a household member needed to self-isolate for 14 days (**Table 5**). This significantly changed over time, decreasing to 5% at deconfinement and then increasing to 10% at the curfew time point (Cochran Q-test, $p = 0.002$), aligning with the trajectory of COVID-19 prevalence in the province over the time points. The remaining results were examined only descriptively, given the limited sample sizes. Among respondents who reported a household experience with self-isolation, ∼40% indicated that the isolation period impacted their household's ability to shop

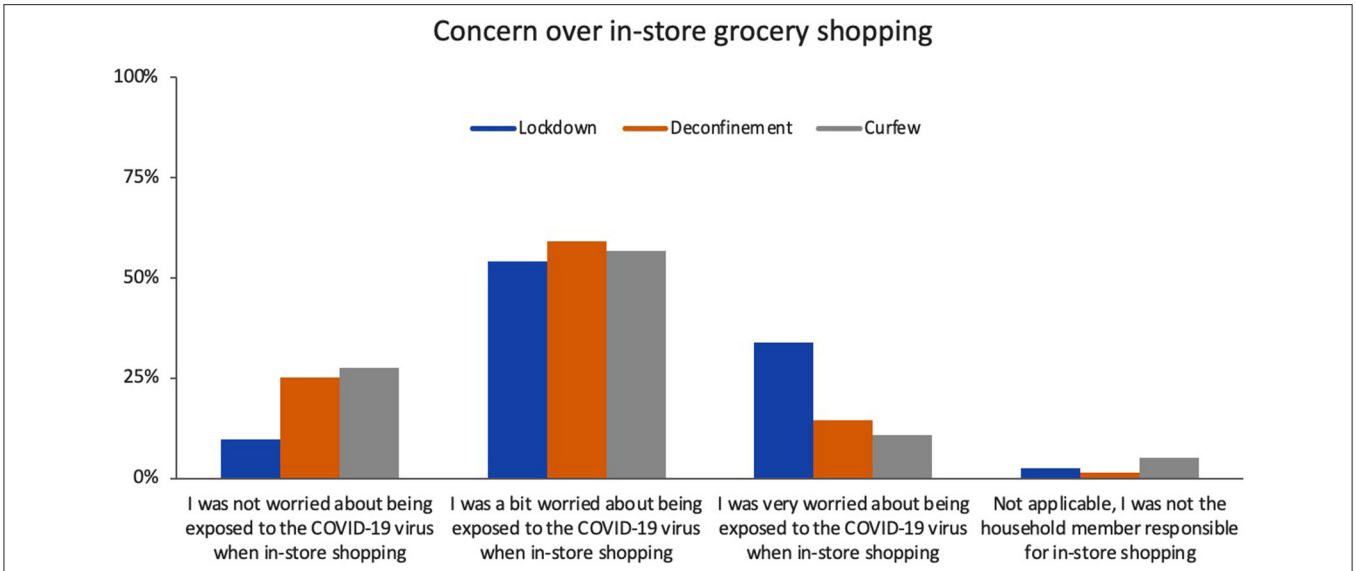

FIGURE 3 | Concerns over in-store grocery shopping. "Between *(time period)*, which of the following statements describes how you felt about possible exposure to the COVID-19 virus when in-store grocery shopping?" Wilcoxon signed-rank test: Lockdown vs. Deconfinement $p < 0.001$, Deconfinement vs. Curfew $p = 0.239$.

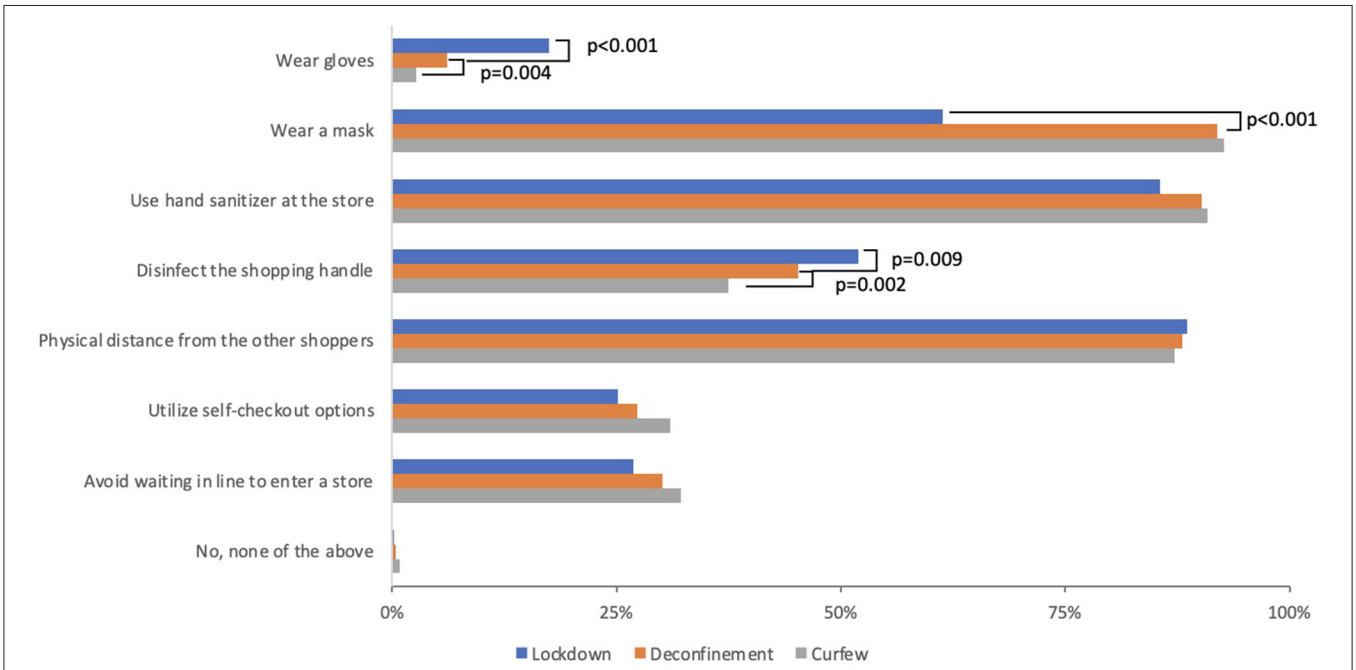

FIGURE 4 | In-store virus exposure mitigation behaviors. "When shopping for groceries in a store did you... (Check boxes if YES and select all that apply)." McNemar test comparing Lockdown (blue) to Deconfinement (orange), and Deconfinement (orange) to Curfew (gray).

for food during the lockdown and deconfinement periods, which decreased to 25% at the curfew time point. The most frequently reported ways of accessing food during the 14 days of self-isolation were through a household member that did not need to self-isolate, a family/friend who did not live within the household, and a delivery service. Few respondents reported use of community volunteers for groceries or going out to buy food because they live alone (≤5%). Assessment of free text responses identified use of food reserves at home as an additional common method.

DISCUSSION

Our findings indicate that the sample of Quebec residents who responded to our three surveys organized themselves around

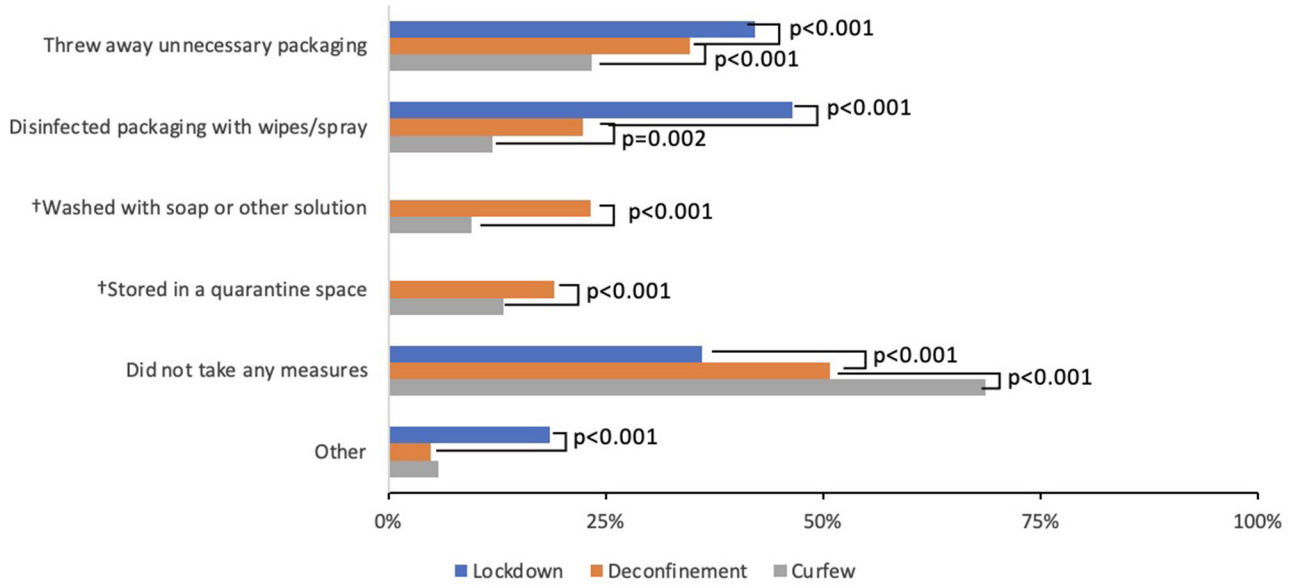

FIGURE 5 | Handling of groceries after purchase. "Between *(time period)* did anyone in your household take measures to disinfect product packaging after getting your groceries? (*Select all that apply)"* McNemar test comparing Lockdown (blue) to Deconfinement (orange), and Deconfinement (orange) to Curfew (gray). †These options were identified as common themes from baseline free text responses to "Other (please specify)", thus only deconfinement to curfew data are available.

purchasing food in a manner that adhered to government directives for physical distancing depending on the status of the public health situation. In-store grocery shopping frequency was lowest during the lockdown period and mostly done by one member of the household, but, as we had hypothesized, frequency increased after this period to resemble the 2019 pre-pandemic Canadian estimate of 1.3 grocery trips per week (17), and reports of more than one household member going grocery shopping increased after the lockdown. In addition, cooking meals at home significantly increased during the lockdown compared to the report for 2019, which also has been reported internationally in Eastern Europe and the Middle East (18, 19). In line with these observations, the number of daily meals consumed was reported to be higher during lockdown periods compared to before the pandemic in an international online survey study with respondents from Europe, North-Africa, Western Asia and the Americas (20). Frequency of cooking meals at home significantly decreased after the lockdown among our sample, while ordering prepared food significantly increased by our final time point. Together, these observations indicate that our sample of survey respondents complied with the directive to limit outings at the time that it was strictly enforced, and likely also reflects our observation of reduced concern over in-store grocery shopping and exposure through food as the pandemic went on. Indeed, while 11% of respondents reported that they did not go in-store grocery shopping during the lockdown, this decreased by roughly half at the follow-up assessments. In line with this, while many respondents reported disinfecting food product packaging and taking other measures to avoid exposure through grocery products during the lockdown (such as leaving items in a quarantine space), these behaviors decreased over time. The lockdown time point findings were concerning as they paralleled reports of increases in calls to poison control centers due to disinfectant exposures since the beginning of the pandemic, and improper food storage can increase the risk of food-borne illness (21, 22). Consumers likely became less concerned over virus exposure through food and packaging as public health information consistently communicated that the potential to contract the virus through food is very low (23). This highlights the importance of clear and consistent communication of public health information in times of public health emergencies.

Our assessment of no-contact grocery use revealed limitations with the approach during the lockdown period, with nearly 50% of respondents reporting receipt of incomplete grocery orders and ∼40% reporting a wait time of 4 days or more. The completeness of and wait time for no-contact grocery methods appeared to have vastly improved by the deconfinement time point and remained stable thereafter. While we can not rule out the possibility that consumers modified their no-contact grocery orders based on the experience during the lockdown period to increase the likelihood of obtaining a complete order, incomplete orders at the beginning of the pandemic may have been a result of lack of retailer preparedness for the sudden higher demand for no-contact methods. Retailers may also have placed limits on the amount of products that they were willing to provide for no-contact orders vs. for patrons shopping in stores, or from actual shortages of some products (24, 25). Although prevalence of no-contact grocery use decreased after the lockdown among our study sample, food retailers likely also adapted to the demand for no-contact orders, which are anticipated to continue to grow in popularity (26).

TABLE 3 | Changes in methods of meal preparation before and during COVID-19.

On average how often did your household...	2019	Lockdown	Deconfinement	Curfew	*p*-value	*p*-value	*p*-value
Cook meals at home?†					**2019 vs. Lockdown**	**Lockdown vs. Deconfinement**	**Deconfinement vs. Curfew**
Daily or more	312 (64%)	424 (87%)	364 (76%)	348 (73%)	<0.001	<0.001	0.580
4–6 times per week	140 (28%)	51 (10%)	83 (17%)	105 (22%)			
2–3 times per week	28 (6%)	10 (2%)	21 (4%)	18 (4%)			
Once per week	8 (2%)	3 (<1%)	4 (<1%)	3 (<1%)			
1–3 times per month	2 (<1%)	0	1 (<1%)	2 (<1%)			
<Once per month/Never	1 (<1%)	0	2 (<1%)	1 (<1%)			
Total	491	488	475	477			
Order prepared food (take-out or delivery)?†					**2019 vs. Lockdown**	**Lockdown vs. Deconfinement**	**Deconfinement vs. Curfew**
Daily or more	0	2 (<1%)	1 (<1%)	1 (<1%)	0.027	0.017	<0.001
4–6 times per week	4 (1%)	1 (<1%)	1 (<1%)	3 (<1%)			
2–3 times per week	30 (6%)	18 (4%)	24 (5%)	33 (7%)			
Once per week	83 (17%)	101 (21%)	89 (18%)	128 (26%)			
1–3 times per month	169 (35%)	114 (23%)	163 (33%)	156 (32%)			
<Once per month/Never	203 (42%)	252 (52%)	197 (40%)	162 (34%)			
Total	489	488	475	483			
Go out to eat at a sit-down restaurant? †						**2019 vs. Deconfinement**	
Daily or more	4 (1%)	N/A*	0	N/A*		<0.001	
4–6 times per week	13 (3%)		0				
2–3 times per week	55 (11%)		3 (<1%)				
Once per week	97 (20%)		19 (4%)				
1–3 times per month	190 (39%)		93 (20%)				
<Once per month/Never	128 (26%)		360 (75%)				
Total	489		475				

† *Percentages may not total to 100% due to rounding.*
* *In-restaurant dining was not permitted at these time points and so was not assessed on these surveys.*
p-values obtained from Wilcoxon signed-rank test.

TABLE 4 | Changes in household food situation.

Which of the following statements best describes the food eaten in your household during the period of *(time period)*?†

	2019	Lockdown	Deconfinement	Curfew	*p*-value
You and other household members always had enough of the kinds of foods you wanted to eat.	455 (93%)	374 (76%)	398 (83%)	439 (90%)	**2019 vs. Lockdown** <0.001
You and other household members had enough to eat, but not always the kinds of food you wanted.	34 (7%)	116 (24%)	77 (16%)	43 (9%)	**Lockdown vs. Deconfinement** 0.004
Sometimes you and other household members did not have enough to eat.	2 (<1%)	1 (<1%)	1 (<1%)	2 (<1%)	
Often you and other household members didn't have enough to eat.	0	0	0	0	**Deconfinement vs. Curfew** <0.001
Total	491	491	476	484	

† *Percentages may not total to 100% due to rounding.*
p-values obtained from Wilcoxon signed-rank test.

TABLE 5 | Food access during 14-day self-isolation.

	Lockdown	Deconfinement	Curfew
Between *(time period)*, did any member of your household need to self-isolate or quarantine for 14 days due to COVID-19?†			
Yes	55 (11%)	24 (5%)	48 (10%)
No	436 (89%)	452 (95%)	437 (90%)
Total	491	476	485
Did the 14-day self-isolation/quarantine impact the ability of your household to shop for food?*			
Yes	22 (40%)	10 (42%)	12 (25%)
No	33 (60%)	14 (58%)	36 (75%)
Total Respondents*	55	24	48
How did your household shop for food during the 14-day period of required self-isolation/quarantine?*			
I went out to buy food because I live alone	3 (5%)	0	0
Relied on a household member that did not need to self-isolate	18 (31%)	11 (42%)	25 (51%)
Relied on a family/friend who did not live within our household	20 (34%)	8 (31%)	9 (18%)
Relied on a delivery service	13 (22%)	6 (23%)	10 (20%)
Relied on volunteer grocery shoppers in the community	2 (3%)	1 (4%)	1 (2%)
Other (please specify)	13 (22%)	6 (23%)	10 (20%)
Total Respondents*	55	24	48

† Percentages may not total to 100% due to rounding. Cochran's Q-test comparing responses across all three time points: $p = 0.002$.

** Follow-up question (denominator is the number of respondents who answered "Yes" to the first question). Percentages may total to more than 100% due to the possibility of selecting more than one answer.*

Contrary to our hypothesis, sociodemographic characteristics of regular users of no-contact grocery methods were not stable over time. The most consistent predictor of regular use of no-contact grocery method was the usual mode of transportation for grocery shopping (public transit, walking or cycling). It is possible that these individuals may have been more likely to have regularly used no-contact grocery methods, particularly home delivery, prior to the pandemic due to preference and issues around transportation. On the other hand, it is also conceivable that pandemic impacts on public transit (reduced hours or concerns over virus exposure) played a role in this observation. Being 60 years of age or older, a risk factor for severe illness from COVID-19 (16), was a significant predictor of regular no-contact grocery use during the lockdown period, suggesting that personal risk perception may have influenced use of no-contact grocery at this time point. Pre-pandemic consumer research indicated that online grocery methods were more popular among younger individuals (26); however, the observation of older individuals utilizing no-contact grocery during the pandemic has been reported both locally in the Quebec context (27), and abroad, such as in China where the elderly population embraced mobile apps for grocery ordering during the first wave lockdown (28). Income was only a significant predictor of regular no-contact grocery use during the lockdown period when use of no-contact grocery methods was highest overall. Therefore, use of no-contact grocery methods during the lockdown was partly driven by higher income households, which is not unexpected given that these methods typically involve an added cost (or minimum purchase) for preparation/delivery of the order. Our previous lockdown assessment of these characteristics also considered regional COVID-19 prevalence (low, medium, high) and found significantly lower likelihood of regular use of no-contact grocery methods among the region with low COVID-19 prevalence (29). A similar result was reported in a framed choice experiment conducted among a sample of US consumers that manipulated COVID-19 case trend according to three scenarios (increasing cases, decreasing cases, or constant) (5). Our results indicate that food retailers may benefit from considering the regional situation and sociodemographic profile around their location when evaluating/refining their no-contact grocery methods, particularly the common modes of transportation.

Food access challenges and indicators of food insecurity were very low among our sample, reflecting the good socioeconomic status of our sample of respondents. In fact, among participants who reported that they skipped meals/reduced their food intake, the reasons were more often related to health consciousness or stress rather than finances. During the lockdown period, we observed an interesting pattern that households appeared to be more rigid with their home food supply compared to pre-pandemic, which noticeably impacted reported *food variety*, but not quantity. Reports of having both enough quantity and variety (kinds) of desired foods increased after the lockdown, ultimately returning to pre-pandemic level. This observation is likely explained by the noticeable reduction in grocery shopping frequency during the lockdown, suggesting that households were making do with food reserves within the home and making fewer trips to obtain desired ingredients/products. Closures of local food suppliers and food shortages during the pandemic have been linked to increased vulnerability to food insecurity in developed countries (30–32), but consistent evidence has demonstrated that the pandemic has caused greater burden among lower socio-economic status groups that are more vulnerable to food and nutrition challenges (30, 33–36). Lockdowns have had the most severe consequences in poor countries as they resulted

in complete loss of income for many daily wage workers, representing most of the labor force in low-income countries (37). Government supports including unemployment benefits, postponement of rent and utility payments, financial support for small businesses (including farmers and restaurants), and free food provision are global strategies that have assisted in the food crisis experienced by low socioeconomic status groups throughout the pandemic (37). For example, India provided free weekly rations of rice, pulses, spices, and cooking oil to low-income households during the first wave's lockdown period (38). Humanitarian organizations also provided relief, as evidenced by the WFP and UNICEF provision of rations, vouchers or cash transfers to children in 68 countries due to the closure of schools that had provided nutritious meals to students (39). While these supports should remain in place as necessary, further attention to enhancing the resilience of food systems is also warranted to support the health of people, the environment, and economies. Indeed, supporting local farmers, urban agriculture, and home gardening have been identified as important strategies to help combat food crises that have arisen during the pandemic (40, 41).

We examined food access during self-isolation and our observations indicate that many individuals who experienced self-isolation reported that it impacted the ability to shop for food. While respondents mostly reported obtaining food by relying on individuals (within or outside of their household) who did not need to self-isolate, many also communicated that they relied on their own supply of food reserves in the home during this period. However, households that do not maintain an abundant supply of food (or those that have limited financial or storage capacity) may experience challenges with food sufficiency during a 14-day period of self-isolation, which could impact compliance. Although our observations must be interpreted with caution given our limited sample size of respondents who reported an experience with self-isolation, it may be prudent for public health messages to continue providing consumers with information on proper ways of keeping an adequate food supply at home to maintain a level of preparedness in the event of any future public health emergency. Income support for lower socioeconomic groups should also be available to support sufficient food access (42, 43), and future work should evaluate availability and reliability of no-contact grocery among disadvantaged groups. These strategies will assist both with ensuring that households are prepared in the event of requirements for isolation/quarantine, and with prevention of panic buying occurrences. Indeed, consumer sales data in Canada provide strong evidence of panic buying at the start of the pandemic (44). A surge in sales of non-perishable food items was observed, which aligns with our observation that canned/frozen produce and grain products were the most common products that respondents reported they were not able to obtain enough during the lockdown period. Therefore, while challenges with food access were not prevalent among our sample, our results support anecdotal reports of shortages with certain food products (e.g., non-perishable items) in grocery retailers early in the pandemic, which may have been the result of consumer panic buying.

Despite the strengths of this investigation's provincial coverage and collection of data during the multiple time points over the pandemic, several limitations are worth discussing. First, our sample was comprised of a large proportion of females and high-income bracket households from mostly large urban regions. However, our survey required the respondent to be the individual who was primarily responsible for grocery shopping. The large proportion of female respondents may reflect the observation that women are more likely to take on responsibilities for household food budgeting, purchasing and preparation within households (45). Indeed, women may be more knowledgeable about the household food situation, justifying their suitability as the respondent for household food surveys (46). The sociodemographic profile of our sample may reflect the online recruitment methods that were predominantly used, which were necessary at the time due to the public health restrictions in place. Nevertheless, online methods of recruitment are increasingly recognized for their efficiency and effectiveness and have been increasingly used over the course of the pandemic (47, 48). We did not collect information on certain demographic variables that are linked to challenges with food access (e.g. being a member of an ethnic minority group or Indigenous community), so we were not able to evaluate outcomes with these considerations (49). Despite this, it is unlikely that our sample was representative of such vulnerable groups. Responses were self-reported, which is subject to potential biases and measurement error, and items that required recollection of 2019 may be subject to recall bias. The voluntary option to respond to all survey questions may have resulted in some response bias being present in results, though response rates for each survey question were high. We did not correct for multiple statistical testing due to the exploratory nature of several comparisons given the unprecedented experience of the pandemic. Finally, to our knowledge, no previous work has evaluated characteristics of no-contact grocery users during the pandemic or food access methods during self-isolation. Thus, we are not able to compare our findings for these outcomes with international data.

CONCLUSIONS

Our findings reflect longitudinal patterns of food procurement and related outcomes spanning 1 year among a sample of Quebec households during different periods of the COVID-19 pandemic. In general, concerns of virus exposure in grocery stores and from food packaging were highest during the lockdown period. Several North American and international sources corroborate our observations of decreased in-store grocery shopping, increased use of no-contact grocery methods, and increased cooking at home during the beginning of the pandemic. Lockdown restrictions and concern of in-store grocery shopping appear to be important contributors to those patterns. Overall, our observations support the following

recommendations and suggestions for future research: (1) Opportunities exist for continued public health communication regarding food procurement strategies in the event of a future public health emergency as well as messages for appropriate food handling and use of chemical disinfectants; (2) Food retailers and public health agencies may wish to monitor regional availability and reliability of no-contact grocery methods to ensure equitable access and reliable service, especially in times of need; (3) Continued research into food access challenges among vulnerable groups and identification of effective government and local supports; and (4) Global investigations into food procurement activities during the post-pandemic period will be needed to identify and understand lasting impacts on consumer food procurement patterns, particularly pertaining to online food environments.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by McGill University Faculty of Agricultural and Environmental Sciences Research Ethics Board. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

DN designed the study, performed statistical analysis, and wrote the first draft of the manuscript. KL, IK, HH, and MT assisted with data collection and statistical analysis. P-GD, LA, CP, and LD provided guidance on the study design and critically revised the manuscript. All authors have read and approved the final manuscript.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2021.752204/full#supplementary-material

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Observations on Food Consumption Behaviors During the COVID-19 Pandemic in Oman

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This paper aims to study the perceptions of the impacts of the COVID-19 pandemic on behaviors related to diet and food shopping on a sample of 356 adults in Oman. The study is based on the results of an Arabic-language online survey conducted between September 15 and October 10, 2020, using the Survey Monkey platform. The questionnaire had 25 questions (multiple options and one option), subdivided into three parts. Respondents were asked to disseminate the survey to their networks as part of the study's snowball sampling method. Descriptive statistics and various statistical tests (e.g., U-Mann Whitney, Kruskal-Wallis, chi-square) have been used to evaluate the study results. The study showed a significant shift in the attitude and behavior of respondents regarding food and health. Indeed, the paper findings indicated (i) a shift to healthier diets, as shown by the fact that 45.5% of the participants increased their intake of fruits and vegetables, 42.4% ate more healthy foods, and 53.1% reduced their intake of unhealthy foods; (ii) an increase in the consumption of local products, owing to food safety concerns, with 25.8% of the cohort stating that they purchase more local food items; (iii) a shift in grocery shopping behaviors, especially with 28.1% of the participants buying more groceries online; (iv) the absence of panic buying in Oman, since 62.36% of the participants said they did not stockpile food items; and (v) a reduction of food waste. Indeed, 78.9% of the participants specified they were not wasting more food than average since the beginning of the pandemic, and 74.72% indicated they were more aware of how much food they were wasting. Surprisingly, COVID-19 appears to bring many beneficial adjustments in Oman to make food consumption more sustainable and healthier.

Keywords: COVID-19, food behavior, food consumption, Oman, Gulf Cooperation Council (GCC)

INTRODUCTION

The COVID-19 epidemic created a global health crisis and became a challenge even to the most advanced health and governance systems in the world (1). Governments worldwide have contemplated various measures, such as school closure, lockdown, banning public events, and social distancing. While these efforts have been critical, many voices have pointed out their worrying psychological, social, and economic effects on global production and consumption systems (2). In the same line of rationale, COVID-19 has impacted agro-food systems at many levels, from farm to fork (3–8). Indeed, the pandemic had several impacts on diet and food behavior. Moreover, COVID-19 is a worldwide pandemic that created a global economic and financial crisis (2), which is expected to seriously affect food access, diet quality, and diversity (9, 10).

Firstly, consumers were worried about their families and the long-term prognosis during the start of the pandemic, so they concentrated on panic buying and stockpiling (11). Various episodes of panic buying of storable food products (e.g., pasta, rice, etc.) have been reported in several countries across the globe shortly after their first coronavirus cases were announced (10, 12–14).

Secondly, COVID-19 has altered people's eating patterns and dietary quality in many ways. COVID-19, on the one hand, triggered nutritional and health deterioration. The severe changes in lifestyle brought about by the lockdown/quarantine, as well as the broader situation, resulted in negative feelings such as boredom, depression, tension, and fear of the disease, which could alter diet, resulting in poor eating habits and frequent snacking (15). In several countries of the Gulf Cooperation Council (GCC) [viz. Bahrain, Kuwait, Oman, Qatar, Saudi Arabia, United Arab Emirates (UAE)], the pandemic aggravated existing prevalent obesity and overweight issues. Many researchers in the region highlighted that negative emotions resulting from the pandemic contributed to overeating, particularly of 'comfort foods' (e.g., chocolate) (16, 17). As observed globally, many consumers in the region developed a mechanism for dealing with negative moods via increasing their consumption of unhealthy, fatty, energy-dense foods (18).

On the other hand, COVID-19 forced people to reassess their habits, and many were more aware of their dietary habits (19). In Qatar (20) and Kuwait (21), people had cut down on unhealthy items, including fast food, cookies, cakes, and pastries. They also drank more water and ate more nutritious meals, including healthy snacks, fruits, and vegetables.

Third, COVID-19 has transformed people's food shopping habits (3). Given the perceived risk of shopping at a grocery store, consumers have decreased the number of grocery visits and purchased more on each visit to minimize their perceived risks of COVID-19 exposure (3, 22). Additionally, consumers turned to online shopping, which accelerated digital adoption and necessitated considerable changes to retail and commerce (23, 24). Since the pandemic outbreak, online shopping in the GCC area has seen tremendous development, as have local delivery applications (e.g., Talabat, Uber Eats, Instashop) (19). Also, online retail food products have experienced record growth, with delivery times ranging from two to 10 days, and minimum order amounts have been increased (25).

Nonetheless, the final COVID-19 findings may differ based on various circumstances, including epidemiological conditions, socio-economic development level, and the effectiveness of national health systems (4). In this regard, the example of Oman, a high-income country and one of the world's most food-secure nations, is particularly intriguing.

The Sultanate of Oman, one of the Gulf Cooperation Council (GCC) countries, covers 309,500 km^2 and has a population of 4.6 million and a GDP per capita of 14971.7 US$ in 2019 (26). Despite substantial diversification efforts, oil is still the backbone of the Omani economy, constituting 70% of government revenues, 30% of the income, and more than 50% of exports in 2019. As a result, the country's budgetary situation is extremely vulnerable to oil prices fluctuations (27). In 2020, Oman's economy was projected to contract by 3.5% due to the twin effects of the rapid drop in oil prices and COVID-19. Consequently, it is expected that the deficit will rise to more than 17% of the GDP in 2020 (27). Oman documented its first case of COVID-19 on Feb 24, 2020 (28), and its first related death on Apr 1 (29). As of Apr 14, 2021, the Sultanate had 174,364 cases and 1,798 total deaths (30). Throughout the initial months of the pandemic, the Omani government adopted various measures to break the spread of COVID-19, such as lockdown, social distance, mobility restrictions, the prohibition of public gatherings, etc. (31, 32). These preventive actions have disturbed several sectors and posed various challenges (33). Likewise, these actions may have affected food consumption and food shopping behavior (11).

Accordingly, in this paper, a sample of 356 Omani adult consumers will be polled about their views on the potential consequences of the COVID-19 pandemic on their diet and food shopping behaviors. The research is based on four hypotheses: H1) the pandemic and the related negative feelings triggered a move toward unhealthy diet; H2) the pandemic caused a rise in online shopping; H3) the pandemic caused an increase in food stockpiling and panic buying; and H4) the pandemic caused an increase in food waste. **Figure 1**, informed by Ashraf et al. (34), depicts the organizational structure of the study.

DATA COLLECTION AND METHODS

From September 15 to October 10, 2020, an online questionnaire[1] in Arabic, Oman's official language, was administered using the Survey Monkey platform. The poll link was shared on social media such as Twitter and Facebook. The survey addresses the broad population of adults in Oman (those above the age of 18). The snowball sampling approach was utilized, and respondents were invited to share the online poll with their friends and relatives. We also opted for a non-probability sample technique, in which survey respondents were chosen at random and without reference to any prior criterion,

[1]"The West Michigan University's Food Consumption Changes 2020 study (57) and the United Nations System Standing Committee on Nutrition's (UNSCN) COVID-19 Survey (58) guided our questionnaire".

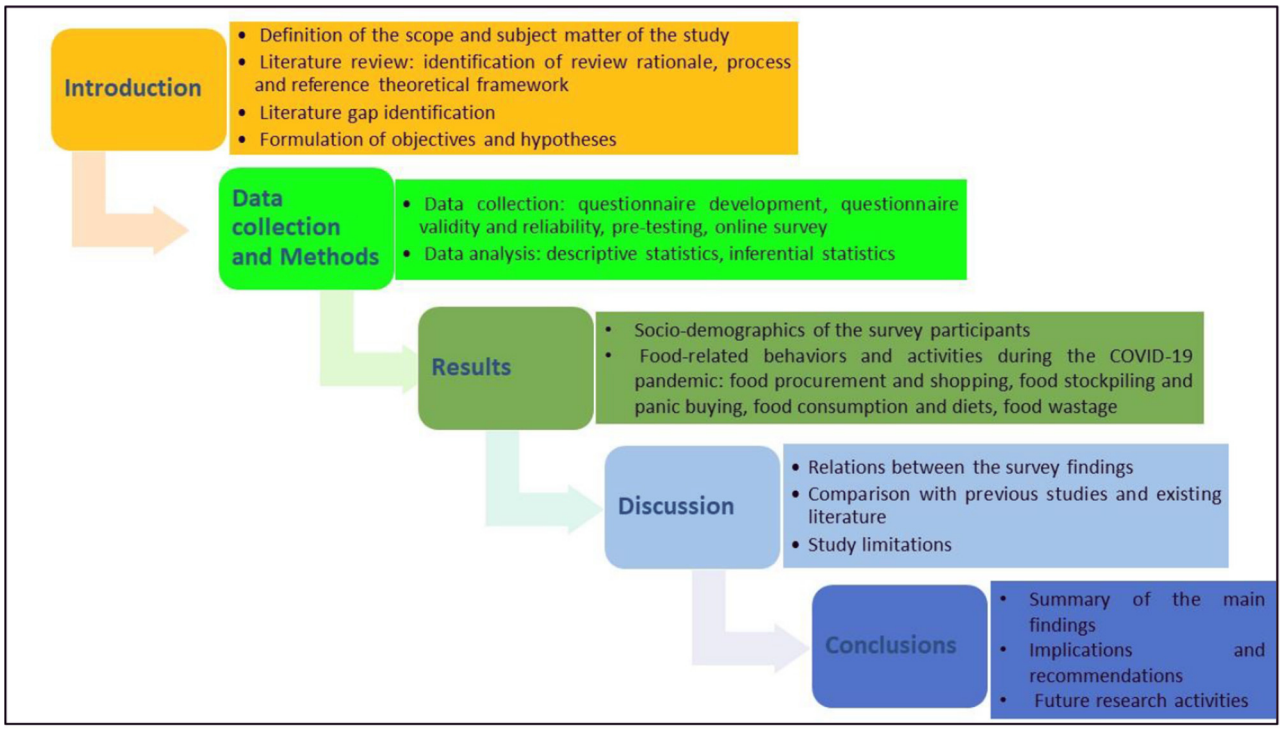

FIGURE 1 | Research flowchart.

except the age. In addition, there was no financial compensation for participating in the survey.

The Western Michigan University Human Subjects Institutional Review Board (HSIRB) approved all procedures involving research subjects following the Helsinki Declaration principles. At the start of the survey, all participants were told about the study goals. They supplied their digital permission concerning privacy and information management standards, as well as their confirmation that they were over the age of 18.

Many questions were raised in the research about the influence of the COVID-19 pandemic on food-related activities, such as food shopping, cooking, diet, and waste. The questionnaire was divided into three main parts, consisting of 25 different types of questions (multiple-choice, one option). (1) 10 questions on the social-demographic characteristics of the participants (e.g., education, gender, income, etc.); (2) 13 questions on food acquisition and diet (e.g., food purchases, food activities, food waste etc.) and 2 questions on emotions during the pandemic (see **Appendix A**).

The questionnaire was evaluated in two phases prior to release. Firstly, an expert panel performed a quality assessment of the content's validity to improve the research's validity and reliability. Inappropriate parts were removed based on professional evaluations, and the remaining items were altered to ensure accuracy and clarity. Secondly, a pre-test with 17 individuals was conducted to ensure the quality of the data. Before administering the survey, feedback was solicited in order to improve it. Finally, 356 valid responses were received. Further, the same questionnaire was utilized in prior surveys in several countries, such as Qatar (20), Lebanon (10), Serbia (13), Bosnia and Herzegovina (35), and Russia (22).

The survey findings were analyzed using the software SPSS (Statistical Package for Social Sciences) version 25.0. The descriptive statistics were computed (means, standard deviations, percentages, and frequencies). The percentages of answers and cases were determined via an examination of multiple responses. Non-parametric tests were utilized since the variables were nominal and ordinal. The U-Mann Whitney test was used for dichotomous, categorical independent variables (e.g., No = 0 / Yes = 1), while the Kruskal-Wallis test was employed to evaluate multiple-choice responses (e.g., occupation). Furthermore, the chi-square (2) test examined the connection between respondent variables and socio-demographic characteristics. The *p*-value for statistical significance was fixed at 0.05 for all tests.

RESULTS

Study Participants' Social and Demographic Characteristics

The socio-demographic features of the respondents are shown in **Table 1**. The results indicated that 57.6% of the participants were men, 30.6% were married with children. Moreover, most respondents were middle-aged (58.4% were 25–45 years old), and 69.3% earned the same income as most of Oman's families. In general, the sample was well-educated, with 75.6% holding a Master's, university, or Ph.D. Only 23.3% had a high school

TABLE 1 | Socio-demographic characteristics of the study participants ($n = 356$).

Variable		Frequency	Valid percent
Gender	Female	151	42.42
	Male	205	57.58
Age	18–24	117	32.87
	25–44	208	58.43
	45 and over	31	8.71
Level of education	No formal schooling or primary School	4	1.12
	Secondary School	83	23.31
	University Degree	224	62.92
	Higher Degree (MSc or PhD)	45	12.64
Income	Lower than most other households	37	10.4
	About the same as most other households	247	69.38
	Higher than other households	66	20.22
Occupation	In paid work (full time or part time)	184	51.69
	Student	117	32.87
	Unemployed and looking for work	32	8.99
	Home duties	21	5.90
	Retired/Age pensioner	2	0.56
Household composition	Single person household	4	1.12
	Living with parents	124	34.83
	Married with children	109	30.62
	Married without children	7	1.97
	Extended family	111	31.18
	Shared household, non-related	1	0.28

diploma, and 1.12% were unqualified. Regarding occupation, 51.7% were working (full-time or part-time jobs), 32.8% were students, 9% were jobless and looking for employment, and 5.9% were homemakers (**Table 1**).

Food-Related Behaviors and Activities During the COVID-19 Pandemic

The results indicated several modifications in participants' food shopping practices during the COVID-19 pandemic. Firstly, as shown in **Table 2**, 25.8% of the participants indicated that they purchased more local food items. Further, 28.1% specified that they purchased more groceries online, and 29.8% never did. Furthermore, 26.7% said they had more meals delivered to their homes from a typical restaurant or a fast-food restaurant or via a delivery app.

Second, 84.2% of the participants said that they go shopping less often than customary, while 39.6% stated that they purchased more and much more quantity than usual on each shopping trip. Thirdly, as shown in **Table 3**, when asked about their diet during the COVID-19 pandemic, 54.5% of respondents indicated that they increased their water consumption, 45.5% increased their consumption of fruits and vegetables, and 42.4% increased their consumption of healthy foods (all by including "moderately more" and "much more"). In the meantime, 43% of the participants reduced their intake of unhealthy snacks, 53.1% consumed less unhealthy meals, and 35.6% consumed less packed frozen foods (all of these figures include "slightly less" and "much less").

Fourthly, there have been some modifications in food-related activities. According to the findings, 56.1% of the cohort ate out less, and 44.6% ordered fewer take-out or fast food meals (all calculated by counting "slightly less" and "much less"). Moreover, 54.2% of those polled ate more with family members, 54.2% cooked and prepared food much more frequently, 46.3% cooked a lot, and 28.1% ate more between meals (e.g., snacks) (all calculated by counting "moderately more" and "much more") (**Table 4**).

Another notable outcome is the low panic buying. In fact, 62.3% of the cohort said that they had not stored food since COVID-19 became serious in Oman. There has been a decrease in food waste, with 78.9% reporting that they were not wasting more food than usual due to COVID-19, and 74.7% reporting that they were more conscious of the amount of food they were throwing away (**Table 5**).

Nonetheless, there have been substantial correlations between the participant's citizenship and food stockpiling (chi-square test $p < 0.05$). Indeed, 64.7% of the Omani respondents and only 33.3% of the non-Omani indicated that they did not stock up food. Stocking up food by the non-Omani was mainly motivated by concerns about obtaining enough food and food prices rising (**Table 6**).

Furthermore, according to **Table 7**, the findings revealed a low prevalence of negative emotions such as fear, anxiety, and depression. Indeed, 40% of respondents said they were not nervous at all, 42% said they were not depressed at all, and 43% said they were not sad at all. Meanwhile, 51.41% of the cohort reported feeling optimistic, and 36.72% declared feeling calm.

DISCUSSION

This paper examined the impacts of the COVID-19 pandemic on diet and food shopping behaviors in Oman based on the perspectives of 356 consumers who participated in this study. Since the outbreak of the COVID-19 pandemic started, we have seen a significant shift in respondents' food and health-related behavior and attitudes. There have been noticeable shifts in the ways how people eat, purchase, and interact with food. The findings revealed several significant consumer trends that have an impact on the diet and eating behavior of the study participants.

First, intakes of unhealthy foods such as sweets and junk food during the epidemic have been reduced by most respondents. Meanwhile, more fruit and vegetables have been consumed in a healthier diet. This created a favorable transformation compared to the pre-COVID 19 State toward better eating habits and may assist in achieving the nation's health and nutrition vision for 2050 (36). Indeed, ranked amongst the

TABLE 2 | Consumers' behavior trends during the COVID-19 pandemic ($n = 356$).

Item	Percentage*					Mean	VR**
	Never	First Time	Less	About the same	More		
Buying local food	9.55	3.37	10.95	43.82	25.84	3.63	0.56
Ordering groceries online	29.78	5.34	9.70	11.80	28.09	2.62	0.70
Buying food in person from a large supermarket	3.93	1.12	22.51	40.17	24.15	3.79	0.60
Having meals delivered directly to home from a full-service or fast food restaurant or by a delivery application	20.51	3.93	14.83	17.42	26.7	2.93	0.79

Scale: never = 0; first time = 1; less = 2; about the same = 3; more = 4.
***VR, Variance Ratio.*

TABLE 3 | Eating and drinking patterns during the COVID-19 pandemic ($n = 356$).

Item	Percentage*							Mean	VR**
	Never	First Time	Much Less	Slightly Less	About the same	Moderately more	Much more		
Water	0.84	0.56	1.97	2.25	39.89	23.31	31.18	4.74	0.60
Fruits/ Vegetables	0.84	1.40	4.78	4.78	42.70	29.78	15.73	4.39	0.57
Healthy foods	1.69	0.84	5.06	4.49	45.51	26.40	16.01	4.35	0.54
Healthy snacks	2.81	1.40	4.49	9.55	53.93	19.94	7.87	4.02	0.46
Candy, cookies,cakes, and pastries	2.53	1.69	14.61	21.63	38.76	11.80	8.99	3.64	0.61
Packagedfrozen foods	10.67	1.69	15.73	19.94	37.92	11.24	2.81	3.18	0.62
Unhealthysnacks	8.43	2.25	22.47	20.51	31.74	10.67	3.93	3.13	0.68
Unhealthyfoods (fast-food)	8.15	1.97	29.21	23.88	23.31	9.55	3.93	2.97	0.71
Canned food	12.92	2.81	21.07	19.10	30.90	10.11	3.09	2.95	0.69

Scale: never = 0; first time = 1; much less = 2; slightly less = 3; about the same = 4; moderately more = 5; much more = 6.
***VR, Variance Ratio.*

most developed countries globally, Oman has experienced a rapid socio-economic development process in the past fifty years. Therefore, the prevalence of over-nutrition and associated morbidities grows in the Sultanate. A survey of 2017, led by the Omani Ministry of Health, indicated that 69.3% of men and 63.3% of women were overweight or obese. It also outlined a sharp rise in adult obesity since 1991 (37). As in the whole Middle East region, Oman is also witnessing some of the highest rates of childhood obesity (38). As a result, there is a high burden of non-communicable diseases (NCDs), particularly type 2 diabetes and kidney and heart diseases, among the Omani population (36). Moreover, in 2017, a survey highlighted that 57.3% of women and 63.9% of men consumed <5 portions of fruit and/or vegetables per day. Further, Afshin et al. (39) highlighted high sodium consumption, trans fats, and sugar-sweetened beverages (SSBs) among the Omani population.

Second, as shown in multiple countries throughout the globe (11, 24), most participants' food buying habits have changed due to COVID-19. On the one hand, as more people shop online to escape congested supermarkets, the digitization of food retail is speeding fast. This supports a general trend in the GCC area, where online shopping has grown significantly since the pandemic's beginning (19, 20). At the same time, several respondents still bought food in person to check the quality and freshness of the items. Similarly, shopping at grocery stores became the only activity available, with most entertainment activities closed (shopping centers, movies, etc.).

Moreover, the pandemic has also affected people's shopping habits since supermarkets are seen as risky places where people are afraid to be near one another. As witnessed in several countries, COVID-19 was linked to fewer shopping trips and increased purchases per trip. In addition, due to food safety concerns, the consumption of local food products rose. Concerns about the transmission of the virus grew with the COVID- 19 pandemic and an increasing number of people want to know where their food originates from. A preference for local products was generated by the unfounded belief of consumers that imported items represent a safety concern. A locally produced item is thought to be handled fewer times and therefore has a higher perception of safety (40). It may also be related to the distributions of global food chains and the resulting lack in the provision stream of imported items. In fact, the pandemic and associated actions caused substantial distortions in the food supply chain via logistical interrupts and restricted access to markets for commodities (4).

Third, the vast majority of respondents did not stockpile food. This is owing to the limited dissemination of negative emotions such as fear, anxiety, and despair. Indeed, most study participants are less concerned about their families and long-term prospects than those in other countries (11). Stress, despair, and anxiety

TABLE 4 | Change of food-related activities during the COVID-19 pandemic ($n = 356$).

Item	Percentage*					Mean	VR**
	Never	First Time	Less	About the same	More		
Eating out	24.72	2.25	56.18	12.64	4.22	2.04	0.60
Ordering take-away or fast food meals with deliveries	19.94	2.53	44.66	15.45	17.42	2.65	0.74
Eating with family members	1.97	0.84	13.77	44.10	39.32	4.39	0.56
Cooking and preparing food	3.93	0.56	6.46	30.06	58.99	4.66	0.70
Spending a lot of time cooking	5.90	0.56	11.52	35.67	46.35	4.27	0.64
Eating between meals (e.g., snacks)	4.21	1.69	21.06	44.94	28.09	3.86	0.55
Making easy meals	9.27	2.53	22.47	34.55	31.18	3.64	0.65

Scale: never = 0; first time = 1; less = 2; about the same = 3; more = 4.
***VR, Variance Ratio.*

may cause panic purchasing and hoarding, which is a way for consumers to reclaim control over their product procurement (41). Indeed, stockpiling food does give people a sense of power and control (42). In several countries in the Middle East and North Africa (MENA) region, there was high dissemination of negative emotions and consequently a spread of stockpiling. For example, in Lebanon, according to Ben Hassen et al. (10), 60.9% of the respondents were feeling depressed, 66.3% were nervous, and 60.2% were sad. Meanwhile, they emphasized the prevalence of panic purchasing in Lebanon, with 73.13 percent of respondents reporting that they stocked up on food once COVID-19 became serious. Similarly, in Morocco, 52.65% of interviewees reported having stockpiled food since COVID-19 became serious (43). Indeed, there was a rush to Moroccan retailers just before the lockdown in March 2020, and demand for flour and grains skyrocketed. Moroccans were worried about the Coronavirus and stockpiling in massive quantities. As a result, food prices have risen (43). In Oman, the government took several initiatives to mitigate the consequences of the epidemic on food supplies. In Oman, 80% of the food consumed is imported. The epidemic, however, had little effect on food supplies or pricing. In 2019, Oman was ranked 46th among 113 countries in the Global Food Security Index (44). In April 2020, at the beginning of the COVID-19 pandemic, the Omani authorities rushed to maintain the strategic food stock. To strengthen the reserve stock of essential food commodities. Moreover, in October 2020, the Omani government announced that essential food items are exempted from the Value-Added Tax (VAT) to ensure that the tax does not increase inflation and living costs (45). Additionally, the Omani government adopted clear and intense communication strategies to reassure its citizens. For example, in March 2020, the general director of commercial operations at the Omani PASFR affirmed that "The authority has made full preparations to confront the Coronavirus pandemic and that the food stock situation is good and there is no concern in providing basic food commodities." Also, the authorities made continuous efforts to monitor markets and regulate prices. For instance, the government developed a range of e-platforms to promote online sales of agricultural products (46).

We did detect specific differences between Omani and non-Omani responders, though. Non-Omani purchased more food than Omani respondents. The socio-economic characteristics of Oman could explain this. In 2018, foreign workers made up 86% of the entire workforce. The private sector employed 86% of all foreign employees in the same year. The number of foreign workers in Oman increased from the 2000's to 2016 but declined. Since 2017, the government has imposed Omanisation quotas and restrictions on hiring foreign workers in several sectors (47). As a result, non-Omanis are more concerned about losing their jobs or having their salaries reduced due to the COVID-19 epidemic. Indeed, in 2020, the drop in oil prices and the disruptions from COVID-19 placed unprecedented strain on Oman's economy. Real GDP decreased by 2.8% in 2020 (48).

TABLE 5 | Changes in food behavior during the COVID-19 pandemic (n =356).

Item	Percentage		Mean	SD*
	Yes	No		
Do you buy more food out of fear or anxiety?	32.58	67.42	1.67	0.47
Do you eat more food out of boredom?	29.50	70.50	1.71	0.46
Are you wasting more food than usual?	21.10	78.90	1.79	0.41
Are you more aware of how much food you waste?	74.72	25.28	1.25	0.44

**SD, Standard Deviation.*

Finally, the absence of panic buying resulted in decreased food waste. Furthermore, this positive change may suggest that most research participants have adopted various positive methods for the administration of food throughout the pandemic (e.g., greater pre-shop preparation, improved food storage, and innovative cooking/prep procedures), as seen in the UK (49). This is a positive change since food waste in Oman is a significant issue, where food is primarily wasted at the level of consumers (50). Indeed, according to the Food Waste Index Report 2021(51), In Oman, 95 kg/capita of food is wasted every year, compared to an average of 79 kg/capita/year for high-income countries. This shows a potential path toward a more sustainable behavior in food consumption. The COVID-19 pandemic has shown an

TABLE 6 | Stocking up and food-related concerns during the COVID-19 pandemic and comparison between groups of citizenships.

Item	Scale*/Percentage					Mean	S.D.	U Mann Whitney test -Citizenship
	Not at all	Less	Moderate	Much	Very much			
Obtaining enough food	39.04	14.04	25.28	11.52	10.11	2.40	1.36	3082.50**
Obtaining a variety of food	38.76	16.29	24.72	14.89	5.34	2.32	1.27	3381.50*
Access to healthy and safe food	37.08	12.92	23.88	18.54	7.58	2.47	1.35	3466.50*
Food prices rising	19.94	14.89	30.06	17.42	17.70	2.98	1.35	3132.00**

Scale: Not at all = 1; Less = 2; Moderate = 3; Much = 4; Very much = 5.
$^{**}p < 0.01$, $^{*}p < 0.05$.

TABLE 7 | Negative and positive emotions since the onset of COVID-19 ($n = 356$).

Emotion Item	Percentage*				Mean	VR**
	Not at all	Less	Moderate	Much		
Nervous	40.06	17.33	24.15	18.46	2.32	0.60
Worried	22.44	18.47	23.86	35.49	2.91	0.76
Depressed	42	19.70	17.70	20.6	2.27	0.58
Sad	43.06	18.70	18.41	19.83	2.27	0.57
Scared	27.68	24.29	19.21	28.81	2.66	0.72
Bored	20.11	14.16	23.80	41.93	3.16	0.72
Total of negative emotions					2.60	
Calm	14.69	18.36	30.23	36.72	3.10	0.70
Optimistic	9.89	13.56	25.14	51.41	3.51	0.67
Excited	22.44	19.32	32.39	25.85	2.76	0.67
Happy	18.47	19.60	32.39	29.54	2.88	0.77
Total of positive emotions					3.07	

Scale: Not at all = 1; Less = 2; Moderate = 3; Much = 4.
***VR, Variance Ratio.*

improvement in food waste behavior in Oman, as shown by studies in various countries in the region, such as Qatar (20), Lebanon (10), Tunisia (52), and Morocco (43).

Nonetheless, some survey methodologies and instruments have some limitations that might impair the sample's representativeness. The most significant limitation of this study is likely to be its sample bias. Indeed, the survey participants were chosen at random and freely. Because the questionnaire was filled out by unpaid volunteers, only those who had a clear interest in the topic could participate (cf. self-selection of the sample). Consequently, our sample may not represent the whole population of Oman. For example, in our sample, those with a university degree were more likely to be included (75.5%). Accordingly, it is challenging to extrapolate survey findings to the whole Oman population because of this biased sample. This bias may lead as well to inaccuracy in the reported behaviors. In general, in surveys, low-educated people tend to be underrepresented (53). Many of the above limitations apply to computer-assisted web interviewing (CAWI), which is often deployed in survey research (54–56). However, face-to-face research is challenging to achieve because of the COVID-19 condition and social distancing measures, and online surveys became more practical. To our knowledge, this is the first research in Oman to examine the influence of COVID-19 on food consumption patterns.

CONCLUSION

Through a cross-sectional online survey, this paper examined the perceptions of Omani consumers on the impacts of the COVID-19 pandemic on food-related behaviors. Overall, the survey findings indicate that the COVID-19 pandemic has improved Oman's transition to more sustainable and healthy consumption practices. The results led to the rejection of three hypotheses – since the pandemic and the related negative feelings did not trigger a move toward unhealthy diets (H1) and it did not cause either an increase in food stockpiling and panic buying (H3) or an increase in food waste (H4) – and the confirmation of only H2 hypothesis relating to the rise in online shopping. Positive developments include purchasing local foods, improving food shopping and procurement planning, healthier diets, and less household food waste. However, since the COVID-19 pandemic is still underway and given the study's limitations described above, the results need to be checked and investigated in the future through a more extensive sample. Moreover, the present cross-sectional survey results represent a good baseline for future longitudinal studies on how the pandemic has affected food-related behaviors in Oman. They also provide valuable insights to inform policies and strategies aiming at mitigating the impacts of the pandemic on food sustainability, food security, and nutrition in the Sultanate and other GCC countries. In crisis circumstances, such as the COVID-19, the pace of collecting and releasing knowledge is especially relevant. A minimal understanding of attitudes, values, information, and behaviors may help new research and strategies.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by this study was performed in compliance

with the Helsinki Declaration guidelines. All procedures relevant to study participants were approved by the Western Michigan University Human Subjects Institutional Review Board (HSIRB). Participation in the research was voluntary. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TBH, HEB, and MSA: conceptualization, methodology, and formal analysis. SM: software and validation. TBH and HAS: investigation. MSA: data curation. TBH and HEB: writing—original draft preparation, writing—review and editing, and project administration. All authors have read and agreed to the published version of the manuscript.

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Food Supply Chain Safety Research Trends From 1997 to 2020: A Bibliometric Analysis

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Background: The COVID-19 pandemic has exposed the fragility of the global food supply chain, strengthened consumers' awareness of the traceability system throughout the supply chain, and gradually changed consumers' consumption concepts and consumption patterns. Therefore, the aim of this study was to analyse the relevant literature on food safety in the food supply chain, examine its current status, hot spots, and development trends, and provide some suggestions for academics and relevant government departments in food supply chain safety research.

Methods: We collected the literature on the food safety research of the food supply chain from the Scopus database, used BibExcel to count the subject categories, published journals, geographical distributions, research institutions, authors, and keywords in the literature, and used Pajek software to analyse the keywords in the literature, perform co-occurrence analysis, draw related knowledge maps, and perform cluster analysis on primary keywords. Finally, to study the development trend, we used CorTexT software to illustrate the theme evolution path map in this research field.

Results: The keyword visualization network revealed the following key research topics: (1) food safety at the consumer end of the food supply chain, (2) food safety management in the food supply chain, (3) risk management of food safety in the food safety chain, and (4) food safety at the production end of the food supply chain.

Conclusions: After comprehensive discussion and analysis, we concluded that food supply chain management may be a hot topic in the future, especially in traceability management combined with the blockchain. It is necessary to explore in-depth how the blockchain can affect the food supply chain to provide a theoretical basis for managing the latter.

Keywords: food supply chain, food safety, bibliometrics, pandemic, traceability

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INTRODUCTION

The COVID-19 pandemic that started in 2020 threatens global food safety in the food supply chain; the main concern revolves around the sources of food safety risks, which alerted stakeholders to the need to revise food safety risk management strategies globally (1). The food industry is becoming increasingly aware of the fragility of agricultural products, the uncertainty of the food supply, and the flexibility of transportation and logistics (2), which have attracted increasing attention from scholars aiming to study the close relationship of food safety with the food supply chain.

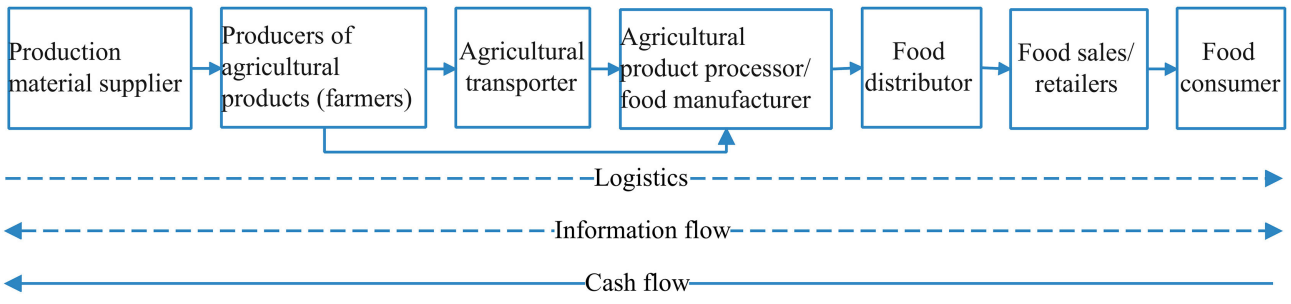

FIGURE 1 | The structure model of the food supply chain.

Den Ouden et al. (3), scholars of agriculture and biology, first proposed the food supply chain, which is a network structure consisting of consumers of agricultural products, food production, the processing, food logistics, and distribution industries, food sales companies, and related entities (4, 5). A simplified food supply chain structure model is shown in **Figure 1** (6). Food has unique attributes such as corrosion and environmental impact (7), combining the food supply chain's complex characteristics, networked organizational structure, and dynamic supply network (8). Food contamination is a significant food safety risk in all aspects of the food supply chain, such as production, procurement, processing, circulation, and sales (9, 10). Therefore, this article discussed the food supply chain safety from the aspects of food quality, health, and biosafety.

As people pay increasing attention to food safety, researchers are beginning to review the relevant articles in the field. Auler et al. (11) systematically reviewed 46 articles on food safety in the field of supply chain management and revealed the main features of the literature in this research field. Wahyuni et al. (12) reviewed the titles and abstracts of articles on food safety and halal food in the supply chain and made a cluster analysis of the research network in this field but did not discuss related topics in depth. Azmi et al. (13) studied the types of risks involved in the halal food supply chain, thereby offering important insights into the strategic development and integrity of the halal supply chain. However, these studies focused on performing traditional literature reviews and only studied some aspects of the food supply chain, thereby failing to comprehensively outline the development of food supply chain safety.

In this study, we used existing literature reviews with bibliometrics analysis methods, analyzed quantitatively the development status and research hotspots of food supply chain safety, and predicted its future development trend. The specific objectives of this study were: (1) to determine the prominent research profile in the food supply chain safety research field, such as research disciplines, influential journals, and geographical distribution; (2) to determine the key themes of analysis in this research field; and (3) to determine the evolution path and future development trend of this research field.

The main contributions of this study are the following: (1) we analyzed comprehensively the research status and disciplinary characteristics of the food supply chain safety field; (2) we discussed comprehensively the evolutionary path of this research field; (3) we pointed out future research priorities for scholars, such as consumer trust in the food supply chain, food supply chain traceability, blockchain application, and risk management.

The rest of this article is organized as follows (refer to **Figure 2**): in Section Materials and methods, we discuss research methods and the initial statistical analysis of the data; in Section Results, we present our research results and analysis, descriptive statistics, cluster analysis, and evolutionary path analysis of the selected literature; in Section Discussion, we discuss the findings of this research and propose future research directions; in Section Conclusions, we summarize our main conclusions.

MATERIALS AND METHODS

Bibliometrics Analysis

In this study, we used bibliometrics to comprehensively analyse the food safety-related literature in the food supply chain and dig deeper into the quantitative and qualitative characteristics of the literature to help researchers to evaluate the food safety field in the food supply chain and the research path and research trend of the research as well as assist scholars in implementing innovative ideas based on existing literature.

Bibliometric analysis is a cross-science analysis that integrates mathematics, statistics, and philology and employs mathematical and statistical methods to quantitatively analyse the data from all research databases (14). Through citation analysis, co-citation analysis, statistical analysis of the title, author, journal, country, institution, reference, and subject category in the bibliographic information of a particular field, bibliometrics can evaluate the development trend of the literature, the research subject, and prominent research institutions, periodicals, essential documents, influential citations, and other comprehensive document systems (15). The main aim of the bibliometric analysis is to analyse keywords and use the co-occurrence of vocabulary pairs or noun phrases in the literature to determine the relationship between the topics (16).

Thematic Evolution Trend Analysis

Thematic evolution analysis is a new research method developed recently in the information science field that is widely used in many disciplines. It can better identify the subject development,

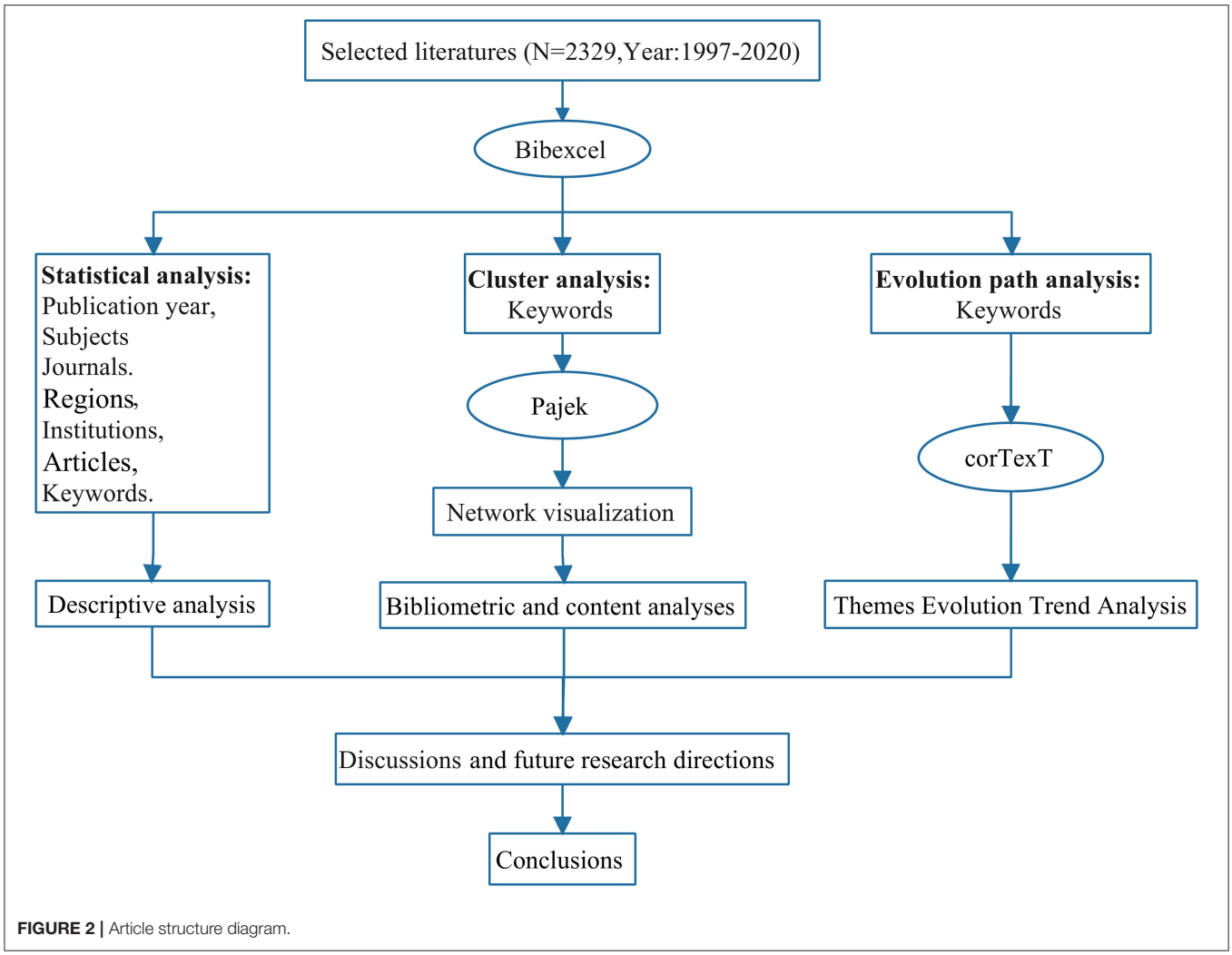

FIGURE 2 | Article structure diagram.

evolution, and flow of a particular research field in a certain period, thereby assisting researchers in understanding more comprehensively the development of a specific field. In this study, we used CorTexT to draw the evolutionary path diagram; the length of the topic direction on the ordinate axis indicates the proportion of the total frequency of keywords in that direction. The expansion and contraction of the alluvial area represent the scale change in different time intervals.

Analysis Tools

In this study, we used the document processing tool BibExcel and network analysis tools Pajek and CorTexT Platform (www.cortext.net). Bibexcel performs basic statistical analysis on the number of articles, citations, and *h*-index of authors, journals, and countries in the bibliographic information downloaded from the Scopus database (17). The visualization software Pajek performs bibliographic analysis, citation analysis, co-citation analysis, and cluster analysis of related data (18). Finally, CorTexT reveals the evolutionary characteristics of food safety research topics in the food supply chain over time (19).

Data Sources and Processing

In this study, we obtained research data from Scopus, the largest abstract and citation database of peer-reviewed literature and international publishers globally that provides a one-stop platform for scientific researchers to access the scientific literature. We employed four steps while using Scopus: keyword identification, selection criteria for inclusion and exclusion, quality evaluation, and data extraction (20).

The term "food safety in the food supply chain" comprises three key elements: food, supply chain, and safety; therefore, we included three search strings to ensure that relevant literature data were obtained. The first search string contained keywords related to food according to the agricultural commodity keywords defined by the Food and Agriculture Organization of the United Nations: food* or dairy or fruit or grain or cereal or meat or pork or beef or chicken or fish or vegetable or grape or wine or rice or coffee or oil or horticulture or "sugar cane" or maize or wheat or potato or "sugar beet" or soybeans or cassava or tomato or barley or cotton or apple. The second string

TABLE 1 | Topic search queries used for data collection.

Set	Records	Search Queries
#1	3,424,449	(TITLE(food* OR dairy OR fruit OR grain OR cereal OR meat OR pork OR beef or chicken OR fish OR vegetable OR grape OR wine OR rice OR coffee OR oil OR horticulture OR "Sugar cane" OR maize OR wheat OR potato OR "sugar beet" OR soybeans OR cassava OR tomato OR barley OR cotton OR apple)) OR (KEY(food* OR dairy OR fruit OR grain OR cereal OR meat OR pork OR beef or chicken OR fish OR vegetable OR grape OR wine OR rice OR coffee OR oil OR horticulture OR "Sugar cane" OR maize OR wheat OR potato OR "sugar beet" OR soybeans OR cassava OR tomato OR barley OR cotton OR apple))
#2	1,312,930	(TITLE("supply chain" OR "supply network" OR "demand chain" OR "value chain" OR purchas* OR sourc* OR logistics OR procurement)) OR (KEY("supply chain" OR "supply network" OR "demand chain" OR "value chain" OR purchas* OR sourc* OR logistics OR procurement))
#3	4,151,056	(TITLE(safet* OR securit* OR risk*)) OR (KEY(safet* OR securit* OR risk*))
#4	11235	#1 AND #2 AND #3

consisted of keywords of supply chain-related terms: "supply chain" or "supply network" or "demand chain" or "value chain" or purchas* or sourc* or logistics or procurement. The third-string consisted of security-related keywords: safet* or securit* or risk* (refer to **Table 1**).

We searched the "title" and "keyword" fields in the Scopus database, with no time limit for the search, and the resulting records were 11,235 (by 12/31/2020). We found the literature retrieved from the Scopus database was first published in 1997. In addition, the Codex Alimentarius Commission issued the "Hazard Analysis and Critical Control Point (HACCP) System and Guidelines for its Application" for food safety and hygiene in 1997, thus providing outline requirements for global food safety management and certification. In the same year, the United States allocated an additional $100 million to launch a food safety program, the European Union began phasing in a traceability system for food information, and Britain's Department for Environment, Food, and Rural Affairs set up a livestock traceability system. So, we considered 1997 as the starting point of the research topic.

The search scope was limited to "journal articles" written in "English", while comments, conference papers, notes, errata, and short articles and surveys were excluded. This reduced the resulting records to 8,282. Then, we screened the titles and abstracts of 2,329 articles based on the inclusion and exclusion criteria. Specifically, in this study, we selected articles published in peer-reviewed English-language journals, such as articles discussing various aspects of food safety in the food supply chain (e.g., definitions, agriculture, chemistry, nutrition, biology, food engineering, and quality risk evaluation). We excluded articles that were not directly related to the food supply chain safety, such as those discussing the intensive development of the dairy industry, gardening market efficiency, fish gathering equipment, and fertilizer production input. Finally, 2,329 relevant articles from 1997 to 2020 were selected for bibliometric analysis (as shown in **Figure 3**).

The aforementioned processes were performed by two collaborators independently screening articles, comparing search results, and reaching an agreement on such as the aforementioned 2,329 articles. The inter-rater reliability was 100%, which ensures the accuracy and rationality of the data analyzed.

RESULTS

Descriptive Analysis

Figure 4 shows the change in the number of publications on food safety in the food supply chain between 1997 and 2020. It can be seen from statistics that although the number of articles published was at a low period in 2014, it has shown an overall upwards trend. The total number of articles published on food safety in the food supply chain in 2020 is the largest, reaching 279 items, accounting for ∼11.98%. Second, the total number of articles in 2019 followed closely, with 249 pieces, accounting for about 10.69%. The number of journal publications on relevant topics peaked in 2015–2020. **Figure 4** also shows that the number of times published articles are cited increases continually, which shows that researchers focus on the in-depth and innovative research content of scholars to advance the systematicity of food safety research in the food supply chain. It can be predicted from the current trend that research related to food safety in the food supply chain will continue to grow and the level of study and research content will continue to improve.

Subject Categories

The 2,329 articles on food safety in the food supply chain are included in our analysis, contained 27 research topic categories according to the Scopus classification. We classify the subject of a single article by the subject category of the source journal. Due to the intersecting nature of food supply chain safety research fields, one article may cover multiple subject categories. We extracted 4,409 subject data from 2,329 pieces of literature by Bibexcel software, involving a total of 29 subject categories. According to different research directions, the main research fields are nine: agricultural and biological sciences, medicine, environmental science, biochemistry, genetics, and molecular biology, social sciences, business, management and accounting, nursing, veterinary, and engineering (refer to **Figure 5**). As it can be concluded from **Figure 5**, the most researched direction today is the agricultural and biological sciences one, with 870 articles accounting for ∼19.73%. With the advancement of science and technology and the increasing number of food contamination incidents in the food supply chain, practitioners, and scholars have been alerted to food safety issues and their consequences,

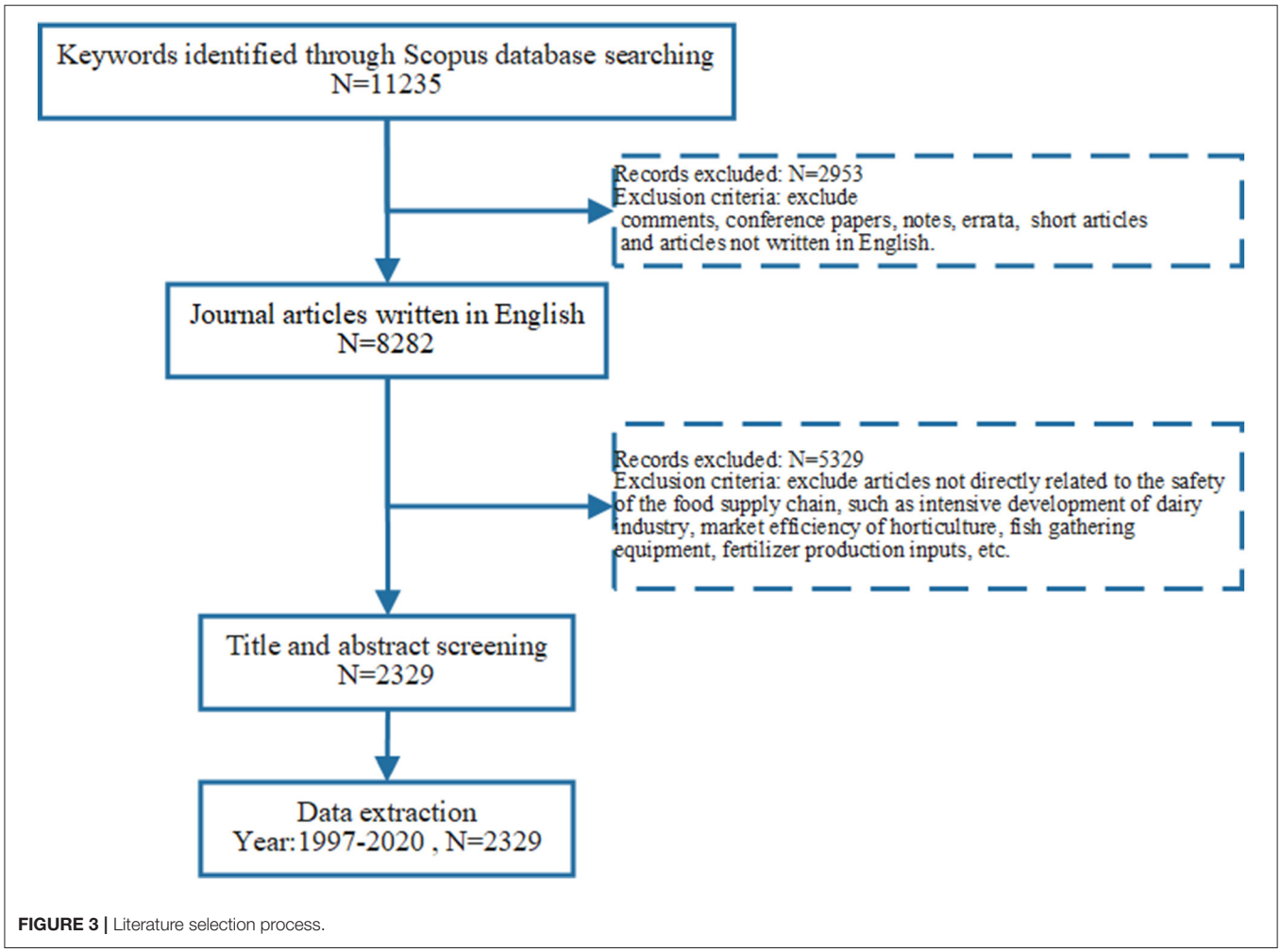

FIGURE 3 | Literature selection process.

such as genetic modification technology, genetic modification supervision, and the application of food pesticides.

Influential Journals

The total number of journals related to food safety in the food supply chain that published relevant articles from 1997 to 2020 was 182. This demonstrates the extent and variety of publications and discussions in this field. **Table 2** lists the top 10 journals in terms of publication volume. Impact factor (IF) is an internationally recognized journal evaluation index. It is generally believed that journals with an IF >1 can be considered valuable journals in social sciences. All the top 10 journals shown in **Table 2** had an IF >1, which ranged from 2.304 to 6.766. Additionally, they focused on the impact of food safety issues on the environment and health in the food supply chain as well as risk identification and risk management. The *h*-index measures the citation impact and productivity of publications and aims to quantify the results of researchers as independent individuals. From 1997 to 2020, "Preventive Veterinary Medicine" published the most articles cited the most times, was cited 2,253 times, and had the highest *h*-index (30). Interestingly, among all journals, the IF (6.766) of the "American Journal of Clinical Nutrition" was the highest. Still, its total publications and *h*-index were much lower than those of "Preventive Veterinary Medicine", which shows that its primary influence was not on the food safety research in the food supply chain.

Geographical Distributions

From 1997 to 2020, researchers from 132 regions published articles on food safety in the food supply chain. The range of areas covered was wide and concentrated in the United States, China, and the United Kingdom. The publication volume in 79 areas was <10, accounting for ∼59.85%. In 19 countries/regions, the publication volume was 10–20, accounting for 14.39% of the total; while in 23 countries/regions, the publication volume was 20–80, accounting for ∼17.42% of the total (refer to **Figure 6**). As shown in **Table 3**, the publication volume in 10 countries/regions is more than 80 articles. The United States, China, and the United Kingdom rank in the top three in terms of publication volume and *h*-index; however, the number of citations of the second-ranked Chinese article is lower than the number of sources of the third-ranked 31 article. Additionally, the *h*-index of China (38) is lower than that of the UK (44), thereby indicating that the articles published by the latter are more influential.

Influential Institutions

The first authors of the 2,329 articles included in this study represented 167 different research institutions, approximating

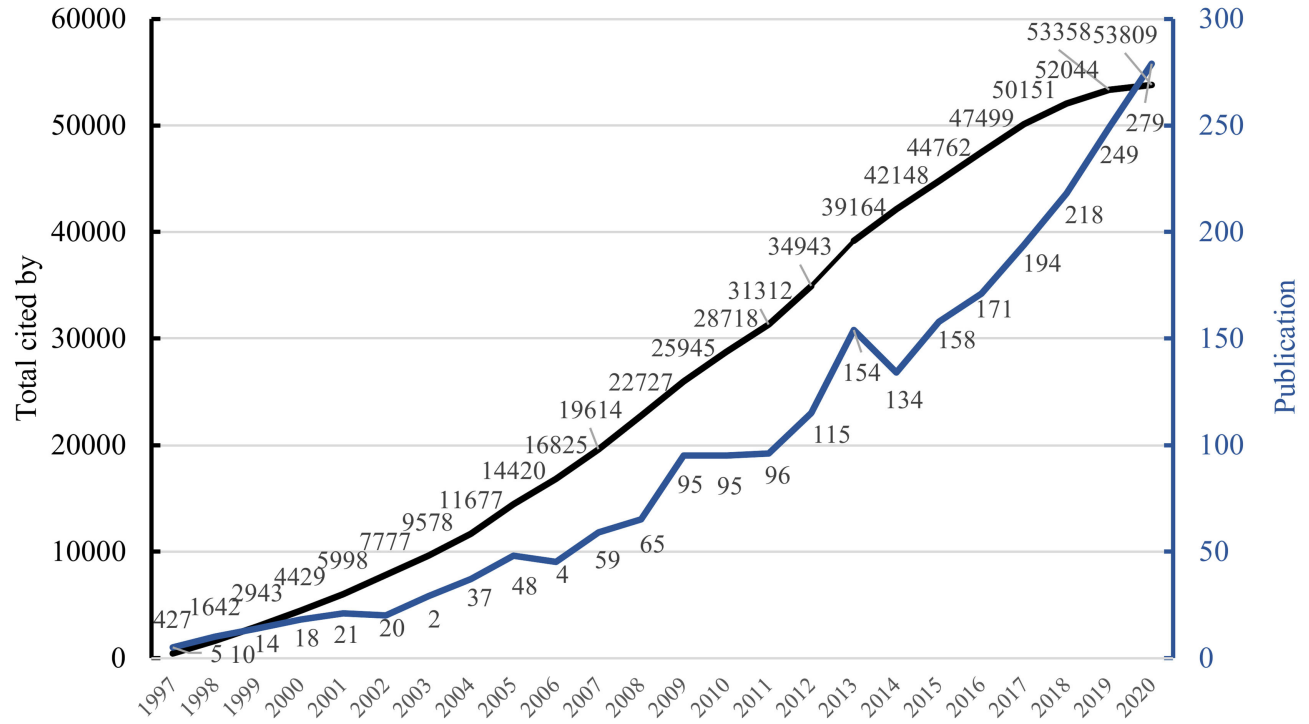

FIGURE 4 | The number of annual publications and total cited between 1997 and 2020.

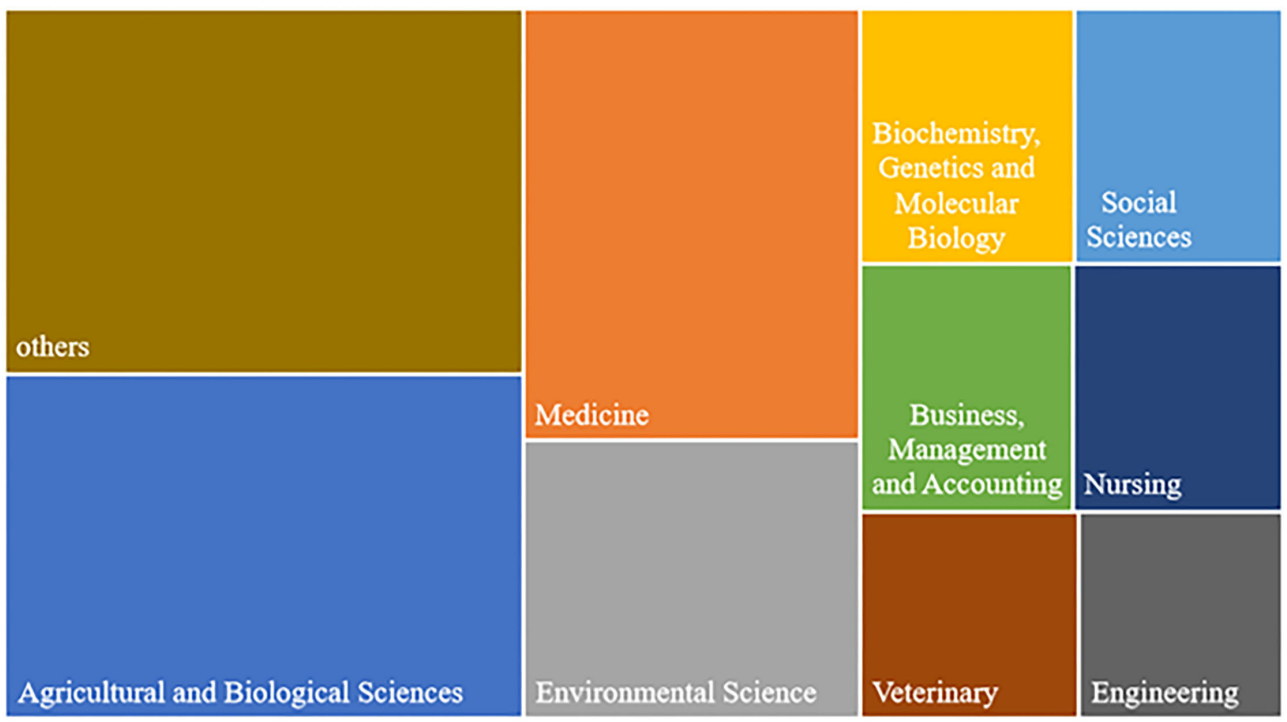

FIGURE 5 | Subject categories.

TABLE 2 | The performance of the 10 most leading journals.

Rank	Journal	IF_{2019}	CS	SJR	SNIP	TP	TC	H-Index
1	Preventive veterinary medicine	2.304	4.1	0.969	1.243	70	2,253	30
2	Food control	4.258	8.4	1.43	1.733	40	1,176	19
3	Science of the total environment	6.551	8.6	1.661	1.977	34	1,653	19
4	Cancer epidemiology biomarkers and prevention	4.344	8.2	2.857	1.729	18	1,199	17
5	Cancer causes and control	2.375	4.2	1.332	0.965	26	1,270	16
6	American journal of clinical nutrition	6.766	12.1	2.704	2.339	18	1,856	16
7	British journal of nutrition	3.334	6.4	1.236	1.297	20	605	14
8	Journal of nutrition	4.281	8.2	1.797	1.644	15	902	14
9	Public health nutrition	3.182	4.8	1.21	1.269	29	733	14
10	Risk analysis	3.137	5.1	1.092	1.482	27	877	14

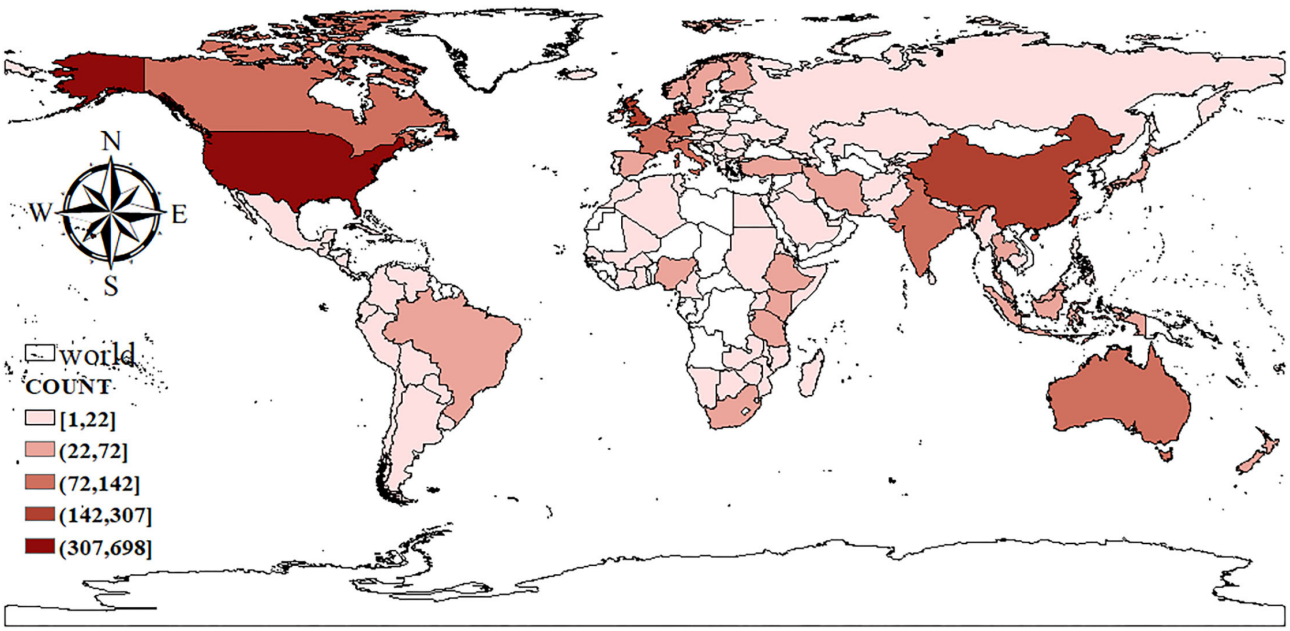

FIGURE 6 | Distribution of national publications.

to the total number of journals (182) mentioned in Influential journals, indicating the breadth of research in food safety in the food supply chain and its interdisciplinary nature. **Table 4** lists the 10 most influential institutions that promote the development of this field, of which seven are universities. These institutions are either comprehensive, agricultural, or medical research institutions. They are located in six countries, four of which are the countries that have the highest publication volume globally. Among the research institutions with the most significant number of publications is Wageningen University & Research in the Netherlands, with 68 publications and 2,778 citations.

Influential Authors

Table 5 lists the 10 most influential authors and their countries of origin, home institutions, publication volumes, citation volumes,

TABLE 3 | The top 10 productive countries.

Rank	Country	TP	%TP	TC	%TC	H-index
1	United States	698	20.42%	22,853	28.01%	69
2	China	307	8.98%	5,059	6.20%	38
3	United kingdom	212	6.20%	5,695	6.98%	44
4	Canada	142	4.15%	3,931	4.82%	33
5	Australia	134	3.92%	2,607	3.20%	29
6	Italy	123	3.60%	2,536	3.11%	29
7	Netherlands	114	3.33%	4,106	5.03%	37
8	Germany	112	3.28%	2,742	3.36%	28
9	India	90	2.63%	1374	1.68%	20
10	France	83	2.43%	2,115	2.59%	28

*%TP = (Total Publications/Document numbers)*100%; %TC = (TC = Total Citations/All Citations)*100%.*

TABLE 4 | The top 10 influential institutions.

Rank	Institution	Country	TP	TC	H-index
1	Wageningen University & Research	Netherland	68	2,778	30
2	Chinese Academy of Sciences	China	59	4,350	29
3	Harvard University	United States	43	2,161	27
4	Swedish University of Agricultural Sciences	Sweden	37	1,365	20
5	University of Milan	Italy	23	519	12
6	University of Copenhagen	Denmark	23	459	10
7	National Cancer Institute (NCI)	United States	21	1,071	16
8	Harvard Medical School	United States	20	959	10
9	Chinese Academy of Agricultural Sciences	China	20	736	9
10	Cornell University	United States	20	200	8

TABLE 5 | Information on the ten most influential researchers.

Rank	Author	Country	Institution	TP	TC	H-index
1	La Vecchia, C.	Italy	University of Milan	16	602	12
2	Talamini, R.	Italy	Centro di Riferimento Oncologico	10	556	10
3	Jacxsens, L.	Belgium	Ghent University	10	340	10
4	Willett, W.C.	United States	Harvard School of Public Health	9	1,715	9
5	Franceschi, S.	France	International Agency for Research on Cancer	9	542	9
6	Mirmiran, P.	Iran	Shahid Beheshti University of Medical Sciences	9	441	8
7	Azizi, F.	Iran	Shahid Beheshti University of Medical Sciences	9	441	8
8	Uyttendaele, M.	Belgium	Ghent University	9	320	8
9	Negri, E.	Italy	University of Milan	9	417	7
10	Grace, D.	Kenya	International Livestock Research Institute	9	103	7

and *h*-index. The top author La Vecchia is employed by the University of Milan in Italy and has the highest number of publications (16), citations (602), and *h*-index (12) in this field. This result demonstrates that La Vecchia is among the most influential authors in the food supply chain research field.

Further analysis of the number of authors in published articles, showed that the average number of authors per publication is 5.47. Among the publications examined, 696 had five authors, 483 had six authors, and 422 had four authors accounting for ∼33.46, 23.22, and 20.29%, respectively, of the total number of articles. Surprisingly, articles written by eight or more authors and those written by 10 or more authors accounted for ∼9.8 and 3.46%, respectively, of the total. These results suggest that food safety research in the food supply chain involves a considerable workload and requires experiments, surveys, and data collection often requiring the contribution of a team.

Frequently Cited Articles

In this study, we used the number of times a publication has been cited to evaluate its performance and scientific excellence; the higher the citation frequency, the greater the influence of the publication. In particular, to more accurately describe the impact of the article, this article excludes the number of self-citations. **Table 6** presents the information of the top 10 most cited articles in food safety research articles in the food supply chain from 1997 to 2020. The most cited article and the sixth most cited article were published in 2002 at the "Journal of the National Cancer Institute"; still, in both articles, long-term research data were used to illustrate the products of the production and consumption ends of the food supply chain and what consumers buy and eat (21, 25). Research has shown that the frequent intake of tomato products or lycopene (lycopene carotenoids) can reduce the risk of prostate cancer (21); high-fat dairy products, mostly skimmed/low-fat milk, can reduce the risk of breast cancer (26). This shows that food supply chain scholars attach great importance to the issues closely related to food safety and human health, especially the impact of food in the food supply chain on certain cancers that cannot yet be treated.

Frequently Used Keywords

In this study, we used the frequency of keywords as a metric to identify sub-areas and topics that have attracted the attention of researchers long-term. Taking into account that in some articles, there were keyword labeling irregularities and the possible lack of keyword fields; in this study, we extracted keywords, removed duplicates to obtain the original record of the keywords without repetition, merged singular and plural forms, abbreviations, and synonyms, and classified keywords into categories. **Table 7** shows some of the most frequently occurring keywords. The top 10 keywords are human (822), country (792), statistical model (708), gender difference (640), age distribution (563), controlled study (481), risk factor (474), risk assessment (452), logistic models (451), and foodborne diseases (429).

TABLE 6 | The top 10 frequently cited articles.

Rank	Author/Year	Journal	TC	PC
1	Giovannucci et al., 2002 (21)	Journal of the National Cancer Institute	570	31.67
2	Kummu et al., 2012 (22)	Science of the Total Environment	459	57.38
3	Hu et al., 1999 (23)	American Journal of Clinical Nutrition	428	20.38
4	Malm, 1998 (24)	Environmental Research	367	16.68
5	Opsomer et al., 2000 (25)	Theriogenology	338	16.90
6	Shin et al., 2002 (26)	Journal of the National Cancer Institute	301	16.72
7	Cornelis et al., 2006 (27)	Journal of the American Medical Association	296	21.14
8	Roth et al., 2008 (28)	Journal of Supply Chain management	282	23.50
9	Ko et al., 1997 (29)	International Journal of Epidemiology	261	11.35
10	Azadbakht et al., 2005 (30)	American Journal of Clinical Nutrition	247	16.47

TABLE 7 | Frequently occurring keywords.

Rank	Keywords	NO	Rank	Keywords	NO	Rank	Keywords	NO
1	Human	822	16	Food supply	329	31	Meat	178
2	Country	792	17	Dietary intake	320	32	Vegetable	175
3	Statistical model	708	18	Food supply chain	288	33	Crop production	165
4	Gender difference	640	19	Major clinical study	263	34	Nutritional assessment	164
5	Age distribution	563	20	Health risk	247	35	Food microbiology	154
6	Controlled study	481	21	Dairy product	222	36	Organic pollutants	151
7	Risk factor	474	22	Questionnaire	213	37	Traceability	149
8	Risk assessment	452	23	Income	197	38	Pevalence	148
9	Logistic models	451	24	Environmental impact	197	39	Food contamination	147
10	Foodborne diseases	429	25	Food consumption	196	40	Heavy metal	147
11	Food security	409	26	Agriculture	194	41	Socioeconomics	144
12	Food safety	408	27	Disease association	189	42	Catering service	143
13	Risk	396	28	Consumer behavior	185	43	Adverse effects	140
14	Animal	391	29	Cross-sectional studies	180	44	Supply chain management	134
15	Diet	355	30	Education	180	45	Chemical contamination	134

NO, Number of occurrences.

Bibliometric Analyses

We selected keywords that appeared more than 20 times for visual analysis and clustering, analyzed and summarized closely related keywords in the visual network, and further analyzed the food safety research in the food supply chain subtopic. Judging from the results of the community division of the topic association network, the current international infographics have formed four research directions (or topic communities) of different scales in significant data research, namely: C1, food safety at the consumer end of the food supply chain; C2, food safety management in the food supply chain; C3, risk management of food safety in the food supply chain; C4, food safety at the production end of the food supply chain (**Figure 7**). We performed a content analysis based on the four groups to determine the detailed subtopics and insights.

Cluster 1 (Yellow): Food Safety at the Consumer End of the Food Supply Chain

In the food supply chain, consumer food safety issues are closely related to consumers, especially consumers' trust in food, safe consumption awareness, and consumer attitudes. Consumers' convictions stem from the food safety information provided by the Environmental Hygiene Department and the Food Standards Agency, especially the food safety information in food packaging (31). However, some food labels lack the information required by consumers, such as nutritional content, production system, traceability, and quality control information. The opacity of food information has led to an increased incidence of foodborne diseases. Gradually, some consumers change their food consumption habits and turn to organic food and food produced with improved safety (32).

Ethical and safe food consumption is not a widely recognized issue and many consumers have not yet developed food safety awareness (33). All localities need to educate consumers on food safety, improve consumers' food safety issues, increase their willingness to buy safe food, and improve local food safety levels (34). The long-term nature of the COVID-19 pandemic also requires consumers to increase their awareness of cold food chain safety, strengthen the maintenance, and understanding of the cold chain within the food framework, assume the responsibility

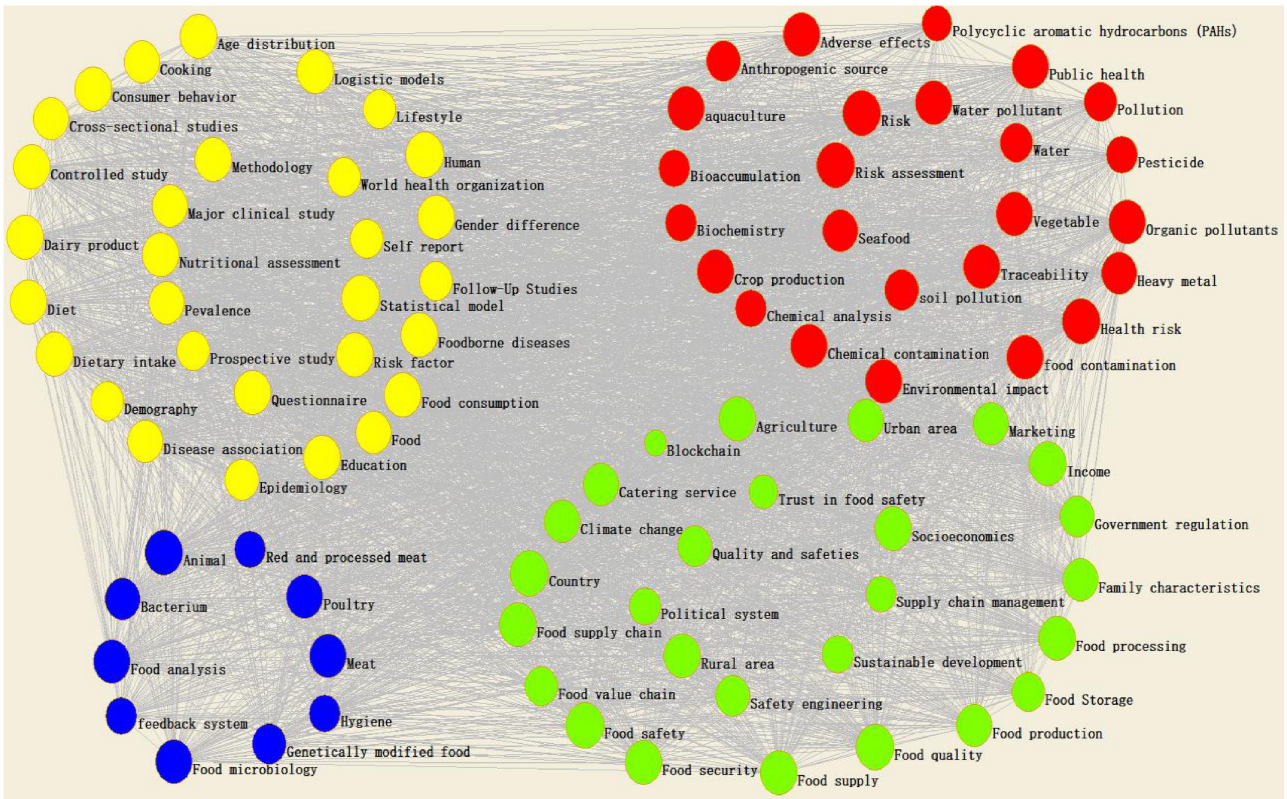

FIGURE 7 | Visualization of keywords' networks (NO > 20).

for maintaining the cold chain and reduce the unknown risk of improper food handling (35).

Many factors affect consumers' food safety behaviors in the food supply chain, such as consumers' age, gender, education, income level (36). The rapid development of e-commerce in the information age has strengthened consumers' willingness to buy food online, increased consumer trust, and increased online purchase rates (37). Consumers are gradually choosing a healthy lifestyle and are more inclined to buy organic food, especially millennials, who are willing to buy organic food at a higher price (38). This creates more opportunities for the food industry and has also attracted the academic community's attention, especially in terms of consumer attitudes toward accepting or resisting organic food (39).

Cluster 2 (Green): Food Safety Management in the Food Supply Chain

The food supply chain needs to be committed to coordinated management among supply chain members, reduce the mileage of the food supply chain, increase the smoothness of information circulation and food safety, and improve the supply chain's sustainability and globalization. This will enhance the market positioning of all links in the food supply chain, help to launch new products and maintain a high degree of safety and traceability (40). Governments' food and agricultural sector policies should be more comprehensive, make full use of logistics network technology, establish a safety information platform, and monitor food safety issues in real-time (41). Countries need to develop food safety agencies, service supply chain management, establish sustainable food supply and food distribution logistics models, and prove the affordability and sustainability of the food supply chain (42). In particular, it is necessary to establish a food logistics framework from suppliers to retailers based on radio frequency identification technology and design a food logistics tracking system to detect suspicious food to prevent the spread of food safety emergencies (43).

In food supply chain management, the traceability system can measure the efficiency of supply chain operations, reduce information asymmetry, and solve food safety issues and potential food safety incidents (44). Food traceability includes logistics, information, production, and quality management. It is implemented in the food chain based on radio frequency identification and sensor technology to monitor agricultural food safety in real-time (45); this improves the food supply chain management and brings a competitive advantage to the food industry (46). Blockchain is a food traceability method; it establishes a shared safe information exchange record, provides visual and reliable data for transactions (47), which meet the traceability needs of new information from any stakeholder or supply chain node (48), further ensures the sufficient safety of products in the food supply chain, and improves the integrity, reliability, and safety of the food supply chain (49).

Cluster 3 (Red): Risk Management of Food Safety in the Food Supply Chain

Food safety issues may appear in all aspects of food production, processing, transportation, and sales. Countries worldwide need to assess and predict food safety risks accurately, confirm the risks, sources, and risk levels of the food supply chain, and maintain transparency and integrity throughout the food industry. The significant food supply chain risks are roughly divided into nine categories: human resource, processing, logistics, raw material, safety certification, traceability, market, packaging, and product characteristic risks. These are related to food manufacturers, transporters, wholesalers, and retailers (13). Researchers use fuzzy analysis of the hierarchical structure process to determine priority food safety risk elements and find that supply related risks are the most prominent ones (50).

The Codex Alimentarius Commission's recommendations to conduct food supply chain management under the acceptable hygiene practices, HACCP systems, and new risk management indicators (such as food safety targets) are indispensable for the optimisation of the food supply chain (51). Food supply chain risks are transmitted through the chain, leading to food recalls and rising costs, and deepening the vulnerability of the global supply chain, especially in terms of food contamination incidents (52). Globalization and the growth of international trade have led to the integration of food safety issues in each country. Countries must formulate consistent food safety standards and measures to coordinate and manage cross-border food trade and use quality management tools to promote global food supply chain risk management systems (53). Simultaneously, mobile technology is essential for food supply chain management, as it helps in improving the food supply chain agility, efficiency, and risk management as well as the economic status of the community, while it reduces risks in the supply chain (54).

Cluster 4 (Blue): Food Safety at the Production End of the Food Supply Chain

The COVID-19 pandemic has led to the realization of the importance of food safety and put the focus on the production of agricultural products and heavy metal pollution in the soil (55). Farmers need to monitor the soil to determine the level of metal pollution, establish and maintain the role of soil in the value of the food chain, optimize production systems, and promote a sustainable circular economy (56). All regions should coordinate agricultural production, avoid regional food surplus or shortage, pay attention to seed quality, ensure food production capacity and sales price stability, rely on the supplier to maximize the value of food, and ensure the integrity of the food supply chain (57).

The genetically modified food industry continues to develop rapidly, and safety issues have always been the focus of controversy (58). The vigorous development of biotechnology provides producers in the food supply chain with more opportunities and attracts more attention to genetically modified foods (59). Experts and scholars have found that the main factors affecting consumers' willingness to buy genetically modified food are potential risks, perceived quality, and related social norm risks (60). Simultaneously, studies have found that many consumers in developing countries are more supportive of genetically modified foods than consumers in developed countries.

Thematic Evolution Trend Analysis

In this study, we analyzed the keywords of 2,329 food safety research articles in the food supply chain field from 1997 to 2020, divided the 24 years into 5-year intervals, and used the CorTexT platform to obtain the evolution of the core topics in the five stages. As shown in the Sankey diagram in **Figure 8**, the trajectory reveals the evolution of certain food safety research topic characteristics in the food supply chain field over time through the direction and evolution of each time interval's core research topics (61).

Overall, since 1997, food safety research topics in the food supply chain have evolved in terms of emergence, expansion, contraction, differentiation, integration, and extinction in the horizontal time interval; their evolution became more evident after 2012. In 2004, food safety research in the food supply chain field formed three research directions, namely "major clinical study & aged", "food industry & food safety", and "animals & animal". Among these three themes, the one studied the most and the most consistently is the former. Scholars pay more attention to the impact of food safety on consumers of different ages in the food supply chain and clinical research is focused on foodborne diseases (62). The theme of "food industry & food safety" has undergone complex evolution. In 2012, it was divided into "educational status & catering service" and "food microbiology & food safety". This demonstrates that the food supply chain gradually intersects with various disciplines, such as food safety and consumer safety in combination with research on food microorganisms (63). The theme "animals & animal" formed a continuous evolutionary trajectory. It evolved into "animal disease & dairying" in 2012, and its scale also began to surge. It grew into "isolation and purification & cattle" in 2015 and into "microbiology & bovine" in 2018. It gradually started to differentiate in 2020 and will continue to differentiate into "isolation and purification & cattle" and "supply chain management & supply chains". This shows that researchers have gradually mastered all aspects of food supply chain management and the overall food supply chain safety management (64), which, combined with the internet and blockchain technologies (65, 66), will help to reduce the food safety incidents.

DISCUSSION

In this study, we used bibliometric analysis and thematic evolution trend analysis methods to systematically measure and describe the academic research on food safety in the food supply chain and help readers to understand the characteristics of articles published in this field. The number of publications and citations on this topic has been increasing, consistent with the emergence of food contamination incidents in recent years. In particular, the COVID-19 pandemic has swept the world and exposed the fragility of the food supply chain. This situation will attract more scholars to pay attention to food safety incidents in the food supply chain.

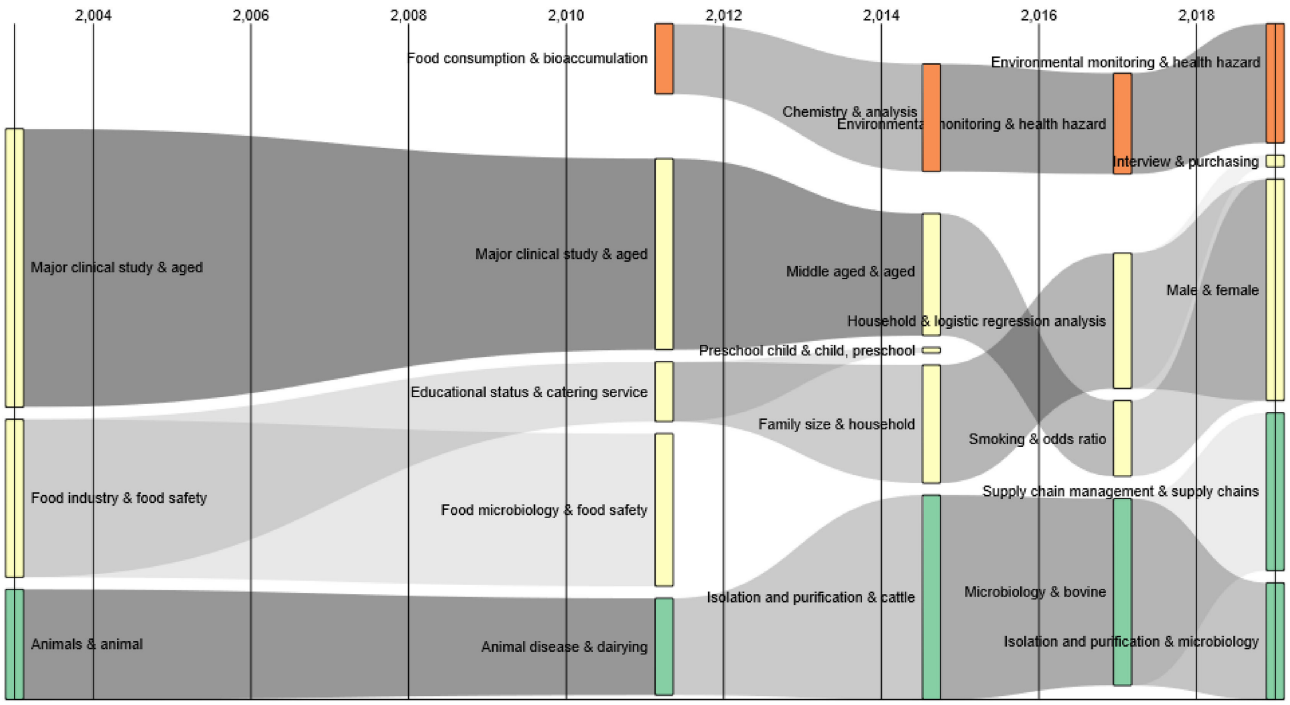

FIGURE 8 | Sankey diagram.

Research on the subject classification of articles related to food safety in the food supply chain shows that this field is not limited to categories such as agriculture, food safety, management, and medical care, but is also involved in environmental, social science, and other areas, reflecting the interdisciplinary development of this topic. In the future, scholars need to continue to strengthen multidisciplinary research, improve the level of food safety research, and solve problems in the food supply chain. An increasing number of journals publish articles in this field, showing that academia is very interested in researching food safety in the food supply chain. Additionally, almost all journals examined have high academic standards, and those that impose stricter requirements on authors also have a significant influence on the literary world.

Among the 2,329 examined articles, the first authors' institutions are located in a wide range of countries, covering ∼5/6 of the world. Still, most of the authors are from the United States, China, and the United Kingdom. Research countries include developed countries, such as the United States; however, emerging markets such as China are also essential participants in this field. The organizations with the highest number of publications are Wageningen University & Research, the Chinese Academy of Sciences, Harvard University, and the Swedish University of Agricultural Sciences. The authors with the most published research articles are La Vecchia, Talamini, and Jacxsens, and most publications were co-authored by five authors. Researchers from these countries and institutions have done more in-depth and critical research in this field. The analysis and presentation of data pertaining to governments, institutions, and authors will help countries, institutions, and authors cooperate with others, share information and knowledge related to the food supply chain, and use innovative and efficient methods to solve food safety issues.

The top 10 most cited articles listed in the present article are powerful in terms of their arguments and persuasiveness. For example, Roth et al. explain the difficulties and risks inherent in the global food supply chain as a whole and propose six quality management frameworks (traceability, transparency, testability, time, trust, and training) (28). Of course, the number of times an article is cited is also related to the year that the article was published. Therefore, in this study, we used the average number of times, a report was cited in a given year to express more accurately the impact of a publication and provide readers with some context.

In this study, we clustered the keywords that appeared more than 20 times and classified the current four themes of food safety research in the food supply chain based on a visual network map. These themes are food safety at the consumer end of the food supply chain, food safety management in the food supply chain, risk management of food safety in the food supply chain, and food safety at the production end of the food supply chain. The research content mainly focused on meat, the risk safety of genetically modified food in the supply chain (67), and strengthening risk management. Simultaneously, the research focused on analyzing the influencing factors that affect food consumption and explained the importance of safe consumption through quantitative analysis (68) or clinical research. Food safety management protocols should be implemented on all food supply chain stages (69). For specific food contamination incidents, traceability management, especially in the past 2 years,

and the emerging blockchain technology have helped improve food supply chain management (70). Different governments educate stakeholders in various links of the food supply chain such as agriculture, consumer markets, cities, rural areas, and households on food safety issues and formulate the relevant policies to enhance food quality and safety for consumers (71, 72). At the same time, governments pay attention to natural factors such as climate change, to achieve the sustainable development of food safety engineering.

By analyzing further, the evolutionary path of keywords and combining this analysis with the clustering results achieved herein, we can conclude that the research hotspots and frontiers of the food supply chain are mainly concentrated on the consumer side of the food supply chain, supply chain management, and the impact of natural factors such as climate on food safety. The four primary directions are entangled with each other in the evolutionary process. The splitting, merging, and reorganization of themes are more pronounced, indicating that the articles are closely related and the degree of differentiation is not high, which suggests that research on food safety in the supply chain still has excellent potential to develop. In particular, blockchain technology in the food supply chain is a research direction that scholars are actively exploring. This interdisciplinary research exemplifies that tackling food safety problems is a systematic task involving agriculture, hygiene, environmental protection, etc., and requires the active participation of all societal sectors.

CONCLUSIONS

In this study, we combined bibliometrics, and thematic evolution trend analysis methods to assess the prominent subjects, journals, research areas, research institutions, and authors in food safety research in the field of the food supply chain. Based on the co-occurrence analysis of keywords, we obtained four main research themes. Next, we performed content analysis and finally analyzed the evolution path diagram. In summary, we explored and examined the thematic evolution, hotspots, and frontiers of research on food safety in the food supply chain. Our results may set the foundations for future research on targeted topics of interest, thereby building a subject knowledge system.

The main contribution of this study was in expanding knowledge in the food safety field. Additionally, we revealed four major research themes and evolutionary paths, highlighted mature and emerging research directions, and proposed new insights into food supply chain safety.

One limitation of this study pertained to data collection from literature databases and the analyzed literature. Specifically, the scope of this study was limited to peer-reviewed publications collected from Scopus. Adding data collected from other databases would expand the publication search. Additionally, in this study, two people were tasked with screening documents as a way of ensuring objectivity. However, a certain degree of subjectivity is bound to remain, especially when selecting the most relevant articles for the final re-analysis.

DATA AVAILABILITY STATEMENT

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found in the article/**Supplementary Material**.

AUTHOR CONTRIBUTIONS

JL: conceptualization and methodology. SL: data curation and writing—original draft. YB: writing—review & editing and supervision. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Rethinking COVID-19 and Beyond: Prevention, Remedies, and Recovery

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In a relatively short timeframe, millions of deaths and illnesses associated with COVID-19 have been reported, accompanied by substantial economic losses, and overall, negatively impacting society. This experience should serve as a wakeup call to those in public health and healthcare, along with politicians and citizens: COVID-19 is considered a predictable and preventable disaster. While various reactive responses to address the pandemic were implemented, some with adverse effects, proactive measures in the years before COVID-19 were neglected. Predominately this involved the development of a preventable overfat pandemic, which played a key role in both rising rates of chronic disease, the comorbidities that increase the risk for COVID-19, along with associated inflammation and malnutrition. This increased the risk of infection in billions of people worldwide, which, in essence, primed society for high rates of COVID-19 infection. Excess body fat evolves primarily from poor nutrition, particularly the overconsumption of sugar and other refined carbohydrates, which replace the vital nutrients needed for optimal immune function. Sugar and refined carbohydrates must be considered the new tobacco, as these foods are also devoid of nutrients, and underly inflammatory chronic diseases. A balanced diet of nutrient-dense wholefood must be emphasized to combat infectious and inflammatory diseases. Implementing proactive preventive lifestyle changes must begin now, starting with simple, safe, and inexpensive dietary modifications that can quickly lead to a healthier population.

Keywords: overfat, obesity, health, immunity, vitamin D, glycocalyx, vaccination

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INTRODUCTION

Individuals with health risk factors, including dyslipidemia, hypertension, poor nutrition, and obesity, develop, on average, significantly more chronic disease than those with low risk. Early primary proactive prevention can help reduce or eliminate risk factors, and postpone, avert, or minimize more serious illness, disease, and premature death (1). While screening for disease can help diagnose various conditions sooner in their progression, and potentially allow for earlier treatment, this *reactive* approach is different from *proactively* preventing, reducing, and/or eliminating risk factors associated with those same diseases. Implementing a healthy lifestyle, such as improving dietary habits, can help significantly reduce disease risk, future illness, and disability (1). While both reactive and proactive approaches can be important in healthcare (**Figure 1**), without a logical, implementable, and proactive approach, reactive palliative care for conditions such as cardiovascular disease, diabetes, cancer, and other chronic illness must be employed, which is more expensive and leads to lower quality of life (2, 3). Unfortunately, most time and dollars in healthcare are spent on palliative care after chronic conditions are diagnosed and/or become

FIGURE 1 | We all have a choice to make with our health. Which road will you choose?

more serious. Despite our immense knowledge of public health and lifestyle prevention, addressing the causes of preventable diseases has eluded much of today's healthcare landscape. Likewise, for the COVID-19 pandemic, which, as stated in an independent review ordered by the World Health Organization (WHO), was a "preventable disaster" (4).

While COVID-19 has been addressed as an isolated pandemic, there are in fact two related pandemics to consider. One is a serious communicable infectious disease (5), while the other is the *overfat pandemic*, an equally serious global disaster comprised of people with excess body fat (6). The overfat condition can increase susceptibility to infection due to secondary immune impairment, malnutrition, and lead to increased disease risk factors and related downstream non-communicable diseases (7, 8). In particular, the presence of excess body fat is a primary risk factor in the development of comorbidities that increase the risk of infections, including COVID-19 (7, 9, 10). Overfat has been described as the sum of obesity, overweight, plus 20–40% of non-obese, normal weight individuals who also have excess body fat (ethnicity influenced) (11), which reflects the considerable proportion of normal-weight non-obese subjects who suffer from the same metabolic conditions associated with obesity (12, 13).

The condition of overfat, which ultimately is indicative of malnutrition, adversely affects various aspects of health, including impaired innate and adaptive immune responses, promoting chronic inflammation and insulin resistance, leading to chronic diseases; comorbidities that raise the risk of COVID-19, and other infections (7). Specifically, overfat can increase COVID-19 severity and disease recovery (9, 14), and raise rates of hospitalization, admission to the ICU, the need for invasive mechanical ventilation, and the risk of mortality (14). Ryan and Caplice (15) proposed a theoretical mechanism whereby adipose tissue in obese individuals may act as a reservoir for more extensive coronavirus spread, with increased viral shedding, and cytokine amplification. A recently published systematic review and meta-analysis of 22 studies from seven countries in North America, Europe, and Asia reported that obesity was associated with an increased likelihood of presenting with more severe COVID-19 symptoms, requiring hospitalization, being admitted to an ICU, undergoing invasive mechanical ventilation, and developing acute respiratory distress syndrome compared to patients without obesity (16). Most recently, Kompaniyets et al. (17) used data from more than 800 US hospitals and found that 94.9% of 540,667 patients with COVID-19 had at least 1 underlying medical condition; predominantly essential hypertension (50.4%), disorders of lipid metabolism (49.4%), and obesity (33.0%). The strongest risk factors for death in this dataset were obesity, fear-related disorders, and diabetes (17). **Figure 2** depicts the relationships between diet-induced overfat, chronic inflammation and insulin resistance, and increased chronic and infectious diseases.

As such, COVID-19 may in fact not be a pandemic. Syndemic theory recognizes that pandemics can occur in synergy with preexisting societal and health conditions, including the individual's susceptibility to disease, and would not occur, or become less serious if social and health vulnerabilities to infections were adequately reduced (18). Rather than an isolated COVID-19 pandemic, it is clear there are synergistic interactions between pre-existing biological and socioecological factors (19), the spreading of an acute infectious disease, COVID-19, fueled by the overfat pandemic and its downstream conditions including impaired immunity, malnutrition, inflammation, and comorbidities (11).

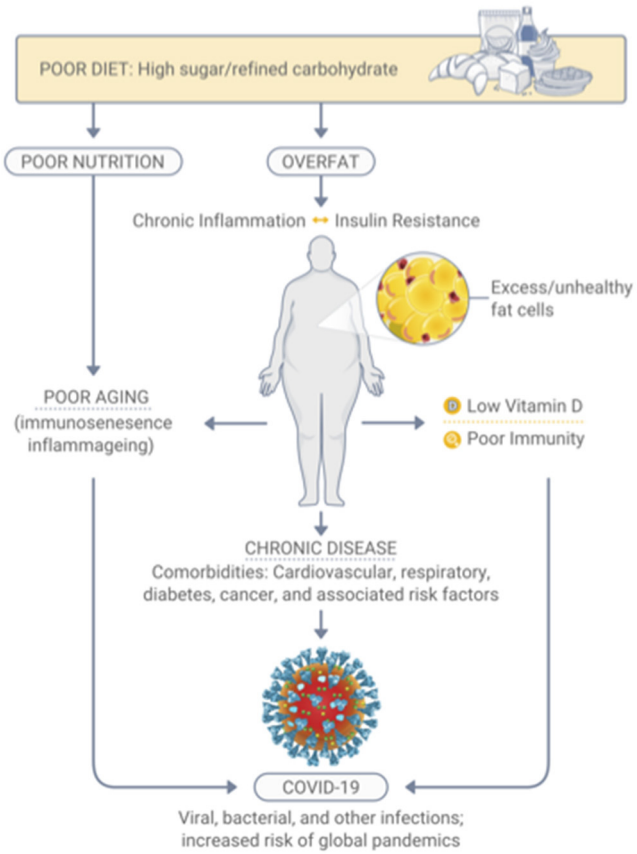

FIGURE 2 | Overfat, which develops predominantly through a diet high in sugar and processed food, is a significant risk factor for infection.

COMMUNICABLE AND NON-COMMUNICABLE DISEASES

Global infectious diseases began diminishing drastically following improvements in public health and sanitation beginning over a century ago. However, infection rates have been increasing in frequency over the past 50 years (20). During this same period, a well-hidden preventable overfat pandemic, one that helped fuel both chronic and infectious diseases, developed. Today, over 80% of the adult world population may be overfat (11), and rates in countries such as the U.S., where the total number of confirmed COVID-19 cases and deaths is among the highest globally, 91% of the adult population was shown to be overfat (21).

In addition to chronic disease representing significant comorbidities that increase the risk of COVID-19 (and other infections), global death from chronic disease remains more than twice that of infections (22). This relationship between the prevalence of chronic and infectious diseases was shown during COVID-19's full year of 2020 in the U.S. (23). Indeed, the U.S. Centers for Disease Control and Prevention (CDC) data showed that 94% of all COVID-19 related deaths occurred in individuals who possessed an average of 4.0 pre-existing comorbidities or illnesses (i.e., obesity, existing respiratory diseases, hypertension, diabetes, cardiovascular disease, cancer, etc.) (24). As discussed below, the diet-induced overfat condition is also associated with malnutrition, which can impair immunity.

While the global prevalence of overfat exceeds 80%, the number of people worldwide with chronic diseases is also increasing, with resurging rates of infectious diseases. Therefore, addressing the overfat pandemic now may help prevent similar infectious pandemics from occurring in the future, and can significantly help reduce the global burden of disease, improve quality of life, and lower healthcare costs. Today, in the United States alone, the cumulative financial cost of the COVID-19 pandemic is so far estimated at over $16 trillion (25), while annual healthcare costs are projected to reach $6.2 trillion by 2028 (26).

LIFESTYLE BEHAVIOR

As many lifestyle-related conditions significantly raise the risk of COVID-19 and other infections, the WHO suggests mandatory actions to improve patient health to reduce the risk of possible future outbreaks (27). Increased risks from tobacco use, excess body fat, and a sedentary lifestyle can promote health impairments earlier in life and have more cumulative disability at any given age than do persons with lower health risks—in other words, for the average person, reducing modifiable health risks can postpone poor health (1). However, reactive responses to COVID-19 in the form of restrictions, lockdowns, and vaccines appear to have significant adverse side-effects that can further raise the risks of infection (28). In particular, the impact of sudden sedentarism caused by home confinement and travel restrictions on the population's physical, biochemical, and mental–emotional health and fitness can lead to measurable impairment occurring in just a few days, sufficient to induce neuromuscular dysfunction, insulin resistance, lowered aerobic capacity, increased respiratory exchange ratio and fat deposition, and cause low-grade systemic inflammation (29). As an example, during COVID-19, significant weight gain suggestive of malnutrition occurred in adults (30) and children (31), potentially further increasing the risk for infection and chronic disease.

It has also been estimated that between 10 and 30% of those with a history of COVID-19 still experience debilitating symptoms months after being infected (32). Referred to as "long-haul Covid" (or "long Covid"), this may be a new public health disaster in the making (33). Importantly, a healthy lifestyle can also play a role in recovery from COVID-19 and especially for those with long Covid (34).

The COVID-19 vaccination program is a reactive public health response to the pandemic (**Figure 1**) with unfortunate consequences (35). Vaccines, which require a robust immune response to work properly, may be less effective in those

with excess body fat due to the associated poor immunity, including those with COVID-19 (36, 37). These inadequate immune responses have been exposed as a major public health liability, and previously have not been well-recognized. In the overfat, malnourished, and immune-compromised host, the viral lifecycle can be altered, complementing an already weakened immune response, lead to severe pathogenesis and prolonged viral shedding, and can permit the emergence of virulent minor variants (36, 38, 39). In addition, shedding of the sulfate-dependent glycocalyx component of cell surfaces may also cause significant pathological consequences in COVID-19 patients (34). Addressing a weak immune system, especially in the overfat and malnourished population, is an urgent public health priority (36), and is an example of proactive healthcare (**Figure 1**). As du Preez et al. (34) state, "A quick fix drug and vaccine approach will not address the underlying etiological factors that made us more susceptible to COVID-19."

Obesity is associated with severe COVID-19, and people who are obese show significantly higher neutralizing antibody titer than non-obese participants (40). As a clinical feature of overfat, insulin resistance can also impair circulating lymphocytes (41, 42). In addition to excess body fat, other modifiable risk factors can impair immunity and reduce vaccine effectiveness. While this may include aging (immunosenescence), immune decline is reduced in elderly people with improved nutritional status (43, 44). Lifestyle influences frailty as well, which is also associated with poorer outcomes from COVID-19 (45) as frailty is associated with reduced immune function and effectiveness of vaccination (46). Unhealthy aging can also increase many inflammatory mediators (inflammaging), predisposing susceptible individuals to the cytokine storm implicated in poor outcomes from COVID-19 (7). However, improved nutrition can help manage oxidative stress and chronic inflammation (47).

Not unexpectedly, other COVID-19 vaccination side-effects have also been demonstrated. Reports from phase 3 clinical trial of the mRNA-1273 vaccine against SARS-CoV-2 have provided information on both immediate and delayed injection-site reactions, both local and systemic, with most signs or symptoms resolving on average after 4–5 days (48). However, some reactions have not been consistently reported by clinicians once vaccine use was implemented, and many patients unnecessarily received antibiotic agents as treatment for these side-effects (49). The pathophysiological mechanisms underlying cases of what has been called "red arms" or "Covid arms" is still unclear, although they appear to be of an immunological/autoimmunological nature (50). Control and Prevention surveys showed reactions after the first dose, including injection site pain (68%), fatigue (31%), headache (26%), and myalgia (19%), with greater reactions after the second dose, and greater reactions in younger than in older patients (51). More serious reactions to vaccines have also been reported, including cerebral blood clots in previously healthy young adults, myocarditis (52, 53), anaphylaxis, possibly due to a nanoparticle carrier system in some vaccines (54), and sadly death (55).

Due to the rapid release of these gene-altering vaccines, the long-term consequences are unknown. The vaccine RNA has specific sequences that could fuse into pathologic prion conformations (misfolded proteins) (35, 56). Furthermore, the spike protein itself, created by the translation of the vaccine RNA, binds to the angiotensin converting enzyme 2 (ACE2) receptor, a zinc containing enzyme. This interaction has the potential to increase intracellular zinc, thereby enhancing prion conformation (56). Together, the outcome could result in serious neurological diseases including ALS, frontotemporal lobar degeneration, Alzheimer's disease, and others (56). Production of the spike protein, a toxin to the body that can desulfate the cell's glycocalyx and impair its first line immune response, has the potential to contribute to a wide range of both acute and long-term induced pathologies, such as blood disorders, neurodegenerative diseases, and autoimmune diseases (35).

The global vaccination programs have quickly evolved with significant effort and expense, with several billion COVID-19 vaccination doses now being manufactured, at costs of up to $16 per dose for Western countries (54). While the balance of safety and efficacy is a primary concern, a single finding of safety and efficacy may not be sufficient for a vaccine candidate to receive US FDA approval. Data on vaccination blocking infection transmission is now being gathered. Computer models suggest 75% efficiency (54), but considering the wide range of personal, social, and economic losses, the many unknowns such as low responders to vaccines, emergence of variant viruses, and durability of vaccine-induced protection, we must still consider the obvious: how preventive actions using simple, safe, and inexpensive preparedness through a healthier population could be a significantly better option moving forward.

PRIMARY LIFESTYLE CHANGES

Exercise and increased physical activity, eating a balanced diet of nutrient-dense wholefood, eliminating tobacco, moderating alcohol, and caffeine, and managing stress are among the lifestyle factors that potentially can reduce risk, and improve health and fitness. However, many individuals can also feel overwhelmed when interventions attempt to modify too many behaviors (57). Multiple recommendations can make the interventions more difficult and demanding, reduce motivation, lower implementation, and lead to poor outcomes. Instead, prioritizing lifestyle recommendations to have less or a more moderate number of behavioral changes can result in better compliance and outcomes, including enlisting those individuals with low motivation, and the ability to improve untargeted or secondary unhealthy behaviors as well (58). Improving diet and exercise are two key lifestyle factors that can significantly reduce excess body fat and improve health. While exercise recommendations alone can have inadvertent effects on food intake (59), diet alone may play a much greater role in reducing the prevalence of overfat (21, 60). Simple dietary recommendations could serve as a significant lifestyle change appropriate for an unhealthy overfat population with rising chronic disease and healthcare costs, increasing rates of infections, and a vulnerability for future infectious pandemics.

Over the past half century, traditional low-fat and low-calorie diet approaches have been a hallmark of weight-loss programs yet are unsuccessful long-term. Despite recent increases in exercise rates, the overfat pandemic has grown dramatically (21). As an alternative, research shows rapid effectiveness and healthfulness once the consumption of refined carbohydrates, including added sugars (glucose + fructose) is lowered; not only for reducing excess body fat but for lowering the risks of and treatment for cardiovascular and metabolic conditions, some cancers, and other health problems (61–64), and recently for COVID-19 (9, 65). While a low-carbohydrate high-fat diet has been used in traditional medicine for about a 100 years, for diabetics since before insulin was developed and for seizure control, the natural lifestyle of the earliest humans relied on this diet to generate large quantities of metabolic energy from the oxidation of fatty acids to develop larger brains and bodies, prevent and reduce disease risk, extend longevity, in addition to other benefits (66). However, a natural balanced wholefood diet in any ratio of complex carbohydrate, fat, and protein should be the emphasized starting point.

As sugar's influence on health is also a key driver of long-term economic growth, public expenditure, and consumer trends (67), addressing the problem may require a combination of public and private policy actions. This may include improved educational campaigns to help influence individual health behavioral changes. Referring to sugar as "the new tobacco" for its health risks (68), there is the potential of rapid and substantial health gains and cost savings with improved sugar labeling (69). Indeed, forecasts on the economic effects of sugar via computer modeling suggests that reduced sugar consumption may result in rapid and significant public health and economic benefits (70). While the political appetite for greater action may be weak, with debates around the appropriateness of government intervention (via an unpopular "sugar tax," tax incentives for "healthy" foods, or other increased regulation), the possibility of incentivizing body fat loss for individuals has been shown to be both effective and cost saving (71).

We are suggesting that global public health guidelines also prioritize addressing current and future infectious conditions, chronic disease, and the overfat pandemic, and recovery from COVID-19, as an all-inclusive, simple, less expensive, and effective recommendation through healthy dietary habits. This can be accomplished with a consensus to approach the problem not unlike tobacco, as a product that seriously impairs population heath and the economy.

VITAMIN D, COVID-19, AND OVERFAT

Vitamin D plays many roles in immune function, including cellular aspects of innate immunity, T-cell mediated immunity, B-cell mediated immunity, improved gut and skin barrier function, and others associated with antimicrobial activities (72). Low serum 25-hydroxyvitamin D (25D) concentrations, vitamin D deficiency, is another preventable global pandemic, with body fat content inversely related to serum 25D concentration and a decline in cutaneous vitamin D synthetic capacity, which is also associated with age (73–75). Sulfur deficiency is also related to low vitamin D status (34). Adequate vitamin D can affect immune modulation, reduce inflammatory cytokines, expresses anti-microbial peptides in neutrophils, monocytes, and natural killer cells, promotes innate immune activation, plays a protective role in the epithelial cells lining the respiratory tract, as well as having other important relationships with infections, including its potential impact on COVID-19 (76–79). Numerous published studies on low vitamin D status and COVID-19 show the potential for significant benefits of this overlooked and inexpensive assessment and treatment option (80–86). While vitamin D deficiency can impair the response to seasonal influenza vaccinations (87), it is not yet known whether this includes the COVID-19 vaccines. In addition to vitamin D, other nutrients may also have important relationships with COVID-19. The early discovery that SARS-CoV-2 engages the ACE2 for entry into the cell for infection has prompted increased research efforts to elucidate the biochemical determinants of CoV-ACE2 interactions (88). Various natural compounds found in a healthy diet may impact positively on these interactions and serve as adjunctive treatments, including the micronutrient zinc (88), and vitamins C and E (55), thiamine, along with quercetin and other phytonutrients (89, 90). In addition to ACE2, cell surfaces also depend on sulfur, as the degree of sulfation of heparan sulfate may play a primary role in the risk of infection and specifically SARS-CoV-2 entrance into human cells, along with its influence on immunity, inflammation, and oxidative stress (34, 91, 92).

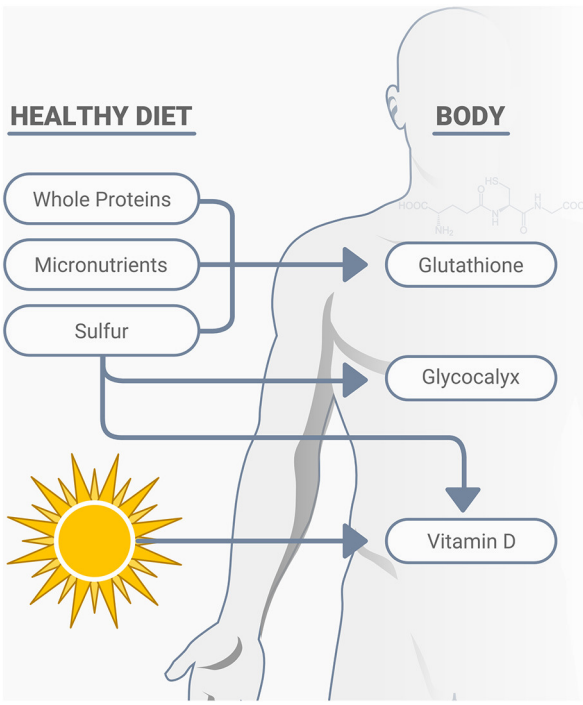

FIGURE 3 | A healthy diet consisting of nutrient dense whole proteins, micronutrients and sulfur rich compounds support cellular immunity, largely through their positive effects on glutathione production, the glycocalyx, as well as the activation of vitamin D.

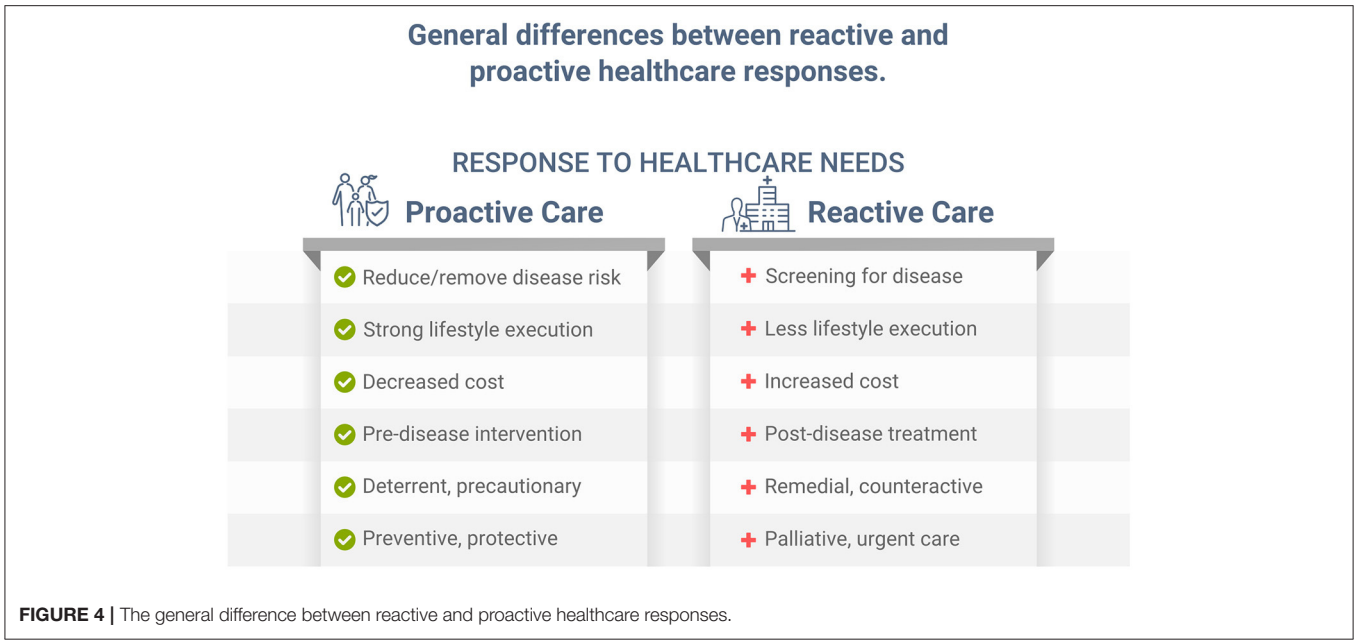

FIGURE 4 | The general difference between reactive and proactive healthcare responses.

du Preez et al. (34) state that, "Undersulfation (less than the normal degree of sulfation) or aberrant sulfation of HS [the degree of sulfation of heparan sulfate] may not only increase susceptibility to viral infection but may also adversely affect the individual's physiological response to the infection." A variety of naturally occurring nutrients impact immunity and resistance of infections, oxidative stress, and excess inflammation, including sulfur and its related amino acid cysteine, various micronutrients, vitamin D, and others (93). A sulfur-rich natural diet that includes cruciferous vegetables and whole proteins, including grass-fed animal products, helps increase glutathione production, the body's most powerful antioxidant (**Figure 3**). A notable concern is the great push for "synthetic or cultured/pant-based" meat, which is low in sulfur-amino acids, and will not replace the health and immunological properties of real grass-fed animal meat.

Another benefit of reducing sugar and other refined carbohydrates is that junk food can replace many other nutrient-dense foods that would typically provide a wide range of natural macro-, micro, and phytonutrients, and otherwise impair one's nutritional status.

DISCUSSION

Early reactive responses to COVID-19 may have been necessary emergency procedures. However, one could argue that preventive measures with a focus on improving health could have also potentially accomplished the same, only better, as the strategy is cheaper, and could help prevent or reduce the severity of a pandemic. Whether we waited too long to respond to the COVID-19 outbreak, or not, we still must consider what proactive, preventable approaches could have better influenced such a familiar and predictable disaster, as medical and public health communities have long warned of the potential for such a pandemic (94). COVID-19 has revealed a world that was unprepared, overconfident, and inept in pandemic control, especially in the U.S., with its trillion-plus dollar annual healthcare budget, extensive infectious disease monitoring and research, and academic and pharmaceutical capacity. One way to address this problem is to quickly and significantly reduce the primary overfat pandemic by promoting and making available nutrient dense foods for society.

The immense overfat global population has a growing impact on both non-communicable and communicable diseases. It is obvious that we must address the long-standing overfat pandemic and its spawning comorbidities that helped promote COVID-19, which may also increase the risk of the next global infectious pandemic. Combining the biological, social, psychological, and other factors to accomplish this task would be like addressing the health effects of tobacco. However, tackling the tobacco problem was a very long slow process due to political, financial, and social issues; and it remains a serious global health problem today. Instead, a rapid, synergistic approach using all our knowledge of public health, clinical, and scientific resources to recover from the COVID-19 pandemic and its fallout, reduce the overfat pandemic and its downstream comorbidities, and prevent future pandemics, can be far more successful than waiting for disease to occur then trying to react to it (**Figure 4**).

This immediate public health focus is an urgent and necessary step following our lessons from COVID-19. Rather than keep repeating the many general lifestyle recommendations most generations have been exposed to during the past half century, when preventable conditions such as the overfat pandemic exploded, and infectious and chronic disease rates rose, it may be best to consider a single and simple

dietary approach of markedly reducing refined carbohydrates, including sugar, as a primary step to help quickly change population health, which can help reduce excess body fat and downstream conditions. This would require a global effort, despite the economic impact on certain industries that produce unhealthy food products. While this may initially appear to be a radical approach, too little has been done in the past, and we cannot afford another COVID-19 pandemic, especially considering that it could be much worse than the current one.

There will be no victory over COVID-19: it has negatively impacted the mental and physical health of society, and we have incurred significant economic loss. The experience should serve as a wakeup call to all those in public health—and the rest of the world, including individuals, who are most responsible for their own lifestyle choices, and governments who influence our health in many ways, especially by allowing unhealthy foods to flourish. With a rising global population, one that is also rapidly aging, and an increasing need for healthcare products and services for conditions mostly deemed preventable, true prevention can be rapid, highly effective, and an inexpensive alternative whose time has finally come.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

AUTHOR CONTRIBUTIONS

PL and PM conceived the idea for the manuscript through discussion and observation of the response to the COVID-19 pandemic in light of the overfat pandemic. Both authors contributed to the article and approved the submitted version.

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Loss of Livelihood, Wages, and Employment During the COVID-19 Pandemic in Selected Districts of Chhattisgarh in India, and Its Impact on Food Insecurity and Hunger

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The COVID-19 pandemic has exacerbated the existing food insecurity in developing nations. The cumulative effect of restricted mobility to curtail the spread of the infection, loss of livelihood and income, worst affected the economically weaker sections. Our work examined the availability, accessibility, and affordability of food during the first wave of the pandemic using the FAO, HFIAS questionnaire, in a random sample (N = 401) from Kanker and Narayanpur districts in Chattisgarh, an Empowered Action Group state, in India. Total food security scores were derived by summing the individual scores. Percentages above and below the median scores were used to assess food insecurity. Proportion Z test was used to compare settings and a generalized linear model was used to determine the association between dependent and independent variables. Of the 63% non-tribal population, a greater percent experienced income loss (13.4%) and worried about not having sufficient food (40%). A significantly higher proportion from the non-tribal regions reported food scarcity in the household (34%) and experienced hunger (15%). Non-tribal participants (77%) scored ≤ median (score 8) demonstrating high food insecurity. The odds of poor food access increased in the non-tribal settings (B: 0.024, 95% CI: 0.011–0.051, $P < 0.001$), income between Rs. 10,000–29,000/- per month (B: 0.385, 95% CI: 0.146–1.014, $P < 0.05$) and among those experiencing total or partial income loss (B: 0.505, 95% CI: 0.252–1.011, $P < 0.05$). Urban residence increased the odds of poor food availability (B: 15.933, 95% CI: 3.473–73.096, $P < 0.001$). Being male (B: 0.450, 95% CI: 0.208–0.972, $P < 0.05$), and not experiencing income loss (B: 0.367, 95% CI: 0.139–0.969, $P < 0.05$) decreased the odds of poor availability and affordability (B: 0.153, 95% CI: 0.067–0.349, $P < 0.001$). Non-tribal setting increased the odds of poor affordability (B: 11.512, 95% CI: 5.577–23.765, $P < 0.001$) and hunger (B: 19.532, 95% CI: 7.705–49.515, $P < 0.001$). Being male (B: 0.445, 95% CI: 0.277–0.715, $P < 0.05$) and higher age (B: 0.936, 95% CI: 0.936–0.906, $P < 0.001$) decreased the odds of food insecurity as per the total food security score. While India is likely to experience multiple waves, actions urgent and targeted toward the needs of the vulnerable sections be prioritized to endure and overcome the impact of the pandemic.

Keywords: food security, migration, tribal, non-tribal settings, loss of livelihood

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INTRODUCTION

The COVID-19 pandemic, one of the greatest crises of the last decade aggravated the existing food insecurity predicaments globally. The United Nations has predicted that an additional 130 million would suffer acute food insecurity, more concentrated in the developing nations (1). In India, the lockdown imposed by the government, to control the pandemic during the first wave led to the down sliding of the Indian economy with seemingly lasting effects on the prevailing nutritional situation (2). Before India recovered from the first wave, the second wave hit with greater intensity. The impact of this multi-fold effect of pandemic leaves India with incalculable consequences, further impeding the achievement of the development goals. As the country experiences an economic slowdown, employment and income losses have driven populations to the brink of poverty (3, 4).

Poverty combined with lockdown extended over long periods worsened food insecurity. Transport restrictions, disruption in the supply chain, and shortage of manpower hamper the production, storage, and distribution of food (5). Consequently, food shortage, escalation of food prices, alongside the loss of livelihood, wages, and employment were experienced across the income groups (6). The dire consequence of these events, escalated the problem of hunger in India, its impact much experienced by the vulnerable in the population; the poor, daily wage laborers, and those employed in the unorganized sectors (7). The first wave witnessed the discontinuation of the supplementary feeding program and school mid-day meal program that contribute to food and nutrition security among the lower-income groups' (6). Pre-COVID statistics of hunger and hidden hunger reflect in child undernutrition (stunting 35%, underweight 32%) and anemia among children and pregnant women [67 and 52% respectively (8)] which is likely to worsen during the pandemic.

In a vast nation with varying degrees of economic uncertainty and food insecurity in different states, the food supply, and value chain vary in different regions and the impact of this pandemic would conceivably be varied in urban, peri-urban, and rural settings (9). It is, therefore, worth exploring the differences in impact, as the lockdown too was implemented with varied stringency in different settings.

Chhattisgarh being an Empowered Action Group (EAG) state is slow in the economic and demographic transition. The geography and demography of Chhattisgarh account for its limited progress that reflects in its 14th position out of 17 Indian states as per the hunger index (10). Almost 77% of the total Chhattisgarh population lives in rural areas and 10% of the total Indian tribal population resides in Chhattisgarh (11). With the already prevailing food-insecure situation, Chhattisgarh was the first state in India to introduce the food security act in December 2012 (12).

In Chhattisgarh, agriculture and engagement in daily labor are the chief sources of income (13, 14). They mostly depend on the public distribution system and mid-day meals, and the Anganwadi (Government preschool centers) plays an important role in maintaining the nutritional requirements of pregnant women and children. Despite the food security policy and programs in place, the maternal and child health indicators are fairly poor, especially in rural and tribal regions. Undernutrition among children below 5 years is higher in rural (39.6%) than in urban regions (30.2%) [NFHS 4, (15)]. In the absence of National prevalence of undernutrition in the tribal regions, regional studies reflect a high prevalence that ranges from 54.7 to 82% (16, 17).

Lessons from the HIV pandemic predict a post-pandemic upsurge in undernutrition and child mortality as a consequence of hunger (18). The impact of this pandemic on food security in Chhattisgarh is worth studying, as the indirect effects of the pandemic perhaps will worsen its maternal and child health indicators. There is little evidence about the prevailing condition of food insecurity during this crisis in EAG states. Studying hunger at the backdrop of income or livelihood loss during a pandemic is vital to plan appropriate interventions and rethink public health policies for emergency preparedness specifically in these regions. The present study aims to assess food accessibility, affordability, and availability in different settings of Chhattisgarh and determine the factors of food insecurity during the COVID-19 pandemic.

This work was motivated by the global effort to study food access and security during the COVID-19 crisis with the international task force (19).

METHODS

Study Design and Setting

A cross-sectional survey was conducted between November 2020 and January 2021 from urban, rural, and tribal regions of Chhattisgarh. Of the 28 states and 7 union territories in India, 8 states are referred to as EAG states. EAG states experience slow socioeconomic and demographic transition and also fare poorly in health indicators. Chhattisgarh is among one of the EAG states located in East-Central India. The greater percent of the Chhattisgarh population reside in rural and tribal settings, about one-third of the population is tribal and 80% of the population resides in the rural regions and fare poorly in health indicators. For the present study, the rural and tribal data were collected from two villages of Kanker and Narayanpur districts, respectively, situated in the south of Chhattisgarh. From these districts f, two villages, Selegaon and Gudadi from Kanker and Narayanpur districts were selected for convenience and ease of access during the pandemic.

Sample

Considering a prevalence of 21% of diet diversity among children under-five as a proxy indicator of food insecurity, from the Comprehensive Nutrition Survey (2018–19) (20), at 95% CI, 5% precision, 1.5 design effect, and 10% non-response, the estimated sample size was $N = 420$. Thus a random sample of 420 respondents was enrolled in the study. Respondents who were above 18 years of age and who consented to participate

Abbreviations: EAG, Empowered Action Group; HFIAS, Household Food Insecurity Access Scale.

in the study were recruited. Of the 420 samples, a usable 401 questionnaires that had complete data were considered for the study.

Data Collection

Data was collected by researchers trained in public health nutrition research techniques. They were aware of the objectives and ethical procedures to adhere to this study. The study is part of a global food access survey that employed online data eliciting procedures (19). However, to study food insecurity in Chhattisgarh, which involved data collection in rural and tribal regions we conducted this study through face-to-face interviews. The list of households covered by the Anganwadi centers was obtained from the Anganwadi workers and the data was collected by household visits.

Tools and Techniques

A modified version of the Household Food Insecurity Access Scale (HFIAS) developed by the Food and Agricultural Organization (21) was used to elicit information about the availability, accessibility, and affordability of food during the pandemic. The questionnaire was translated to the Hindi language. It was pretested to check the flow of questions and usage of relevant terminologies. Each interview lasted for 20 and 45 min.

Variables

The HFIAS questionnaire elicited information on the dependent variables that included availability, accessibility, affordability of foods, and experience of hunger. Independent variables included socio-demographic characteristics such as age, gender, education, loss of employment, or livelihood. The respondents answered the questions for the household.

Ethical Consideration

The study was approved by the Institutional Ethics Committee (Ref: SPPU/IEC/2020/83). Participants were briefed about the study and written consent was obtained before the interview and confidentiality of data was ensured. The respondents were free to withdraw from participating in the survey at any point during the interview.

Data Analysis

Data were entered cleaned and coded in excel and then imported to Statistical Package for the Social Sciences (SPSS, NY: IBM Corp version 20) for analysis. Descriptive statistics were used to describe the study population. Food security was evaluated by deriving food security scores from the variables selected from HFIAS (21). Food access [2 questions, MPS = 10] was scored using the Likert scale where the responses were scored from one to five, the highest score indicated poor access to food. Food availability [maximum possible score (MPS) = 6], affordability [MPS = 4], and hunger [MPS = 3] scores were derived from dichotomous responses where a positive response of food insecurity experience scored one and a negative response scored zero. Proportion *Z*-test was used to test for differences in proportions between non-tribal and tribal settings. A generalized linear model was used to determine the association between the variables.

RESULTS

Sociodemographic Characteristics

Table 1 shows the distribution of socio-demographic characteristics. Among the total respondents, over 60% represented the non-tribal settings. Almost 60% of the respondents were females and the mean age of the respondents was 30.11 years (SD ± 9.77). Almost three fourth (74.8%) of participants received secondary education and over 60% [247 (61.6%)] were married. Nearly 90%, [355 (88.5%)] participants reported having less than two children. Almost 70% [283 (70.6%)] reported a family income of less than Rs. 10,000 per month. And <20% each reported a family income category between Rs. 10,000, 29,000, and >30,000, respectively.

Comparison of Food Security in Different Settings

Table 2 shows the differences in food security indicators between tribal and non-tribal settings during the pandemic. We used income loss or income uncertainty as proxy indicators to study *affordability*. A greater percent of non-tribal respondents reported having experienced income loss (non-tribal 13.4% vs. tribal 3.4%) and experienced fear of income loss (Non-tribal 27.7% vs. Tribal 4.7%) during the pandemic. With regards to *access to food,* a significantly greater percentage of the respondents from non-tribal (56.1%) regions reported having visited local markets more than three times in a week than in the

TABLE 1 | Distribution of socio-demographic characteristics.

Variables	Frequency (n = 401)	Percentage (%)
Setting		
Non-tribal	253	63.1
Tribal	148	36.9
Gender		
Male	172	42.9
Female	229	57.1
Mean age (years)	30.11 ± 9.771	
Education		
Primary	101	25.2
secondary	300	74.8
Marital status		
Married/ Co-habiting	247	61.6
Single/ Divorced	154	38.4
Number of children		
<2	355	88.5
>2	46	11.5
Income		
<10,000	283	70.6
10,000–29,000	72	18.0
>30,000	46	11.5

TABLE 2 | Distribution of reported experiences of food insecurity during the pandemic.

Variables for food security	Non-tribal (%)	Tribal (%)
1. Affordability: Income loss or insecurity as proxy indicators for affordability		
Loss of income		
Yes	19	3.4
No	81	96.6
Worried about losing income		
Yes	27.7	4.7
No	72.3	95.3
2. Accessibility		
Visited local weekly markets*		
More than three times	56.1	4.1
Three times	7.5	1.4
Twice	12.3	4.1
Once	16.2	60.8
Never	7.9	29.7
Consumed food from outside		
More than three times	1.6	1.4
Three times	2.4	0.0
Twice	3.6	0.0
Once	3.6	1.4
Never	88.9	97.3
3. Availability		
Worried about not having enough food		
Yes	41.9	6.8
No	58.1	93.2
Not able to eat kind of food preferred		
Yes	43.1	8.1
No	56.9	91.9
Had to eat a limited variety of food		
Yes	39.5	5.4
No	60.5	94.6
Had to eat some food that you did not want to eat		
Yes	34.8	6.8
No	65.2	93.2
Had to eat a smaller meal than you felt you needed		
Yes	22.1	3.4
No	77.9	96.6
Got free donated food		
Yes	12.3	41.9
No	87.7	58.1
4. Reported experience of hunger		
No food to eat of any kind*		
Yes	34.8	4.1
No	65.2	95.9
Went to bed hungry*		
Yes	14.2	2.0
No	85.8	98.0
Remained hungry both during day and night*		
Yes	16.6	0.7
No	83.4	99.3

*$P \leq 0.05$.

TABLE 3 | Median scores of different components of food insecurity.

Scores of food security domains	Non-tribal (%)	Tribal (%)
Accessibility* (MPS 10)		
<=median (8)	77.1	11.5
>=9	22.9	88.5
Availability* (MPS 6)		
<=median (1)	70.5	98.5
2	29.5	1.5
Affordability* (MPS 4)		
<=median (0)	41.9	91.9
>median (1)	58.1	8.1
Hunger * (MPS 3)		
<=median (0)	55.7	95.9
>median (1)	44.3	4.1
Total food insecurity score* (MPS 22)		
<=median (10)	50.6	73.6
>median (11)	49.4	26.4

**MPS, Maximum Possible Score.*

tribal regions (4.1%). A significantly higher proportion [>60%] of tribal respondents reported to have visited the local market once and another 29.7% never visited the market. About 90–97% of respondents from both settings reported having never consumed food from outside services. The results need to be carefully interpreted as markets in tribal settings often operate weekly and therefore cannot be interpreted as having poor or less access to food. Concerning household *food availability*, a significantly higher percentage of urban and rural respondents (41.9%) were worried about not having enough food to eat than those from tribal settings (6.8%). A significantly higher proportion of urban and rural respondents experienced the inability to eat the preferred food (40%), had access to a limited variety of foods (Non-tribal 39.5 vs. Tribal 5.4%), and ate smaller meals than the tribal respondents (Non-tribal 22.1 vs. Tribal 3.4%), while the tribal respondents had significantly more access to free food (41.9 vs. 12.3%). Similar was the reported experience of hunger, where close to 15% of the non-tribal regions remained hungry during the day and or night and 34% did not have food in the household which was higher than the tribal households and these differences were significant ($p = 0.05$).

Table 3 shows the comparative scores of food security indicators between settings. A greater percentage of non-tribal participants (77%) scored $\leq$ median (8) representing high food insecurity and 88.5% of tribal respondents scored above the median (9) indicating better food security.

Determinants of Food Insecurity During the Pandemic

Table 4 shows a generalized linear model that was used to examine the association of background characteristics with the food insecurity scores. Socio-demographic characteristics were tested with food accessibility scores in model 1, availability score

COVID-19 PANDEMIC, FOOD BEHAVIOUR AND CONSUMPTION PATTERNS

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in model 2, affordability in model 3, hunger in model 4, and model 5 with total food security score.

In model 1, setting, income, and income losses were associated with food accessibility scores. The respondents from non-tribal settings had 0.024 times less access to food (B: 0.024, 95% CI: 0.011–0.051, $P < 0.001$). The respondents with income between Rs. 10,000 and 29,000/month had 0.38 times more access to food (B: 0.385, 95% CI: 0.146–1.014, $P < 0.05$). The participants who did not lose either part or full source of income had 0.50 times more access to food during a crisis (B: 0.505, 95% CI: 0.252–1.011, $P < 0.05$).

In model 2, setting, gender, and income lost showed a significant association with food availability scores. The residents of the urban settings in Chhattisgarh showed 15.93 times higher odds of poor food availability as compared to their rural counterparts (B: 15.933, 95% CI: 3.473–73.096, $P < 0.001$). Between gender, males experienced 0.45 times fewer concerns related to food availability compared to women (B: 0.450, 95% CI: 0.208–0.972, $P < 0.05$). The respondents who did not lose their income were 0.367 times less likely to face issues related to the non-availability of food (B: 0.367, 95% CI: 0.139–0.969, $P < 0.05$).

In model 3, settings, family income and income lost showed significant association with affordability score. The non-tribal residents showed an 11.51 higher odds of poor affordability score (B: 11.512, 95% CI: 5.577–23.765, $P < 0.001$). Respondents with family income <INR. 10,000/- showed 2.39 times higher odds of poor affordability (B: 2.390, 95% CI: 1.106–5.162, $P < 0.05$), whereas income between INR10,000 and 29,000 faced 2.82 times lesser odds of poor affordability (B: 2.825, 95% CI: 1.179–6.771, $P < 0.05$). The respondents who never lost their income during the COVID-19 crisis showed 0.153 times lesser odds of poor affordability (B: 0.153, 95% CI: 0.067–0.349, $P < 0.001$).

In model 4, settings and income losses were significantly associated with hunger scores. The non-tribal respondents faced 19.53 times more hunger than those in tribal regions (B: 19.532, 95% CI: 7.705–49.515, $P < 0.001$), and the population who never lost their income have 0.477 times experienced less hunger than those who have lost their income (B: 0.477, 95% CI: 0.251–0.98, $P < 0.05$).

In model 5, settings, age, gender and income lost showed significant association with total food insecurity score. The population residing in the non-tribal area was 1.28 times more food insecure during the pandemic than those in the tribal regions (B: 1.28, 95% CI: 1.028–3.251, $P < 0.001$). It was found that as age increased there are 0.936 times lesser odds of food insecurity (B: 0.936, 95% CI: 0.936–0.906, $P < 0.001$). Men were 0.445 times less food insecure than women (B: 0.445, 95% CI: 0.277–0.715, $P < 0.05$) and those who never lost a part or full source of income during the crisis were 0.477 times less food insecure than those who lost their income (B: 0.477, 95% CI: 0.251–0.908, $P < 0.05$).

DISCUSSION

This work was an attempt to study food insecurity in Kanker and Narayanpur districts of Chhattisgarh during the lockdown period. A state categorized as EAG is likely to have experienced varying levels of food insecurity and its consequences during the extended lockdown. In India, with the rising number of infections, the fear of another lockdown is experienced by the population. This work is therefore important as it highlights the prevailing conditions of income loss and the consequent hunger experienced which is likely to worsen in an EAG state.

Loss of Livelihood, Migration, and Food Insecurity

During the pandemic, loss of employment, daily wages, or income in any form was experienced across settings. This included the urban poor who are often migrants from rural or tribal settings who are daily wage laborers, and those who represent the middle and upper-income groups. With income loss or financial insecurity as the context during the pandemic, we studied the four domains of food insecurity viz. accessibility, availability, affordability, and hunger during the pandemic. India, state-wise data on food security in the pre-COVID era are unavailable as per the core indicators (Accessibility, Availability, and Affordability). However, comprehensive data on direct and proxy indicators are available from the Food and Nutrition Security Analysis (FNSA), India (22), and the NFHS 4 (2015-16) (15). The per-capita expenditure on food between 2011 and 12 in the rural and urban Chhattisgarh was 45.1 and 78.8% respectively (23). Chhattisgarh was among the four states that showed a decline in protein intake with a per-capita per-day intake lower than the RDA of 48gm. It is the only state where the protein intake was less, both in the 2004–5 and 2011–12 statistics. Concerning energy, between 2004–5 and 2011–12, per-capita per-day intake increased in most states of India. On the contrary, 11 states including Chhattisgarh showed declining trends during this period. Fat intake too was lower than RDA andower intake was significant among SC and ST (24).

Loss of income and fear of income loss together reported by nearly 50% points to the gravity of economic insecurity experienced. A higher percent from the non-tribal regions reported economic loss and instability. In the absence of core indicators, indirect indicators from the NFHS 4, indicate an infant mortality rate (IMR) of 54%, and an under-five mortality rate (U5MR) of 64%. Prevalence of stunting was 31.6 and 39.2, wasting was 20.6 and 23.7 and under-weight was 30.2 and 39.6 percent in the rural and urban regions respectively (24). These figures indicate high prevalence in urban settings. Also, our findings reveal that the population from non-tribal settings in Chhattisgarh faced more food insecurity than the tribal regions, similar to the pre-COVID literature, which reported that food insecurity is higher in urban and rural settings than in isolated settings of India (25–27). Due to migration from rural and tribal settings to urban regions for better livelihoods, they face serious challenges to meet the basic requirements (28, 29) in addition to the loss of livelihood during the pandemic. While the pandemic has worsened the situation, these settlements have been projected to increase by 2050 as food

insecurity and poverty are already prevailing in the isolated regions (30). It is well known that food security prevails in the tribal regions, but the urban poor has become the "new hungry" due to the pandemic. This could contribute to a net increase in the proportion of the population who are hungry deviating further from the sustainable development goals. It is thus clear that poverty increases the risk of hunger irrespective of setting.

Access to Food in Different Settings During the Imposed Lockdown

We explored the accessibility to food by studying the access to local markets and the frequency of consuming food from outside sources, we observed that the tribal population visited local markets and consumed foods prepared outside than homes less frequently. However, these should be interpreted with caution as we cannot conclude that they have restricted food access during the pandemic as the chief occupation of tribal people is agriculture which is a product yielding activity that results in agricultural produce (31) and their dependence on markets and shops for their livelihood is minimal. Markets are often weekly and therefore weekly access as an indicator of food access may not be the right indicator for tribal settings.

Better food access need not necessarily indicate food security. The stringent 21 days lockdown which further extended to 60 days affected the availability of the food in non-tribal settings. The disruption in the supply chain perhapsbe the led to the unavailability of food in urban settings. This has been documented in other studies where the lockdown disrupted transportation and supply networks, induced labor shortage, fuelling a panic situation that brought about the hoarding of food items which further increased the burden on the demand side (32, 33).

Although the majority of the study participants did not require food assistance, almost 42% from the tribal setting have reported having received help from family and friends which portrays the sharing culture of the tribal population that could have contributed to better food security whereas the non-tribal population majorly depend on the public distribution system (PDS), which suffers from disrupted supply chain that prevents optimal functioning during a pandemic. Although our study identified non-tribal residents consumed fewer or skipped meals due to lack of money, other studies reported similar situations in the tribal region (34). We found. The difference in observations in the tribal and non-tribal settings could have been the dependency on farming, fisheries, and hunting in the tribal regions. Also, a majority of our study population reported a low-income level per month, which likely is to have contributed to this observation. Various mathematical models have projected public health strategies such as masks, social distancing, and media for behavior change (35). Identification of strategies to improve income security or prevent financial setbacks is a critical need to address as it is projected that the virus will become endemic and seasonal (36, 37). Such models are therefore essential to project food and income security situations.

The study identified the factors contributing to food insecurity during the pandemic. Our analysis suggested that residents of the non-tribal areas, who lost their income during the COVID-19 crisis, women and young people who represent the production section of the population were those affected with high food insecurity scores in Chhattisgarh. Evidence of vulnerability of women to poverty and high propensity of migration among the young in Chhattisgarh exist (38). Similar experiences of food insecurity leading to hunger due to the restrictions imposed, in urban regions have been reported by other studies in India and its neighboring countries (33, 39). The results were consistent that in the pre-COVID times where food insecurity was more prevalent among households with lower monthly income especially among women and children (34, 40).

Limitations

Despite capturing the seriousness of food insecurity our work had several limitations. Due to restrictions, we studied selected areas which limited the generalization of our findings. Vulnerable populations such as pregnant women and households with children could have faced varying levels of food security and our sample and analysis did not consider these specific population groups. Data on food groups that were not elicited in our work limited assessment of diversity and pattern of foods consumed in different settings of Chhattisgarh. The results of our study from tribal settings need to be carefully interpreted as availability of food may already be a concern and implementation of lockdown would not have been stringent in these settings. Further, the loss of income in the urban and rural settings was much more in our study as compared to tribal regions. It is also likely that income loss in tribal regions would have yielded limited responses as income in tribal regions need not always be in the form of cash. Gainful activities leading to gaining agricultural or farm or forest produce are also considered as income (41) and this was not elicited in this study. Further, we have not considered the exposure to the virus in these settings that would have added to the multiple burdens. The second wave affected the rural and tribal regions severely more than the first. Therefore, the findings are limited to the experiences during the first wave.

CONCLUSION

The unprecedented crisis of COVID-19 has worsened the existing problem of food insecurity, especially in urban Chhattisgarh. To address this situation nutritional programs must run uninterruptedly in previously vulnerable territories. Emergency feeding programs extended to all age groups would be an immediate response and financial support to the vulnerable population can increase the affordability of food to reduce hunger and prevent undernutrition. Long-term strategies should be planned based on lessons learned from this pandemic, this would be the first step for preparedness for future disasters.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions will be made available by the authors on request.

ETHICS STATEMENT

The study was approved by the Institutional Ethics Committee (Ref: SPPU/IEC/2020/83). Participants were briefed about the study and written consent was obtained before the interview and confidentiality of data was ensured. The respondents were free to withdraw from participating in the survey at any point during the interview.

AUTHOR CONTRIBUTIONS

AJ and MA conceptualized the study. DD collected data and performed the analysis under the guidance of AJ and MA. The first manuscript was written by AJ and edited by all authors.

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COVID-19 Impact on Household Food Security in Urban and Peri-Urban Areas of Hyderabad, India

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This paper investigates the impact of the COVID-19 pandemic on food security and on coping-strategies in urban and peri-urban areas of the Hyderabad, India. Household survey data were collected before (October 2018) and during (January 2021) the onset of the pandemic. Results from logistic regression with the standarized Food Insecurity Expecience Scale (FIES) as dependent variable reveal that close to 40% of the households surveyed experienced a deterioration in food security status during the pandemic. In particular, we find that food security is closely related to the sector of employment in which the primary income- earning member of a household is engaged. To mitigate the impact of the pandemic on their food security, our sampled households adopted a variety of consumption-smoothing strategies including availing credit from both formal and informal sources, and liquidating their savings. Compared to households with severe or moderate level of food insecurity, households facing a mild level of food insecurity relied on stored food as a strategy to smoothen consumption in response to the income shock imparted by the pandemic. In addition, the results indicate that urban households, who adopted similar coping strategies as those adopted by peri-urban households, tended to be more food-insecure. Finally, the duration of unemployment experienced during the pandemic significantly influenced the status of household food security. These findings can inform the formulation of immediate and medium-term policy responses, including social protection policies conductive to mitigating the impacts of the COVID-19 pandemic and ameliorating the governance of urban food security during unexpected events and shocks.

Keywords: food security, pandemic (COVID-19), livelihood, coping strategies, urban, peri-urban, Hyderabad (India), India

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INTRODUCTION

On top of the direct health impacts of the COVID-19, the pandemic has disrupted food supply chains in developing countries, destabilized food prices and created profound negative effects on food security (1). In particular, the measures that governments in developing countries adopted to contain the spead of the virus have caused disruptions in transportation, manufacturing and service provisioning, which subsequently increased unemployment and caused an income loss estimated

at USD 220 billion (2). These losses will reverberate across societies and impact education, human rights, and in most cases, basic food security and nutrition (3).

Economic lockdown and confinement measures implemented due to the pandemic have impacted employment across sectors within and between countries asymetrically (4–8). It has resulted in increased in unemployment rates, work from home arrangements and affected labor force participation. The overall economic downturn globally forced companies or firms to downsize their businesses, in some cases even complete shutdown, which got translated as reduced work hours for partial pay or losing their jobs entirely for many employees. The segments of the workforce most likely to be impacted are the most vulnerable groups, less educated low–wage workers, and those with non-standard contracts (temporary contracts, self-employed) (9, 10) and exacerbate the labor market iniquities.

In India, the sudden nationwide lockdown imposed by the national government from March 24, 2020 to May 31,2020 was one of the most extensive and stringent COVID-19 lockdowns in the world. In thus clamping down, the government's singular focus was on saving lives, not livelihoods. The lockdown froze economic activity across the country and delivered a large aggregate supply and demand shock to the economy. The consequences have been unprecedented in scale and intensity. Livelihoods were devastated due to the inability to maintain job security, food production was compromised and supply chains were distrupted. The adverse effects of a countrywide lockdown combined with weak political, economic, and social interventions had extended beyond income shocks and affected household food security (11, 12). Loss of employment, curtailed contracts and reduced wages exacerbated food insecurity risk (13).

These unfolding COVID-19 impacts on food security in developing countries have a strong territorial/spatial dimension (14), as regions have been heterogeneously affected in the short-run, and the medium- and long-term impact will vary significantly across regions. One of the greatest challenges facing the world's rapidly-growing urban population is how to access sufficient, affordable, and nutritious food (15). In particular, densely populated and deprived urban areas were the reportedly hardest hit than other areas (16). For many urban households, especially those living in poorer communities, labor is the most important asset. The fact that the majority of workers in such communities tend to work in the informal sector, earn a variable income and have little or no access to private or social insurance makes access to sufficient food a crucial issue (17). It is in this context that the global economic slowdown trigerred by the COVID-19 pandemic, as well as the disease itself, has exacerbated existing societal inequalities in most countries (7). Thus, COVID-19 impacts on food security in developing countries should be understood in the light of the rapid urbanization processes that many developing countries have been experiencing in recent decades. In this respect, evidence suggests that the burgeoning challenges posed by increased urbanization to the economic and social futures of developing countries through its effects on the resilience of food systems to unexpecteded shocks, such as disease outbreaks and other nature-induced changes. That is, urbanization is often associated with poverty, overburdening of social services, limited access to basic amenities and the resulting public health risks. The relationship between food security, food systems and sustainability needs to be given engaged consideration in the urban areas. Understanding this relationship is crucial because urban poverty and food insecurity are interrelated. However, there has been a lack of or limited systematic analysis of how urbanization affects contemporary food insecurity risk.

Literature on impacts of the pandemic on various sectors has been emerging since the onset of the global COVID 19 pandemic. Research has focused on impacts of the Covid 19 pandemic on social and associated psychological and health impacts due to the restrictions of social and physical mobility of people (18, 19) on the positive and negative environmental impacts (20–22), agriculture,supply chains and food systems (1, 23–26).

Extensive focus has been dedicated to observing the potential impacts of the pandemic on various economic indicators such as global poverty, government expenditures, budget deficits, employments etc. limited only to global and national scale (27–31). Contextualized data on the insidious growth and extensive impact of the COVID-19 pandemic on individuals and households (micro scale) is still emerging. The varying effects of COVID on the different economic strata needs to be assessed thoroughly on various economic parameters like livelihoods and income, access to markets etc. to build evidence that can support policy formation to develop robust coping strategies that ensure income smoothing and consumption.

Food security and financial security are fundamentally interconnected but there is sparse literature showing this connection. Income volatility has been gaining attention within the broader literature of economic well-being, and qualitative research suggests plausible association with the considerable challenges of meeting household food needs (32–35). Income shock and expenditure shock are strongly associated with food insecurity. Similarly, extended periods of unemployment increase the risks of food insecurity (36).

The combined effect of food price and income shocks arising from global crises such as the COVID-19 pandemic has been suggested as the likely cause of a sharp increase in hunger and poverty in low-income countries (37). There are reasons to expect that the pandemic has deeply altered food environments. First, the way people engage and interact with the food system to acquire, prepare and consume food has changed due to the lockdowns and the subsequent supply chain disruptions. Although most households in urban regions are net buyers of food, higher food prices are likely to have reduced household access to staple food. Secondly, the economy-wide negative impact of the pandemic and the subsequent lockdown which resulted in a loss of jobs across the country, has likely further limited households' ability to purchase food at higher prices (38). This only reinforces the need to understand the lockdown's impact on household food security status and coping mechanisms in the face of income shortfalls and food price shocks (39).

With this background, this study adds to the emerging literature on the impact of COVID-19 on food security in developing countries in several important ways. Leveraging on

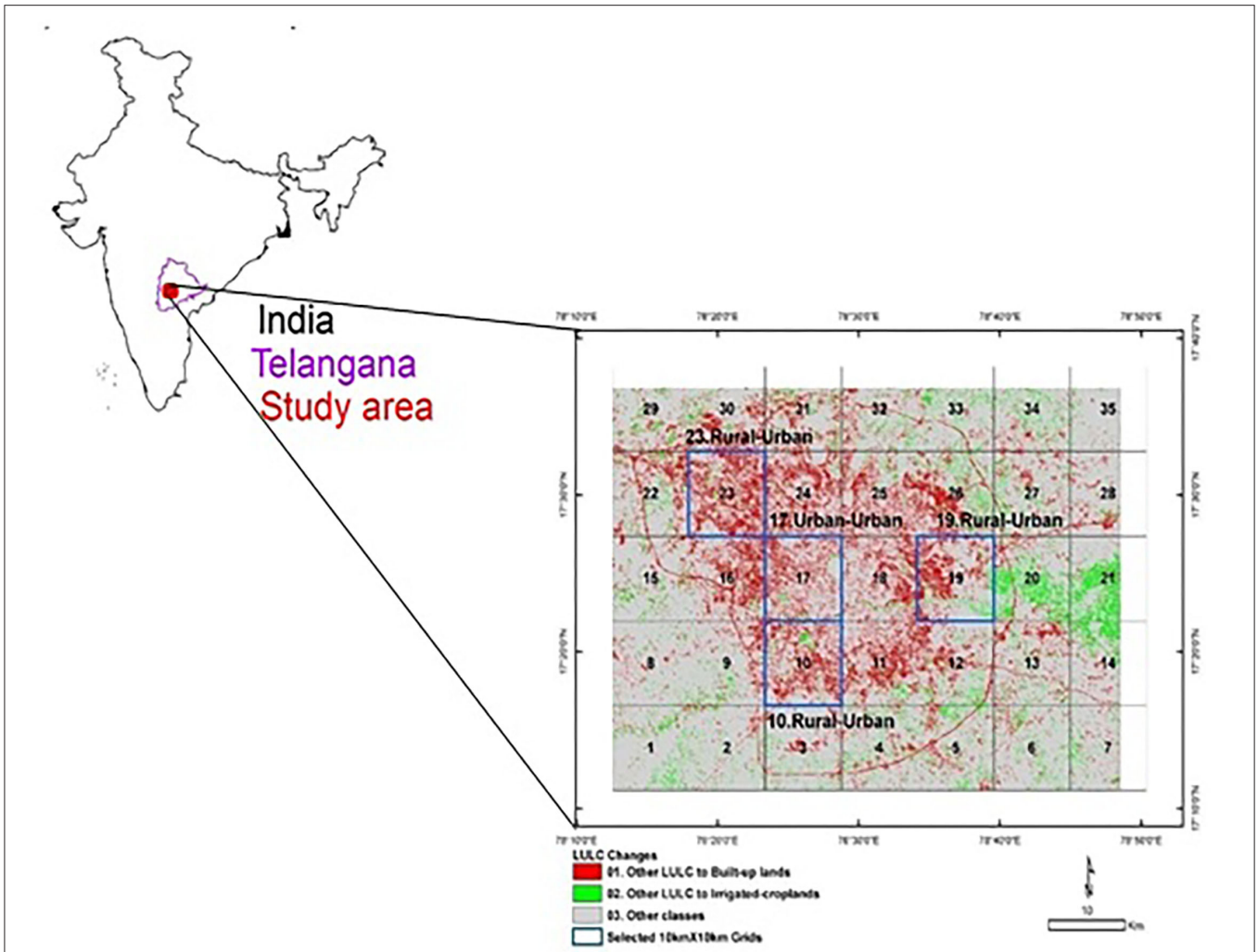

FIGURE 1 | The grid of locations selected on the basis of GIS data for a study of the COVID-19 lockdown's impact on household food security in Hyderabad, India [based on Gumma et al. (40)].

the multiple point data availability spanning across 4 years between 2018 and 2021 from a larger project the study makes a unique contribution to the emerging literature to understand the dynamics in the food security status in the aftermath of the pandemic and the phased lock down at a micro level using the food security status of the households prior to the pandemic in 2018 as benchmark capturing the spatial differences among urban and peri-urban households. We also attempt to assess the effect of pandemic on food security mediated through impact on changes in labour force participation and associated income loss.

In this paper, we seek to reach the following interrelated objectives:

- To analyze the impact of COVID-19 on the livelihoods of households residing in urban and peri-urban areas.
- To understand, by employing the Food Insecurity Experience Scale (FIES)[1], the dynamics of food security at the household level in the context of the pandemic and the coping strategies employed to smoothen consumption.

MATERIALS AND METHODS

Study Location

The selection of the study area for the present study was based on the GIS/remote-sensing analysis by Gumma et al. (40), which assessed urban expansion and other land-use and land-cover changes in Hyderabad from 2005 to 2016. Using the outer ring road of Hyderabad as a boundary of the city (**Figure 1**) and following the method of Gumma et al. (40), we identified four quadrants/grids, each having similar features, on the map of Hyderabad: two grids in peri-urban areas and two in urban areas (**Figure 1**).

The population data of each mandal[2] falling within the grid, fully or partly, were collected from the District Census Handbook

[1]Food Insecurity Experience Scale | Voices of the Hungry | Food and Agriculture Organization of the United Nations (fao.org).

[2]A sub-administrative division commonly used in India and some Asian countries.

TABLE 1 | Grid-wise proportionate sampling framework.

Grid number	Population	Category	Sample proportion (%)
10	209,524	Rural-Urban	16.51
17	347,141	Urban-Urban	27.36
19	230,543	Rural-Urban	18.17
23	461,156	Rural-Urban	36.34

2011, and the proportion of geographic area contributed to the grid by each mandal was calculated. The mandal population in the respective grid area was proportional to its geographical area in the grid. The proportion of the geographical area of a mandal within the grid was multiplied by the total population of the mandal. Using this method, the total population of each grid and its contribution to the total sample were calculated (**Table 1**, **Appendix 1**). Refer to **Supplementary Materials** for appendices.

Household Selection

It should be highlighted that this study is part of a larger project in which a longitudinal panel of data was to be collected in four rounds (between 2018 to 2021) with the aim of identifying the status and implications of urbanization on food and nutrition security. The selection of the households was done in consultation with the local government workers (Anganwadi teachers[3], sarpanches[4], and ASHA[5] workers) and based on the sampling strategy illustrated in the previous sub-section and presented in **Table 1**.

Data Collection

Prior to data collection in the first round, a written approval for the survey was taken from the local administration of the Greater Hyderabad Municipal Corporation. The formal approval letters helped our personnel gain access to the chosen locations and elicit the cooperation of people in the community. As part of the ethical consideration, prior written consent was also taken from the respondents before each interview with the households.

The first round of data collection took place before the onset of the pandemic (October, 2018-February, 2019). In this round, 660 households were selected on the basis of the criteria laid down for this project as explained in the above section. The enumerators recorded the data on tablet computers using CsPro software[6] For this present study, this round forms our baseline data against which we are measuring the changes. The second and third rounds of data collection for the project was carried out during June 2019 and November 2019, respectively. These rounds had some common modules from round one and also some additional modules. Data from these two rounds is not considered for this study.

After the onset of the COVID-19 pandemic in March 2020, from March 24 to May 31, 2020 strict lockdown restrictions were imposed nationwide in India on movement of goods and people. During the pandemic, there were three phases of withdrawal (unlock) of restrictions. The first unlock covered the period from June 1 to July 31, 2020 when certain essential services were restored and limited movement of people was allowed. The second unlock covered the period from August 1 to September 30, 2020 when there was a gradual opening up of the economy for a restricted time during the day and curfews were restricted to the late evening and night. The third unlock covered the period from October 1 to November 30, 2020, which saw the economy starting to get back to normalcy with restrictions on businesses and movement completely removed for all practical purposes.

During December 2020 to January 2021, a telephonic/remote survey was conducted on the same sample households as in the first round to understand the impact of COVID-19 pandemic on household food security. The telephonic survey covered the post-outbreak lockdown and three phases of withdrawal (unlock) of restrictions. The mobility restrictions due to the pandemic imposed by the Government of Telangana did not enable personal face to face interviews during this period. Out of the 660 households that were interviewed in round one, only 325 households could be interviewed through the telephonic survey. Audio recorded consent was taken from the households after the objectives of the survey were explained to the respondents. Data was recorded on tablet computers running KoBo Toolbox software[7].

Data and Variables Used in Analysis

The pre- and post-pandemic survey questionnaires including the standardized Food Insecurity Experience Scale (FIES) are presented in **Appendix 2** and in **Appendix 3**, respectively. We would also like to particularly mention the following:

- The number of unemployed days for a household was calculated on the basis of the number of days of participation in the labor force during March—November 2020. The respondents self reported the availability of employment or non-employment during this period.
- The self-reported actual income and the approximate range of income received by the household during February 2020 was taken as the baseline to assess changes in income and income class. Income received in February 2020 served as the baseline as it was the closest proxy to liquid cash available within the household to meet immediate expenses during the lockdown.

We used 240 days as the benchmark figure for the purpose of our computation (of the number of unemployed days) as it was the maximum number of days that a primary income earner could have been employed across all types of employment[8] during the

[3]Anganwadis are rural child care centers in India. They were started by the Indian government in 1975 as part of the Integrated Child Development Services (ICDS) program to combat child hunger and malnutrition. Each center is managed by an anganwadi teacher.

[4]The elected head of a village assembly or gram sabha.

[5]ASHA = Accredited Social Health Activist.

[6]Census and Survey Processing System: https://www.csprousers.org/.

[7]https://www.kobotoolbox.org/

[8]Refers to the nature of primary employment of the main income earner of the household: self-employment, salaried work which includes private and public sector, casual work, etc.

above period. Thus, unemployment percentage was calculated from the number of days out of 240 that a household reported its primary earner as being out of employment. Households were categorized into three groups in terms of change in income status—"improved," "reduced," and "maintained status quo"—relative to the income range reported by them for the month of February 2020. The categorizing households by food insecurity level was done as per Ballard et al. (41). Household food insecurity was the outcome variable of interest in these models, whose covariates were categorical variables coded as 1 if the household was food-insecure, mildly food-insecure, or moderately food-insecure, and 0 if it was food-secure. The other categorical variables included in the model were area of residence, type of employment (and interaction between these two variables), coping strategies adopted, income, and number of unemployed days.

RESULTS

Economic Loss

From the information provided by each household on labor force participation by its primary income earner, we computed the number of unemployed days endured by the household during the lockdown and three phases of unlock, a period spanning from March 24 to November 30, 2020 (In our sample of households, we found that there was none that had more than one employed member at any time during this period.). During the lockdown period, the majority of households in our sample-except a small proportion-were not able to participate in the work force. In the subsequent three unlock phases, households located in the urban areas found it relatively easier to get back into the job market than peri-urban households. Accordingly, the percentage of unemployed days was relatively higher for peri-urban households compared to urban households (**Figure 2**).

However, while urban households found it less difficult to get back to work, they experienced greater income reduction compared to their counterparts in the peri-urban areas. Income loss was particularly steeper for households engaged in a self-employed enterprise (with and without employees of their own). This could be attributed to the dampening of overall demand due to income and job losses as a consequence of the pandemic. The impact of dampening of overall demand is evident from the higher loss of income suffered by self-employed urban households with one or more employees compared to similar households in the peri-urban areas. Between urban and peri-urban areas, income losses sustained by other categories of households were comparable (**Figure 3**).

Analyzing the data for changes in household income status,[8] we found that, in urban as well as peri-urban areas, the majority of households that depended on casual work, which was not related to agriculture or allied activities or were self-employed, experienced a reduction in income status. The number of such households reporting a lower income status during the pandemic was higher in the peri-urban areas. On the other hand, the majority of households that had a primary income earner in a regular salaried job did not experience a change in income status; however, 24% of such households did experience a reduction in income status, perhaps due to a pay cut. About 5% of households earning regular salaries improved their income status. These were households whose primary earners had jobs related to health sectors or had got into jobs offering a higher salary.

The pandemic and the restrictive measures taken by the government had a differential impact on different classes of workers; salaried workers having secure employment were the least affected in both urban and peri-urban areas. A comparison of the maximum incomes received by households during the lockdown and three phases of unlock with corresponding income data gathered in our pre-pandemic survey (October 2018 to February 2019) showed that most of the households that drew their income from regular salaried work with secure employment managed to maintain their income level or even saw a slight increase. In both urban and peri-urban areas, households whose income came from casual work in non-farm employment experienced a decline in income compared to the pre-lockdown period. The number of such households was slightly higher in the peri-urban areas (**Figure 4**).

Food Insecurity

Background Characteristics of Households by Food Insecurity State

The majority of households in our survey experienced a deterioration in their food security status during the pandemic. Households with moderate food insecurity status had the highest FIES score as well as number of unemployed days and lowest income. Around 25% of the households experienced mild food insecurity, and 17% experienced moderate food insecurity. Around 15% of the households reported an improvement in their food security status, while about 40% said it had worsened. Though the pandemic was a covariate shock, its idiosyncratic nature is evident from its differential impact on household food insecurity even in cases where the primary income earner belonged to the same class of worker. Overall, workers from peri-urban households bore a greater brunt of the impact than their counterparts in urban areas, as is evident from the higher incidence of worse food insecurity (both mild and moderate) among such households (**Tables 2A**,**B**, **Figure 5**).

Determinants of Household Food Insecurity in the Post-pandemic Period

Based on a logistic regression model approach, **Table 3** shows that income is negatively associated with all forms of food insecurity. We found that income and the type of employment of the primary income earner of a household are the determinants of a change in the food security status of a household. Since income stability is largely dependent on the nature of primary employment of a household (self-employment, regular salaried work, casual work, etc.), being employed in the private sector is associated with a lesser likelihood of household food insecurity. Similarly, residing in an urban area was associated with an increased likelihood of household food insecurity. Self-employed households living in urban areas seemed to face an increased risk of being food-insecure, a finding that could be attributed to the

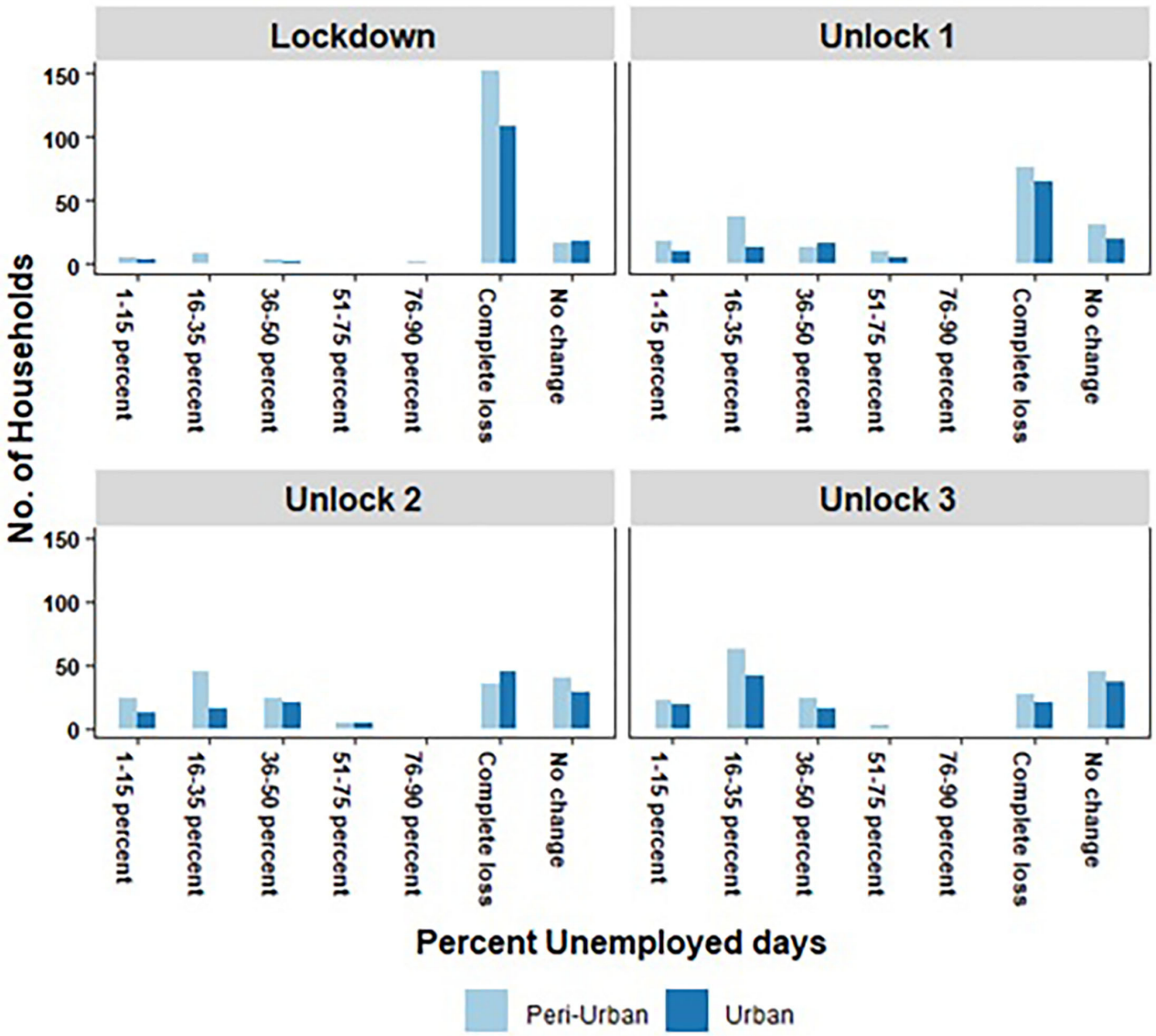

FIGURE 2 | Unemployment (%) experienced by households in urban and peri-urban areas of Hyderabad, India during the COVID-19 lockdown and three-phased unlock (removal of restrictions).

large income losses such households have suffered during and after the lockdown (**Table 3**).

The results reflect that those employed in the private sector were less likely to experience food insecurity. Urban households were found to be at greater risk of food insecurity than peri-urban households with similar employment status. This possibly was due to the drastic reduction in job opportunities during the lockdown and the higher cost of living in the urban areas. Urban households, despite having better access to financial resources/services such as loans and savings, found it difficult to cope with the stress of food insecurity as can be seen from the positive association between urban dwelling and food insecurity.

The negative coefficients on savings could be attributed to the possibility that these households have lesser savings to tide over a food insecurity situation for long. Once the savings are spent, these households find themselves food-insecure (**Table 3**). The positive coefficients on loans show that access to finance was employed as a coping strategy by food-insecure households in both urban and peri-urban contexts. The positive association between self-employed urban households and food insecurity is plausibly due to the supply chain disruptions that impacted their business and the overall dampening of demand due to reduction in income.

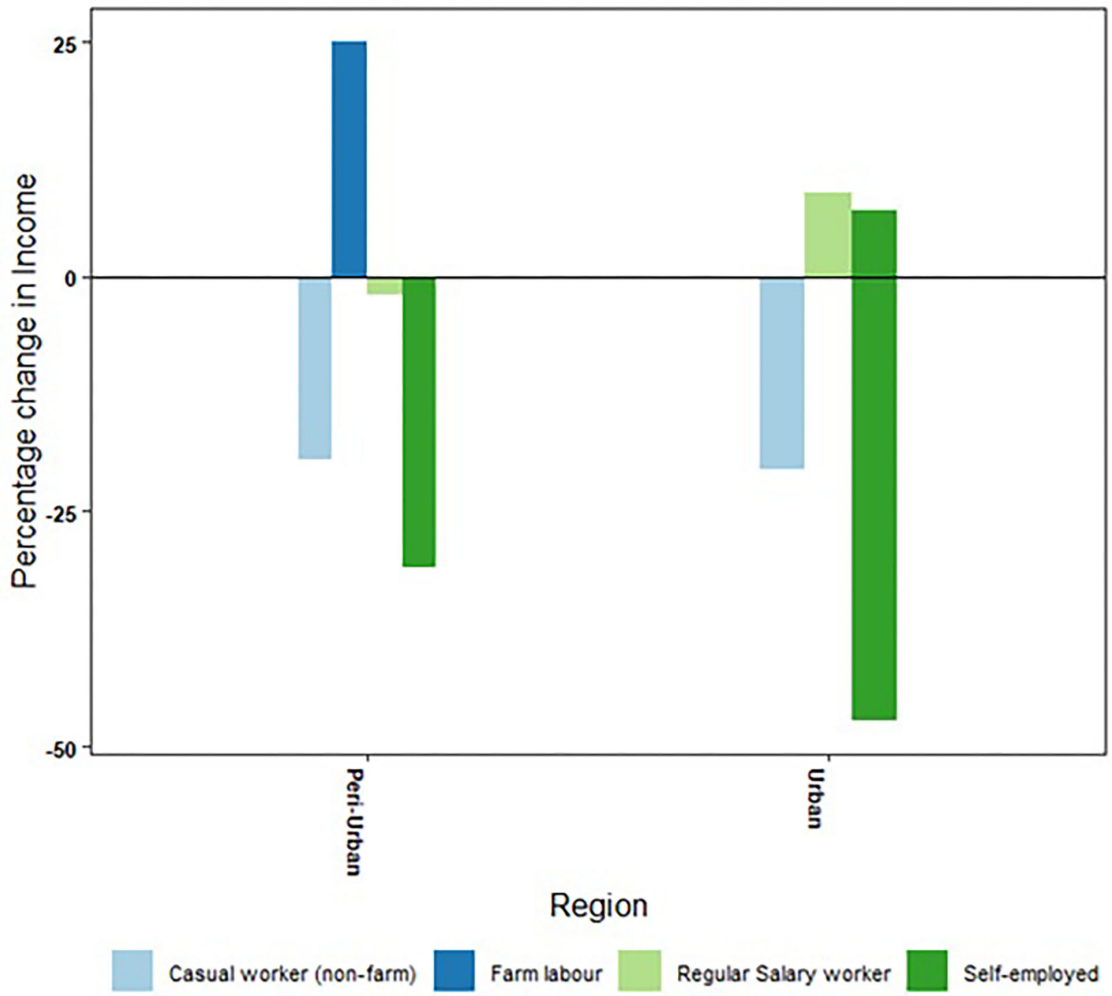

FIGURE 3 | Change in income experienced by various categories of workers during the lockdown and unlock phases of the COVID-19 pandemic in urban and peri-urban areas of Hyderabad, India.

Dynamics of Household Food Security

In assessing the food security status of households during the pandemic, we used data that we had collected before the onset of the pandemic (pre-pandemic food security status) as a benchmark against which to understand the changes that occurred during the 5-week-long lockdown and the three-phased relaxation of restrictions.

We found that the pre-pandemic food security status of a household based on the assessment using the first round of data collected in 2018 was a major determinant of its food security status in the lockdown-unlock period as well. This finding highlights the need to prioritize and target the already vulnerable households and ensure that they are covered by the assistance programs and social safety net schemes launched by various agencies in the aftermath of the outbreak. Savings are positively associated with improvement in household food security, while also being negatively associated with deterioration in food security status. This effect points to a likely correlation between private job holders who have greater income stability and also the inclination and opportunity to save more money and resources relative to, for example, non-farm workers. This proposition indeed finds resonance in the negative coefficients we found for urban households employed in the private sector. However, this benefit did not accrue to self-employed households, which endured deterioration of food security as they suffered large reductions in income besides having less access to savings (**Table 4**).

Coping Strategies

We found that households with different food insecurity status employed different coping strategies—depending on their access to such options. Households in both urban and peri-urban areas employed similar coping strategies to deal with the stress to their food security. Households in a state of mild food insecurity tended to fall back on their store of food as a coping mechanism. Households who were in a more intense state of food insecurity

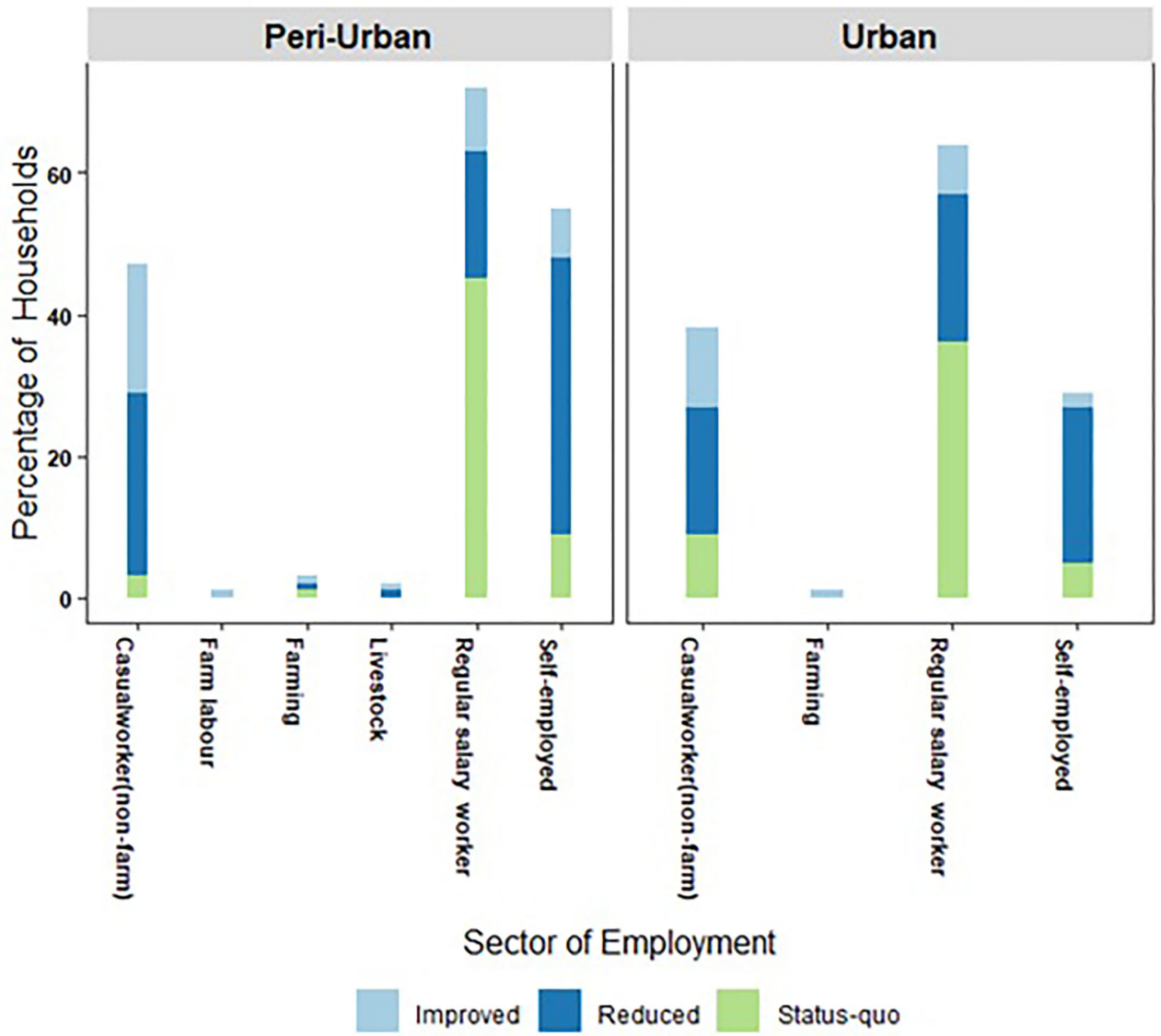

FIGURE 4 | Change in household income status (improved/reduced/status quo) relative to pre-pandemic income levels experienced by different categories of households (categorized by type of employment) in urban and peri-urban areas of Hyderabad, India.

TABLE 2A | Food insecurity status of sample households before and after COVID-19 outbreak in March 2020 in Hyderabad, India.

	Pre-pandemic						**Post-pandemic**					
	Peri-urban			**Urban**			**Peri-urban**			**Urban**		
	Mild	**Moderate**	**Secure**	**Mild**	**Moderate**	**Secure**	**Mild**	**Moderate**	**Secure**	**Mild**	**Moderate**	**Secure**
No.of households	22	19	151	12	13	108	49	33	109	34	21	76
FIES score	2.04	5.42	0.00	2.33	7.07	0.00	2.18	5.15	0.00	2.32	4.76	0.00
Proportion	6.76	5.84	46.46	3.69	4.00	33.23	15.07	10.15	33.53	10.46	6.46	23.38
%Change							**8.31**	**4.31**	**−12.93**	**6.77**	**2.46**	**−9.85**

FIES score is the number of affirmative responses of the households to the Food Insecurity Experience Scale administered.

(see columns "moderate" and "FIES" in **Table 3**) tended to take loans or liquidate into savings to cope with the stress (**Table 3**). Households in the "mild food insecurity" category have relatively more access to stored food compared to other households. Similarly, those in the "moderate food insecurity" category have relatively more access to financial resources in the form of loans—from both formal and informal sources—but have the lowest access to savings. Households that experienced an improvement in their food security status have relatively high access to financial resources both in the form of loans and savings besides being protected by various social safety schemes. On the other hand, households that experienced a deterioration in their food security status have better access to loans compared to savings (**Table 5**).

TABLE 2B | Improvement/deterioration in household food security (in terms of FIES score) due to impact of COVID-19 outbreak in March 2020 in Hyderabad, India.

	Improved (n =45)[†]	Deteriorated (n = 123)[ℓ]
FIES score	0.82	3.47
Unemployed days	136	140
Family Size	5.00	4.00

[†] *Improved: Household whose food security status has improved in the pandemic period compared to the pre pandemic period.*
[ℓ] *Deteriorated: Household whose food security status has deteriorated in the pandemic period compared to the pre pandemic period.*

Households whose food security status deteriorated (**Table 2B**) had the highest number of unemployed days on average. Households experiencing "moderate food insecurity" have less access to savings like those in the "deteriorated" category. More than 70% of the households in the "moderate" and "deteriorated" categories borrowed money to cope with the exogenous shock of the pandemic. Households in the "mild food insecurity" category employed stored food as a coping strategy to a greater extent as they have that tendency to store food more

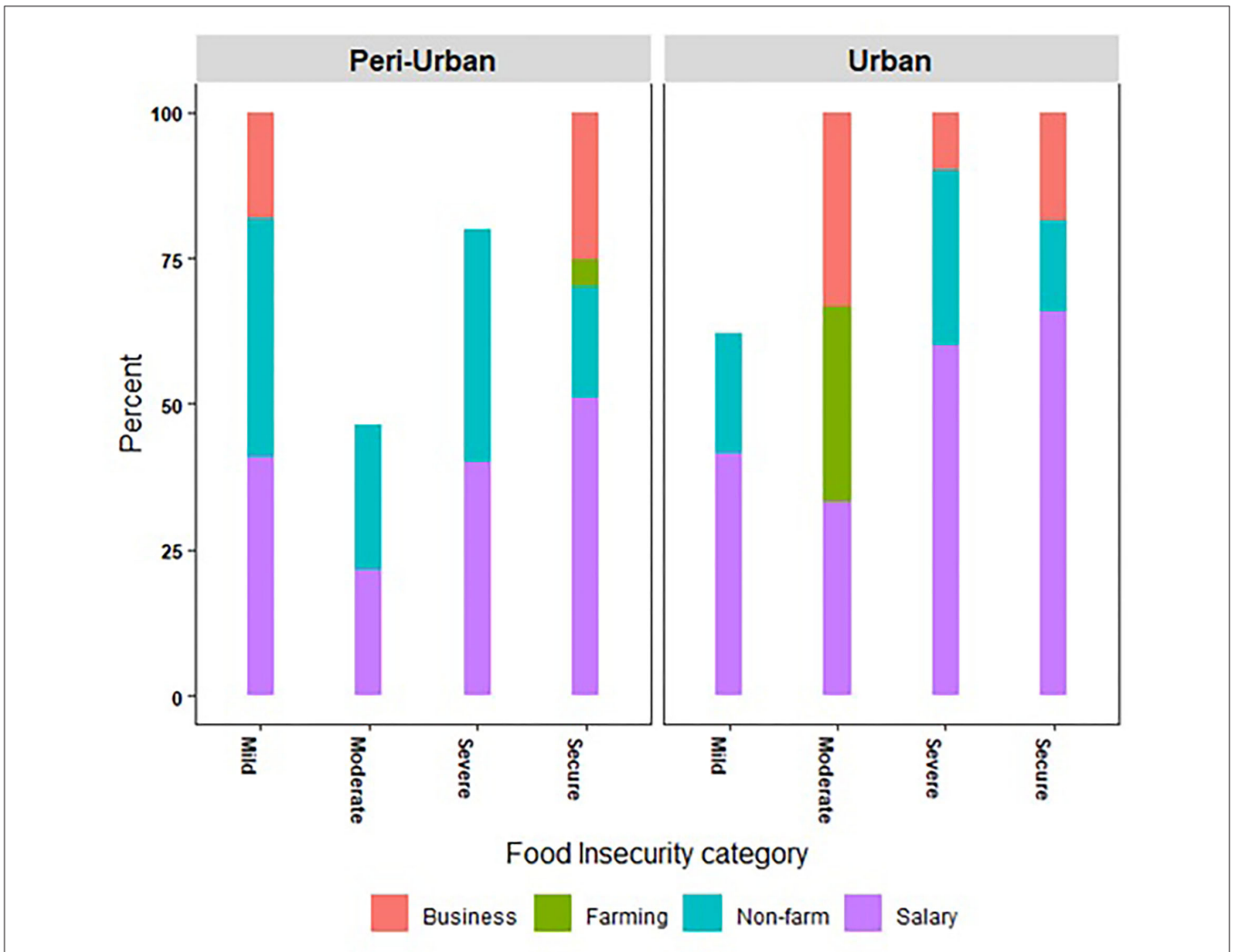

FIGURE 5 | Household food insecurity status by type of employment in urban and peri-urban areas of Hyderabad.

TABLE 3 | Determinants of household food insecurity in urban and pei-urban locations during the COVID-19 pandemic (March-November 2020).

	Insecure	Mild	Moderate	FIES
Intercept	5.137**	2.846	0.878	
	(2.047)	(2.076)	(2.529)	
Income	−0.554***	−0.433**	−0.315	−0.432**
	(0.207)	(0.211)	(0.259)	(0.171)
Unemployed days	0.004*	0.001	0.007**	0.005***
	(0.002)	(0.002)	(0.003)	(0.002)
Place (Base category: Peri-Urban)				
Urban	−1.406*	−1.726*	0.337	−0.870
	(0.77)	(0.896)	(1.013)	(0.688)
Occupation (Base category: Casual Non-farm worker)				
Farm	−1.101	0.120		−1.444
	(0.974)	(0.972)		(0.893)
Private sector	−0.975**	−0.299	−1.134*	−1.014**
	(0.479)	(0.501)	(0.667)	(0.43)
Public sector	−0.156	−0.267	0.562	0.213
	(0.684)	(0.719)	(0.875)	(0.609)
Self-employed	−0.877*	−0.0173	−1.219*	−0.828*
	(0.484)	(0.494)	(0.674)	(0.429)
Others	−0.022	−0.953	1.079	0.440
	(1.005)	(1.171)	(1.048)	(0.847)
Place × Occupation				
Urban × Farm				
Urban × Private sector	0.925	0.914	0.505	0.926
	(0.684)	(0.774)	(0.917)	(0.628)
Urban × Public sector	0.540	1.289	−0.789	−0.034
	(1.045)	(1.105)	(1.453)	(0.923)
Urban × Self-employed	1.581**	2.075***	−0.637	0.691
	(0.748)	(0.796)	(1.103)	(0.65)
Urban × Others	−0.069	1.936		−0.974
	(1.639)	(1.747)		(1.53)
Coping strategies				
Place × Savings				
Peri-Urban × Yes	−1.291***	−0.347	−1.982***	−1.324***
	(0.368)	(0.384)	(0.591)	(0.343)
Urban × Yes	−1.082**	0.214	−2.518***	−1.313***
	(0.488)	(0.547)	(0.796)	(0.477)
Place × Loans				
Peri-Urban ×Yes	0.676*	0.221	1.186*	0.718**
	(0.386)	(0.389)	(0.624)	(0.353)
Urban × Yes	1.118**	0.548	1.122*	0.962**
	(0.435)	(0.462)	(0.59)	(0.388)
Place × stored food				
Peri-Urban × Yes	0.373	0.787**	−0.493	−0.079
	(0.374)	(0.377)	(0.524)	(0.332)
Urban × Yes	0.809*	1.157**	−0.336	0.323
	(0.483)	(0.551)	(0.669)	(0.453)
Observations	316	316	306	316
Pseudo R^2	0.176	0.071	0.287	0.099
Akaike's Crit	393.099	370.362	237.258	871.183

Standard errors are in parentheses.
****p < 0.01, **p < 0.05, *p < 0.1.*
Logit estimates reported. The dependent variable in column 2 is 1 if household is food-insecure and 0 if there is no food insecurity. The dependent variable in column 3 is 1 if household faces mild food insecurity and 0 if no food insecurity, or faces moderate or severe food insecurity. The dependent variable in column 4 is 1 if the household faces moderate and severe food insecurityand 0 if there is no food insecurity or mild food insecurity. Finally, the dependent variable in column 5 is FIES score 0–8, where ahigh number corresponds to high food insecurity.

TABLE 4 | Dynamics of household food insecurity 'as assessedin terms of FIES scores.

	Improved	Deteriorated
Intercept	−0.388	2.712
	(2.702)	(1.985)
Income	0.715	−0.422**
	(0.622)	(0.213)
Unemployed days	−0.006	0.004*
	(0.009)	(0.002)
Precovid score	3.063***	−0.431***
	(0.694)	(0.108)
Region (base category: Peri-Urban)		
Urban	6.557	−0.989
	(5.687)	(0.789)
Occupation		
Farm	−0.799	−0.098
	(27.111)	(1.013)
Private sector	2.676	−1.15**
	(1.638)	(0.501)
Public sector	−0.072	−0.788
	(2.182)	(0.73)
Self-employed	1.516	−1.219**
	(1.955)	(0.509)
Others	4.739	0.635
	(5.263)	(1.247)
Region × Occupation		
Urban× Farm		
Urban × Private sector	−7.095	1.244*
	(4.468)	(0.71)
Urban × Public sector	−2.366	1.298
	(3.558)	(1.077)
Urban× Self-employed	−2.548	1.728**
	(4.28)	(0.781)
Urban × Others	−14.31	
	(165.654)	
Coping strategies		
Region × Savings		
Peri-Urban × Yes	6.212***	−1.349***
	(2.201)	(0.389)
Urban × Yes	4.338	−1.36**
	(4.763)	(0.553)
Region × Loans		
Peri-Urban × Yes	−0.787	0.781*
	(1.279)	(0.41)
Urban × Yes	−3.05	0.99**
	(1.99)	(0.451)
Region × stored loans		
Peri-Urban × Yes	0.480	0.380
	(1.076)	(0.396)
Urban × Yes	−3.141	0.267
	(4.791)	(0.522)
Observations	316	312
Pseudo R^2	0.825	0.211
Akaike's crit	84.11	365.35

Standard errors are in parentheses.
****p < 0.01, **p < 0.05, *p < 0.1.*
Logit estimates reported. Dependent variable in column 2 is 1 if household experienced improvement in food security status and 0 if there was no change in food security status, or faced deterioration in food security status. Dependent variable in column 3 is 1 if household experienced deterioration in food security status and 0 if there was no change in food security status, or experienced improvement in food security status.

than other kind of households. Nearly 60% of the households experiencing "mild food insecurity" lacked access to savings.

DISCUSSION

Economic Impacts and Impacts on Food Security

There has been a severe contraction of labor demand in India that has materialized unevenly across different occupations and skill levels. According to the Center for Monitoring Indian Economy,[9] the labor force participation rate fell to an all-time low in March 2020, and the unemployment rate rose sharply. Employment slumped by 9 million jobs, going from 443 million in January 2020 to 434 million in March 2020. This decline was the result of a fall of 15 million (from 411 million to 396 million) in the number of employed people and a 6 million rise (from 32 million to 38 million) in the number of unemployed people in March 2020.

As the COVID-19 lockdown progressed, 80% of India's informal workers lost their jobs (42). The livelihoods of daily workers, street vendors, small enterprises, and retail traders came to a complete stop for various reasons (43). More than 50% of informal workers and their families are estimated to have been pushed into poverty due to the reduction in labor incomes triggered by the lockdown (44). In the urban regions of the state of Telangana—whose capital is Hyderabad—the labor force participation rate and the greater unemployment rate were 40.47 and 5.20%, respectively, between September and December 2020 (45).

Being the major city in Telangana, Hyderabad was an interesting case to examine the trends in labor force participation in and around the city. The trends observed in our study can be attributed to the restrictions imposed on physical mobility in the city when the lockdown was announced on March 24, 2020. For people who live in the peri-urban areas around the city and commute to work in the non-farm sector everyday, this cut off access to employment. The mass layoffs and the closure of many small businesses in and around the city further added to these difficulties. The results of our study indicate that the lockdown's impact on livelihoods was more severe in peri-urban areas than in urban areas. This is consistent with the general consensus in India that the pandemic hit small businesses, daily-wage earners, and low-wage earners, leaving them with no jobs or reduced incomes (46). These findings are also in line with the macro trend observed at the national level: the national unemployment rate increased to 26% in April 2020, before easing to 19% in the subsequent months (45).

It is reasonable to expect that income losses across sectors in the urban areas resulted from the closure of businesses across sectors, especially small businesses. Such a major impact on livelihoods leads to reduced economic access to resources and services and thereby increases the risk of food insecurity. In addition, food accessibility in urban areas is largely the result of food affordability (47). The increase in staple cereal prices due to the COVID-19 outbreak in Asia has started to impact prices in local markets (48). Reduced purchasing power due to a drop in household incomes impacts their food security.

Besides reduction in income, urban consumers were also affected by the disruption of long-distance food supply chains, which resulted in product non-availability and higher retail/online prices. There was an 8% decline in the availability of fruits and vegetables and a 14% decline in the availability of edible oils in three of India's metropolitan cities immediately after the lockdown was imposed. The prices of major food items—constituting more than 25% of the urban food consumption basket—spiked immediately after the lockdown was announced in March 2020: pulses by 6%, edible oils by 3.5%, potatoes by 15% and tomatoes by 28% (49, 50). Economic access to food was constrained due to reduced income, restrictions on physical movement and restricted consumer access to affordable food markets, as reflected in the Composite Consumption Behavior Change Index (CCBCI) (51).

However, not all non-farm workers were equally affected by the lockdown. The differential impact observed across the informal sector could be attributed to the two separate branches of employment that exist within the informal sector: One group comprises those who operate/work informally within informal enterprises and those outside of informal enterprises Valodia et al. (52). The second group includes casual laborers, domestic servants, and other forms of labor-intensive employment, who tend to rely on cash income. Those in the latter group may be the most at risk of food insecurity as they face the challenge of inconsistent income. Households with members employed in the formal sector, where income is regular, do not have the same risk of food insecurity (53).

The findings of our study show that the type of employment in which the primary income earner of a household is engaged and the income it earns for the household are the determinants of any change in the food security status of the household. The sensitivity of food consumption to income changes, particularly labor income, is well-established in literature (54, 55). Liquid savings and access to credit influence heterogeneous consumption responses to income shocks (56). Our results support these findings as households that are primarily employed in sectors that provide better job security and greater stability in income relative to non-farm work which is characterized by high levels of insecurity both in terms of job and income. As a result, they are less likely to face more intense levels of food insecurity (moderate category). Overall, our results support the findings of Egger et al. (57), who report that both negative income shock and income level affect the predicted probability of households facing food insufficiency or insecurity.

Regular salaried employment such as in the private sector helps households improve their food security status gradually compared to households primarily employed in the non-farm sector as casual labor. Most of the households in our sample went from being food-secure in the pre-pandemic period to being food-insecure since the outbreak in March 2020. Relatively, private sector jobs offer higher job security and other optional benefits than jobs in the non-farm sector. Private sector jobs also offer better income stability compared to non-farm jobs. With relatively higher income, households are better equipped to

[9]https://unemploymentinindia.cmie.com/

TABLE 5 | Household access to coping strategies based on FIES scores.

	Percent households with access				Percent households without access			
Coping strategy	**Mild**	**Moderate**	**Improved**	**Deteriorated**	**Mild**	**Moderate**	**Improved**	**Deteriorated**
Loans	66.27	80.36	64.44	71.54	33.73	19.64	35.56	28.46
Savings	43.27	16.07	71.11	30.08	56.63	83.93	28.89	69.92
Stored food	57.83	41.07	28.99	52.03	42.17	58.93	71.11	47.97
Gov Aid	86.75	87.5	93.33	87.8	13.25	12.50	6.67	12.20

Mild and Moderate denote actual food insecurity status of the household in the pandemic period.Improved and deteriorsated denote the dynamics in the food security status of the household in the pandemic period compared to the pre pandemic period.

make savings, which can be utilized to withstand an unexpected shock corroborating with findings of Gjerston, 2016 (58). Our findings support similar findings by Kesar et al. (59), who reported that self-employed households were better off in terms of food security, especially in urban areas despite facing job losses. Furthermore, our results also corroborate the findings of literature, our results show that households that are able to overcome short-term liquidity constraints by borrowing seem to smoothen food consumption and are less likely to be food-insecure, implying that they can mitigate the risk of becoming food-insecure (58, 60–63).

Households that were already food-insecure before the pandemic experienced higher levels of food insecurity on a relative scale. The findings of Gaintan-Rossi et al. (64) support our finding that economic shocks more strongly affect households that were already vulnerable prior to the shock. Though households did use savings to cope with the exogenous shock of the pandemic, they probably did not have sufficiently large savings to sustain their food security for an extended period. Once the savings dried up, they were not in a position to access adequate food.

Our findings also show that there exists a relationship between low food security and households whose members are employed as casual workers (65). This link could be attributed to the implicit challenges present in the informal sector stemming from the absence of formal regulations. The multiple challenges faced by those employed in the informal sector are well-documented in the literature (66–69). The difficulties faced by a household in getting an assured employment that provides a sustained livelihood is one of the primary challenges in achieving food security in the urban areas. Food accessibility in urban areas is largely a result of food affordability (48).

Coping Strategies

The coping strategies observed by our study corroborate with patterns observed in other developing countries and Low and Middle Income Countries (LMICs). Households have used formal and informal borrowing as a strategy to meet immediate expenses (70–73). Lack of access to such a coping strategy is reported to increase the likelihood of a household being food-insecure (74, 75). Also, the fact that most of the households' food security has deteriorated implies that they also relied on and employed both food-based coping strategies of reducing the quantity and quality of food consumption and financial coping strategies to tackle the stress to their food security caused due to an income shock (76). Since a large portion of the total household income goes toward food purchase and consumption in urban areas, these findings are expected. The monthly percapita food consumption expenditure in the urban regions of the study location (Hyderabad district) as per the 68th national sample survey stood at INR 1196.78 which was higher than the state avaerage in 2011–12. The inflationary pressure as reflected by the CPI and food inflation during the lockdown and the subsequent months of phased withdrawl were high at 6.6 and 9.1%, respectively, in 2020–21 in the country which had a huge impact on affordability. The impacts of high food inflation on consumption during the period were reflected in the CCBCI as elucidated in the above section on economic impacts. Our results on increased prevalence of food insecurity in the post pandemic period resonates and corroborates with findings of Srivastava and Sivaramane (77) who estimate reduction in the overall food expenditure between 4.98 and 21.34% compared to the pre pandemic period.

CONCLUSIONS

The COVID-19 pandemic has negatively impacted food systems and food security in the Hyderabad region of India. The impact of the pandemic on the households has been heterogenous.Households have experienced both idiosyncratic and covariate shocks (78, 79). The findings of our study reflect the transitory nature of food security in the region as a result of the shock. Household food security dynamics are largely influenced by the sector in which the main earning member of a household is employed, income, and access to different coping mechanisms. The use of coping strategies seems to depend on their availability and accessibility to the household. Our results reaffirm the significance of employment oppurtunities and savings for the poor to circumvent unexpected shocks.Our study thus underscores the need for policy that promotes saving behavior among the poor in addition to ensuring them secure employment oppurtunities that provides stable income. These results confirm the importance of savings for poor households and underline the crucial role policies can play to support savings and ensure stable incomes through secure employment opportunities. Ex-ante or forward-looking risk and vulnerability analyses are essential for targeting and implementing risk

mitigation interventions. Since our study is based on cross-sectional data, the findings of the study are not generalizable to a wider context. We recommend such assessments in the future which will help improve the preparedness of society and communities to cope with such unprecedented situations through targeted efforts.

Limitations

Using remote/telephonic survey as a methodology for data collection during the pandemic period is not unproblematic. Even though these surveys are cost effective compared to face to face interviews, the most important issue is the reduction in the response rate, i.e., the loss in the sample due to either telephone not working, change in the contact numbers given earlier, and repondents refusal to take the survey. Other issues with phone-based that were observed include infrastructural constraints in some settings (e.g., electricity and mobile connectivity issues), length of the interview and concerns around ensuring participant privacy. Thus, even though phone-based surveys are considered suitable in many settings, these limitations appear and have to be addressed.

Another limitation of the study is its inability to apply a gender lens to this understanding of food security during the pandemic. There were cases when women could not be contacted during our telephonic survey as many of them did not have access to a personal mobile phone, or their husbands were not interested in their wives participating in the telephonic survey. Further, women we contacted also said their care responsibilities had increased due to the pandemic and hence they were not available to participate in the survey. A gendered understanding would have brought out interesting insights on the differential impacts of the pandemic.

DATA AVAILABILITY STATEMENT

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

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by ICRISAT. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

RP: conceptualization, methodology, data curation, investigation, formal analysis, writing—original draft, and writing—review and editing. SN: conceptualization, methodology, writing—original draft, and writing—review and editing. PJ and KK: data curation, investigation, formal analysis, and writing—original draft. C-JL and AA: conceptualization, methodology, writing—review and editing, and funding acquisation. All authors contributed to the article and approved the submitted version.

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Detection of SARS-CoV-2 RNA in selected agricultural and food retail environments in Tehran, Iran

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The SARS-CoV-2 pandemic has and continues to impose a considerable public health burden. Although not likely foodborne, SARS-CoV-2 transmission has been well documented in agricultural and food retail environments in several countries, with transmission primarily thought to be worker-to-worker or through environmental high touch surfaces. However, the prevalence and degree to which SARS-CoV-2 contamination occurs in such settings in Iran has not been well documented. Furthermore, since SARS-CoV-2 has been observed to be shed in the feces of some infected individuals, wastewater has been utilized as a means of surveilling the occurrence of SARS-CoV-2 in some regions. This study aimed to investigate the presence of SARS-CoV-2 RNA along the food production and retail chain, from wastewater and irrigation water to vegetables in field and sold in retail. From September 2020 to January 2021, vegetables from different agricultural areas of Tehran province ($n = 35$), their irrigated agricultural water ($n = 8$), treated wastewater mixed into irrigated agricultural water ($n = 8$), and vegetables collected from markets in Tehran ($n = 72$) were tested for the presence of SARS-CoV-2 RNA. The vegetable samples were washed with TGBE buffer and concentrated with polyethylene glycol precipitation, while water samples were concentrated by an adsorption-elution method using an electronegative filter. RT-qPCR targeting the SARS-CoV-2 N and RdRp genes was then conducted. SARS-CoV-2 RNA was detected in 51/123 (41.5%) of the samples overall. The presence of SARS-CoV-2 RNA in treated wastewater, irrigation water, field vegetables, and market produce were 75, 37.5, 42.85, and 37.5%, respectively. These results indicate that SARS-CoV-2 RNA is present in food retail and may also suggest that produce can additionally be contaminated with SARS-CoV-2 RNA by agricultural water. This study demonstrates that SARS-CoV-2 RNA was detected in waste and irrigation

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water, as well as on produce both in field and at retail. However, more evidence is needed to understand if contaminated irrigation water causes SARS-CoV-2 RNA contamination of produce, and if there is a significant public health risk in consuming this produce.

KEYWORDS

SARS-CoV-2, vegetables, irrigation water, wastewater, food-safety, Iran

Introduction

The coronavirus disease 2019 (COVID-19) pandemic began in Wuhan in December 2019 (1). According to the World Health Organization, over 527,806,881 infected individuals and 6,300,785 deaths have been reported. The first confirmed COVID-19 case in Iran was reported on 19 February 2020, and subsequently has spread rapidly in the Iranian population (2).

Transmission of SARS-CoV-2 is primarily thought to occur directly from person to person via respiratory droplets, as well as indirectly through contact with contaminated surfaces (3, 4). Although fecal-oral transmission of SARS-CoV-2 is unlikely to be a major route of transmission, replication in intestinal epithelial cells has been observed (5), with both viral RNA and infectious virus being isolated from patients' feces on the other hand, fecal-oral transmission in other coronaviruses such as SARS-CoV-1 and MERS-CoV is a secondary route of disease transmission, although this transmission has not been proven in SARS-CoV-2 and in it is ambiguity (4, 6–8). Recent studies have shown that SARS-CoV-2 RNA can be detected from the feces and urine of some patients (9–16). Given this, the presence of SARS-CoV-2 RNA in hospital and municipal wastewater has been used as a means of tracking SARS-CoV-2 occurrence in different regions (17–24). SARS-CoV-2 RNA has also been detected in surface waters contaminated by treated or untreated wastewater (25–27).

Further, the presence of the virus in different communities has been studied by examining raw and treated wastewater, which shows the presence of the virus regardless of the severity of the disease, whether it is symptomatic or not. These studies, known as Wastewater-Based Epidemiology (WBE) studies, were well received after the identification of the virus genome in sewage (28–30). Other studies have also shown the presence of the virus RNA in surface water (25, 27, 31–33) and even in groundwater (33). Thus, contamination of surface and ground water used for irrigation by untreated or treated wastewater presents the possibility that viral contamination of agricultural products could occur. Alternatively, agricultural products that involve a high degree of handling by humans could alternatively be contaminated with SARS-CoV-2 via direct contact or by respiratory droplets at various points during the farm-to-table cycle (33) (Figure 1).

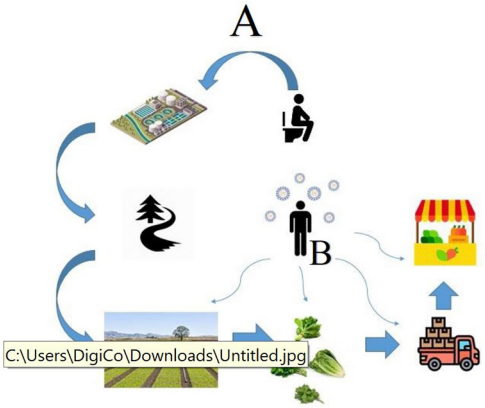

FIGURE 1
The possible routes of transmission of the SARS-CoV-2 RNA from an infected person to agricultural products. Route A indicates the possible way of contamination in the pre-harvest stages. Route B indicates the possible ways of contamination by food handlers in the post-harvest stages.

Although fecal-oral transmission of SARS-CoV-2 is not likely, understanding its presence in agricultural water and agricultural products can provide insight into the relative prevalence of SARS-CoV-2 in different communities and food production and retail environments, where SARS-CoV-2 transmission has been noted to occur (34). The potential for contamination of agricultural products by irrigated water that has been contaminated by wastewater exists.

Tehran, is the largest and most populous city in Iran as well as its capital. It is located at the foot of the Alborz Mountains and has a semi-arid climate. Most agricultural production occurs in the south of the city, a region which contains vast agricultural plains near rivers and wells that are used to irrigate these plains. In some cases, irrigation with treated wastewater has been reported. The presence of SARS-CoV-2 RNA in agricultural environments in Iran has not been well characterized, and the purpose of this study

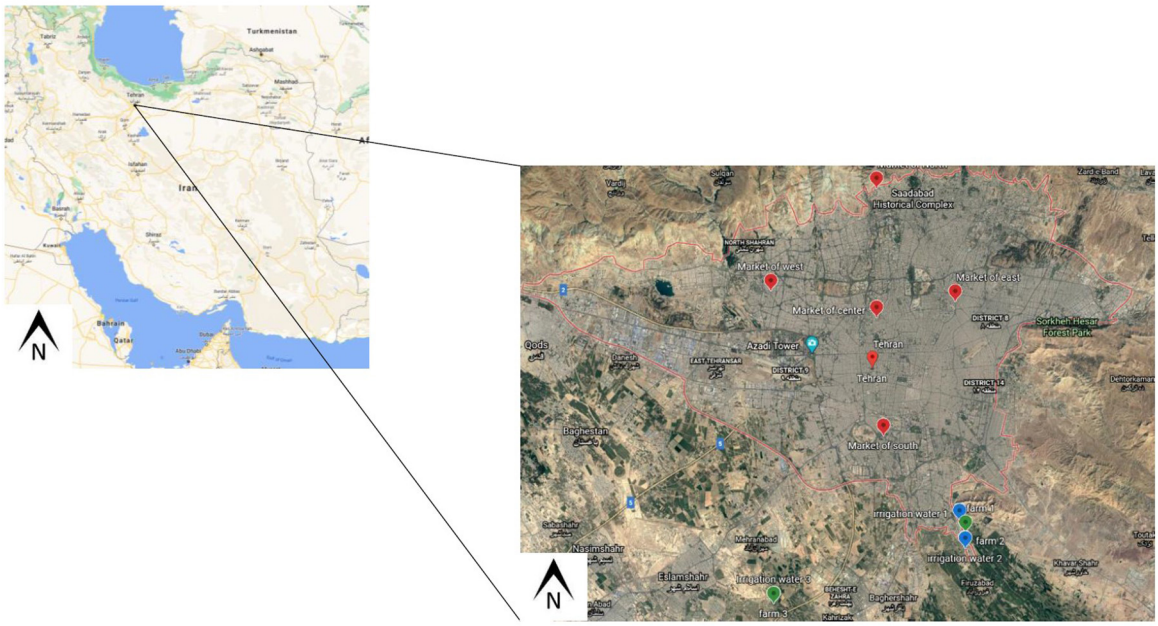

FIGURE 2
Maps of Tehran, Iran showing the locations where the samples were collected (Locations of fruit and vegetable centers, fields and irrigation water are shown in red, green, and blue, respectively).

was to attempt to better understand the presence of SARS-CoV-2 RNA in select agricultural production environments, markets, and produce in Tehran. It should be noted that due to resource limitations, the presence of infectious SARS-CoV-2 was not investigated, and detection of viral RNA does not directly mean that infectious virus was present in the tested samples.

Materials and methods

Background and study design

The study is designed to investigate the presence of SARS-CoV-2 RNA in treated wastewater, irrigation water, vegetables on farms, and vegetables in markets. Two wastewater treatment plants (WWTPs) in Tehran, three farms in the south of Tehran, and five fruit and vegetable markets were selected for sampling (Figure 2). Farms were selected based on their irrigation water source that was likely to be contaminated via wastewater, and their distance from WWTPs. The size of the farm and the variety of products that were also considered, with similar sizes and products farms selected. Also, regarding fruit and vegetable centers, their geographical location and their size and population have been among the factors involved in their selection.

Fruit and vegetable markets are the primary means that vegetables are purchased in Tehran, with these markets being primarily supplied by farms located in three southern regions of Tehran (Varamin, Kahrizak, and Shahr-e-Rey). Farmers in these areas utilize water from wells, rivers, and urban water canals for irrigation. These water sources have the potential to be contaminated with pathogens by several sources; with treated or untreated wastewater being a prominent example (Figure 2).

Sampling

From September 2020 to January 2021, 123 samples were collected from in Tehran, Iran. Leafy green samples (n = 72) were collected from five fruit and vegetable markets in Tehran, which were geographically divided into five regions (north, south, east, west, and center). In addition, 35 samples were purchased from farms in three important agricultural areas located in the south of Tehran (Varamin, Kahrizak, and Shahr-e-Rey). Furthermore, eight irrigation water samples were collected from a water canal used as an agricultural water supply. Eight treated wastewater samples were taken from a WWTP close to the farms and agricultural water supply (Table 1). All samples, including vegetables (Basil, spinach, cress, lettuce and parsley), irrigation water, and wastewater samples, were stored at in sterile boxes at 4°C, and the viral concentration process was performed within 24 h.

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TABLE 1 Distribution of different samples by month and site of sampling.

Month		2020									2021				Total
		September			October			November			December		January		
Sample		Farm	Market	Total	Farm	Market	Total	Farm	Market	Total	Farm	Market	Total	Farm	Market	Total	
Wastewater		-	-	2	-	-	0	-	-	2	-	-	2	-	-	2	8
Irrigation water		-	-	2	-	-	2	-	-	2	-	-	1	-	-	1	8
Vegetable	Lettuce	1	3	4	1	2	3	1	4	5	2	4	6	0	4	4	22
	Parsley	2	4	6	2	3	5	2	1	3	2	3	5	1	4	5	24
	Cress	1	2	3	2	2	4	2	5	7	2	3	5	1	1	2	21
	Basil	3	4	7	3	3	6	0	0	0	0	0	0	0	0	0	13
	Spinach	0	1	1	1	5	6	3	5	8	2	5	7	1	4	5	27
Total		7	14	25	9	15	26	8	15	27	8	15	26	3	13	19	123

Process control virus

The Massachusetts H120 vaccine strain of infectious poultry bronchitis virus was used to evaluate and optimize the concentration method used to isolate SARS-CoV-2 from the agricultural and produce samples. It is a member of the *Coronaviridae* family which is very similar in morphology to SARS-CoV-2. To determine the percentage of virus recovery and validate the concentration method used in this study, 1.5×10^6 $TCID_{50}$ (Median Tissue Culture Infectious Dose) and 1.5×10^5 $TCID_{50}$ of virus were inoculated onto 25 g of lettuce in duplicate. The inoculation process was performed with 50 µl of virus solution, at 10 points with each drop being 5 µl on the surface of lettuce leaves. Virus suspension was then air-dried in a laminar flow hood for 3 h prior to concentration (below). Similarly, 1.5×10^5 TCID50 of the virus was inoculated into 0.5–2 L of agricultural water, then concentration performed.

Virus concentration

Twenty-five grams of inoculated leafy green samples were cut into 2.5×2.5 cm^2 pieces and placed in a sterile plastic bag. Then, 40 ml of TGBE buffer (100 mM Tris-HCL, 50 mM glycine, 3% beef extract, pH 9.5) was added and the bag was subjected to gentle shaking for 20 min at room temperature. The mixture was passed through a filter (Whatman Grade 41, Fast Ashless filter paper, 150 mm circle, 1441–150) to remove debris particles. All samples were carried out in duplicate. The resulting filtrate was transferred to a centrifuge tube and centrifuged for 30 min at 11,000 × *g* at 4°C. The supernatant was then transferred to a new centrifuge tube to concentrate the eluted viruses with polyethylene glycol (PEG) 6000. PEG precipitation was done by overnight incubation with rocking at 120 rpm at 4°C in the presence of 10% (wt/vol) polyethylene glycol (PEG) 6000 (Sigma-Aldrich, St. Louis, MO) and 0.3 M NaCl at pH 7.2 ± 0.2. After centrifugation at 11,000 × *g* for 30 min at 4°C, pellets were suspended in 200 µL of PBS (pH 7.4) for RNA extraction and stored at −20°C until use (35).

Virus concentration from wastewater and irrigation water samples was performed in a two-step process; electronegative filtration (36) followed by further concentration using polyethylene glycol precipitation (37). In brief, $MgCl_2$ was added to the samples to reach a final concentration of 25 mM. Then, 2–3 L irrigation water or about 0.5 L wastewater was filtered using a six-branch filtration system (Sartorious, Goettingen, Germany) with 47 mm nitrocellulose filters with a 0.45 µm pore size (Sartorious). Nitrocellulose filters were then washed with 200 ml of 0.5 mM H_2SO_4, and 20 ml of 0.1 mM NaOH to elute the virus from the filter surface and transferred to a solution of 100 µl Tris-EDTA and 50 µl of 100 mM H_2SO_4. Afterward, 12.5% PEG 6000 (Sigma-Aldrich, St. Louis, MO) and 2.5% NaCl was used for the second concentration step.

At this stage, the samples were placed on the mixer overnight at a temperature of 4°C. The samples were then centrifuged at 11,000 × *g* for 30 min at 4°C. At the end of this step, the supernatant was discarded and precipitate dissolved in 200 µl of PBS. Samples were stored at −20 °C until use.

RNA extraction

Viral RNA was extracted using the QIAamp RNA mini kit (Qiagen, Germany) using 140 µl of the dissolved pellet suspension above, with 60 µl used for final elution and suspension of RNA per kit protocol. The extracted RNA was stored at −70 °C until use.

RT-qPCR

To detect the presence of SARS-CoV-2 RNA, a commercial COVID-19 One-Step RT-PCR kit (Pishtaz Teb Diagnostics, Iran) was used containing oligonucleotide primers and probes designed targeting the RdRp and the N regions of the SARS-CoV-2 genome. Furthermore, a primer-probe set targeting human RNase P on a separate channel was used as an internal control. The reaction mix (20µl) consisted of 9 µl resuspended master mix [COVID-19 enzyme mix and RT-qPCR buffer (5x)], and 1µl COVID-19 primer-probe mixture, per kit instructions. Thermal cycling conditions included reverse transcription at 50°C for 15 min, preheating at 95°C for 3 min and 45 cycles of 95°C for 15s and 55°C for 40s, using a Rotor-Gene Q MDx thermal cycler (QIAGEN Hilden, 212 Germany). This Commercial Pishtaz Teb Diagnostics kit is an IVD-approved medical diagnostic kit capable of detecting at least 200 copies/ml of the SARS-CoV-2 genome.

To confirm the detection of SARS-CoV-2 RNA in presumptive positive samples, RT-PCR targeting the ORF-1ab region was also conducted. This amplification was performed using a forward primer (5-TATTATGATTCAATGAGTTATG-3) and reverse primer (5'- GTACTACAGATAGAGACACCAG-3'). Amplified products were electrophoresed on 1.5% agarose gel to visualize DNA bands with expected an product size of 152 bp.

In addition, one PCR product of a positive sample was purified using QIAquick PCR purification kit (Qiagen) and subsequently sequenced using Sanger sequencing in a bi-directional manner with the ABI 3500 automated sequencer from Applied Biosystems (provided by the Genomine Biotech Company, Tehran, Iran). Sequencing results were analyzed using BLAST search with NCBI BLASTN (https://blast.ncbi.nlm.nih.gov).

For control samples, IBV RNA was first converted to cDNA by a high capacity cDNA Reverse Transcription Kit (Thermo Fisher Scientific, USA). A SYBR green qPCR assay containing 12.5 µl of realQ plus 2x master mix green (Ampliqon, Denmark), 5 pmol of forward primer, 5 pmol of reverse primer and 6.5 µl of RNase free water was then used to detect the cDNA. Thermal cycling included preheating at 95 °C for 15 min, and 45 amplification cycles at 95°C for 15 s, 56 °C for 30 s, and 72°C for 30 s (Table 2).

IBV RNA was quantified by plotting cycle threshold (CT) to standard curves produced by serial dilution method with RNA extracted from the Massachusetts H120 vaccine strain. The standard curve showed a linear dynamic range from 10^2 to 10^6 copies for IBV ($y = -3.710x + 41.110$, $R^2 = 0.99$).

Quality control

On a regular basis in each sampling period, 2 samples were spiked with 1.5×10^6 $TCID_{50}$ IBV as a positive control sample and one sample which was thoroughly washed and exposed to ultraviolet light for 20 min as a negative control sample to ensure the absence of false-positive (possible cross-contamination) and false negative (possible recovery failure) results. Further, a positive sample and negative sample were tested for quality control along with all water samples in each sampling period. Both RT-qPCR assays included negative (nuclease-free water) and positive amplification controls (For IBV, RNA extracted from the Massachusetts H120 vaccine strain was used, and for SARS-CoV-2, a plasmid designed by the SARS-CoV-2 RT-qPCR kit (Pishtaz Teb Diagnostics, Iran) with target RNA fragments, RdRp and N, were used as a positive control).

Results

The method of detecting SARS-CoV-2 RNA from the vegetable samples as well as concentrating samples of irrigation water and wastewater treated by IBV inoculation was tested. On average, IBV recovery in vegetable samples was calculated to be about 22.4 ± 9% for direct samples and 16.8 ± 3% for 10-fold dilutions. Furthermore, in the samples of irrigated water and treated wastewater, 21.1 ± 3.2% and 11.8 ± 1.8% recovery were observed, respectively.

From September 2020 to January 2021, 123 samples from 2 WWTPs, 3 irrigation sites, and 3 farms, and 5 fruit and vegetable markets in Tehran were tested twice for the presence of SARS-CoV-2 RNA. Samples were considered positive if at least one target gene in one of the duplicate samples had a CT below 40. SARS-CoV-2 RNA was detected in 51 of the 123 (41.5%) samples, overall. SARS-CoV-2 RNA was detected in 75% (6/8), 37.5% (3/8), and 39.25% (42/107) of treated wastewater, irrigation water, and vegetable samples, respectively. Leafy greens purchased from the farms and markets were positive for SARS-CoV-2 RNA in 42.85% (15/35) and 37.5% (27/72) of samples, respectively (Figures 3, 4). In all duplicate

TABLE 2 Primers of PCR assay used in this study.

Assay	Target		Primer sequence
RT-qPCR SYBR Green	IBV	F	5- GCACAAGGTCGGCTATACG—3
		R	5- GCCATGTTGTCACTGTCTATTG—3
RT-PCR	SARS-CoV-2 (ORF-1ab)	F	5-TATTATGATTCAATGAGTTATG-3
		R	5- GTACTACAGATAGAGACACCAG- 3

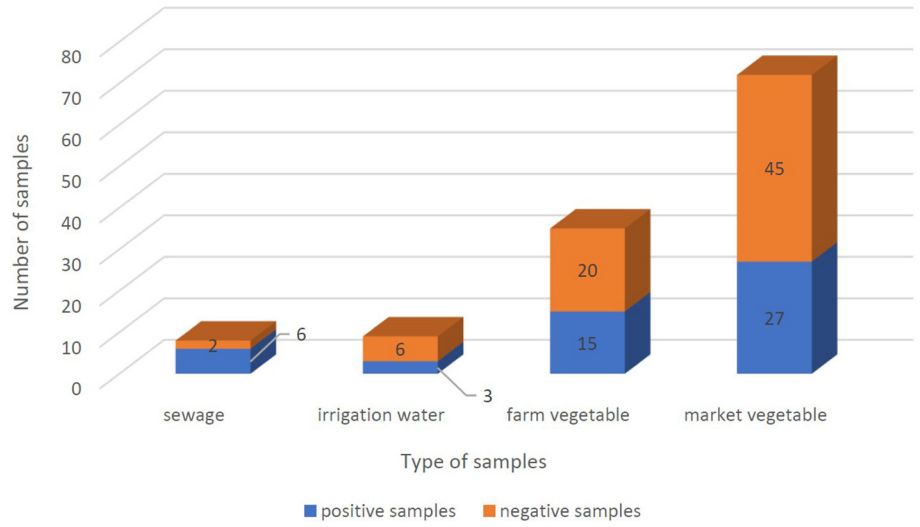

FIGURE 3
Positivity of SARS-CoV-2 RNA frequency in sewage, irrigation water, farm vegetables, and market vegetables samples. Positive samples and negative samples are shown in blue and orange, respectively. And the whole columns show the total number of samples.

samples, the RdRp gene was examined, and its CT ranged from 30.54 to 39.22. RdRp gene compared to the N gene, a better range of CT (29.5–36.59) was also observed compared to the N gene.

Discussion

This study evaluated the presence of SARS-CoV-2 RNA in agricultural and food samples in Iran, as markets and agricultural environments have been known to be sites of SARS-CoV-2 outbreaks. The results of this work suggest that SARS-CoV-2 RNA was present in a notable percentage of agricultural water and produce samples, as well as wastewater samples. These samples could have been contaminated at pre- or post-harvest stages. At the pre-harvest stage, the crops can be contaminated at different phases of growth by contaminated fertilizers, sewage, or irrigation water; however, the specific means by which contamination occurred was not determined in this work. One report suggests that treated wastewater caused SARS-CoV-2 contamination of irrigation water in the south of Tehran, and this is potentially an explanation for the observed contamination of irrigation water reported here, (37.5% of irrigation water samples contained SARS-CoV-2 RNA) but more work would need to be conducted to confirm this. In the post-harvest stage, person-to-person or food handler contamination in markets are could be sources of contamination, though the specific means of contamination of produce in the markets was not determined in this work. Infected food handlers can be important sources of transmitting the virus products at the time of harvesting, packaging, transmission, classification, and selling (38). Additionally, post-harvest contamination could occur through washing with contaminated water. SARS-CoV-2 RNA has been detected in municipal wastewater in several countries such as Australia, Japan, Italy, Spain, USA, Germany, and others, including Iran (17–23). Following these cases, a study was conducted in Iran on treated wastewater that suggested the effluent of treatment plants was discharged into surface water, contaminating it with SARS-CoV-2 RNA (24). Similar work in Italy (25) and Japan (26) failed to detect SARS-CoV-2 RNA in surface water, while it was observed in a study in Ecuador (27). Subsequently, a study in India reported the presence of SARS-CoV-2 RNA in 56% of river samples and 53% of lake samples. In Serbia, 50% of collected river samples were found to contain SARS-CoV-2 RNA. In a recent study in Nepal, 47 and

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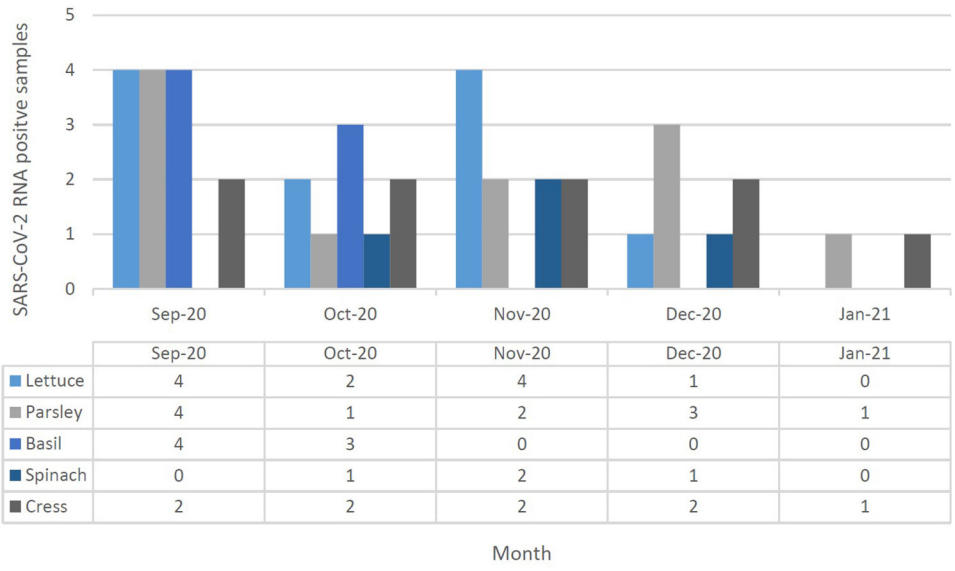

	Sep-20	Oct-20	Nov-20	Dec-20	Jan-21
Lettuce	4	2	4	1	0
Parsley	4	1	2	3	1
Basil	4	3	0	0	0
Spinach	0	1	2	1	0
Cress	2	2	2	2	1

FIGURE 4
SARS-CoV-2 RNA presence in leafy green vegetable (lettuce, parsley, basil, spinach, and cress) collected in September 2020 to January 2021 at Tehran, Iran. Different leafy green vegetables were shown in different color in each month, separately.

69% of treated wastewater and river water contained SARS-CoV-2 RNA, respectively. In the present study, SARS-CoV-2 RNA was found in 75 and 37.5% of treated wastewater and irrigation water, respectively. SARS-CoV-2 RNA can directly contaminate surface water by dumping of treated or incompletely treated wastewater, or in some cases, raw wastewater, and this water may have been used to irrigate Tehran vegetables; however, further confirmatory work to determine the specific routes of contamination is needed. To our knowledge, this is the first systematic investigation of the presence of SARS-CoV-2 RNA on vegetables and their irrigation water in Iran.

Our results demonstrate that the presence of SARS-CoV-2 RNA in Tehran is not limited to surface water, as SARS-CoV-2 RNA was also detected in vegetables on farms and in markets; suggesting that SARS-CoV-2 RNA is prevalent in agricultural production environments, produce, and in markets in Tehran. Two agricultural areas in the south of Tehran were studied, in one (Varamin and Shahr-e-rey area) the field was irrigated with surface water, while the other one (Kahrizak area) was irrigated with well water. Water samples taken from these two areas show surface water pollution as opposed to well water, as we failed to detect SARS-CoV-2 RNA in the well water source tested as well as the vegetables on which it was applied. However, SARS-CoV-2 RNA was detected in the surface waters of Rey city, and like their water, 63.15% of the vegetables tested were observed to contain SARS-CoV-2 RNA.

In fruit and vegetable markets, the different levels of contamination were observed. These markets were in different parts of Tehran, and differed in client volume, the volume of products offered, and the number of employees; all of which have potential to influence the level of contamination observed. For example, the southern fruit and vegetable markets are one of the largest fruit and vegetable centers in Tehran, with a larger number of customers and staff, as well as a high range of products, which in turn can cause less observance of personal and social hygiene. As expected, the amount of vegetable contamination seen in these markets was higher than the others, suggesting such contamination may be an indicator of more widespread infection in the markets (Table 3). On the other hand, the results show that the presence of SARS-CoV-2 RNA in the studied vegetables seems to be different, which requires further investigation in the future (Table 4). This study is the first to indicate contamination of vegetables with SARS-CoV-2 RNA in Iran. Based on results, there is a good amount of value in understanding the presence of SARS-CoV-2 in agricultural production and retail environments, and that irrigation water might be one route through which SARS-CoV-2 can be introduced into these environments. This is particularly relevant to agricultural workers, as the irrigation water itself may be aerosolized in its application/handling, and the produce may also have potential to serve as fomites to agricultural and retail workers who handle the produce. The hypothesis that food packages can become contaminated with SARS-CoV-2 and thus cause fomite transmission of SARS-CoV-2 in humans was suggested by Liu et al. (39) on frozen Cod fish packages. However, more research is needed to determine the relative risk

TABLE 3 Geographical prevalence of SARS-CoV-2 RNA in fresh produce from food and vegetable center of Tehran.

Site No.	Food and vegetable center	Geographical location	Positivity of SARS-CoV-2 RNA
1	Velenjak	North	6
2	Sayad Shirazi	East	5
3	Jalal Alahmad	Center	3
4	Jannat Abad	West	4
5	Bahman	South	10

TABLE 4 Prevalence of SARS-CoV-2 RNA in different type of vegetable samples that was selected from farms and markets.

Type of sample	Farm		Market		Total	
	No. of samples	No. of positivity	No. of samples	No. of positivity	No. of samples	No. of positivity
Lettuce	5	2	17	10	22	12
Parsley	9	5	15	6	24	11
Cress	8	4	13	5	21	9
Basil	6	3	7	4	13	7
Spinach	7	1	20	3	27	4

such presence of SARS-CoV-2 in these environments poses to agricultural and retail workers.

Further, it should be noted that all of the data reported here involves detection of SARS-CoV-2 RNA, and not infectious virus. This is an important distinction, as viral RNA can persist in the environment notably longer than infectious virus. Future work is needed to elucidate the degree to which infectious SARS-CoV-2 occurs in these agricultural and retail settings in Iran; and this would be crucial to better gauge the degree to which the presence of SARS-CoV-2 in these environments poses a threat to public health.

In addition to the fact that only viral RNA was detected and not infectious virus, there were a number of other limitations in this study. (1) The number of farms was limited due to a lack of broader cooperation among farm owners. (2) Vegetables were not available in all sampling months due to their seasonal cultivation, and the potential influence of seasonality could confound results. (3) Specifically, only farms that utilize irrigation water were tested and not farms that did not utilize irrigation water. The degree to which SARS-CoV-2 RNA occurs in those types of farms should be determined in subsequent work. (4) Specific lockdown and other public health measures also limited the degree to which sampling could occur.

Conclusion

In summary, this is the first study to report the presence of SARS-CoV-2 RNA in irrigation water samples and on vegetable surfaces in Iran. From 123 samples, SARS-CoV-2 RNA was detected in 51 of them. Among the 42 positive vegetable samples, 35.7% and 64.3% were tested in farms and markets, respectively. Although the specific routes of contamination of these samples was not determined, these results suggest a high prevalence of SARS-CoV-2 RNA in agricultural and retail settings in Tehran, and suggest that such prevalence can be observed across multiple ends of the produce production chain. However, more studies should be conducted in future to examine the degree to which infectious SARS-CoV-2 occurs in these settings, and if so, where significant points of contamination occur.

Data availability statement

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

Author contributions

MR: formal analysis, methodology, investigation, writing—original draft, and supervision. SM: conceptualization, formal analysis, methodology, validation, writing—review and editing, and project administration. SH: conceptualization and writing—review and editing. MT: formal analysis, methodology, software, investigation, and writing—original draft. MS and SK: investigation and formal analysis. HA: resources, writing—review and editing, and funding acquisition. MM: writing—review and editing. MZ: conceptualization, resources, writing—review and editing, and funding acquisition. All authors contributed to the article and approved the submitted version.

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Conflict of interest

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

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