



eISSN 2239-7132

Italian Journal of Food Safety

<https://www.pagepressjournals.org/index.php/ijfs/index>

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Ital J Food Saf 2026 [Online ahead of print]

Please cite this article as:

Abughoush M, Olaimat AN, Alholy MA, et al. **Assessing microbial safety and food safety knowledge and practices among representative fast-food restaurants in the United Arab Emirates during the COVID-19 pandemic.** *Ital J Food Saf* doi:10.4081/ijfs.2026.15643

Submitted: 09-05-2026

Accepted: 19-06-2026

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Assessing microbial safety and food safety knowledge and practices among representative fast-food restaurants in the United Arab Emirates during the COVID-19 pandemic

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Key words: fast foods, COVID-19, food safety, AL Ain City.

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Conflict of interest: the authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

Ethics approval and consent to participate: the Institutional Review Board (IRB) at Al Ain University authorized the study and procedure, including the consent form, in Reference number COP/AREC/AD/01.

Availability of data and materials: data from this study will be available upon request from the corresponding author.

Acknowledgments: the authors thank Al Ain University for their financial support of this research. With support from the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA), this research was made possible by vendors' readiness to participate, employees' assurances of collaboration, and sellers' relative ease of access.

Declaration of generative artificial intelligence and artificial intelligence-assisted technologies in the writing process: the authors declare that no generative artificial intelligence was used in preparing this manuscript.

Abstract

To date, no studies have examined the status of food safety knowledge and practices among representative fast-food restaurants and vendors in Abu Dhabi (Al Ain City). The primary objective of this study was to assess awareness of food safety practices and attitudes and to examine their effects on consumer health in representative fast-food restaurants. The research was conducted at 6 fast-food vendors across various locations in Al Ain City, Abu Dhabi. A desirable practice scored one, whereas an undesirable practice received no score, as determined by a standardized questionnaire applied to all food establishments. We used this scoring system to see how each operation's percentage score compared with the maximum possible score for that operation. To test for significant differences among the attributes analyzed across food outlets and suppliers, an analysis of variance was conducted (significance level: $p < 0.05$). The study demonstrated significant differences among various vendors regarding the production area (78-94%), production safety (61-100%), and physical facilities ranging between 38% and 88%. Product-related aspects range from 29% to 88%. Food handlers' and personal hygiene practices ranged from 47% to 83%. Finally, knowledge of food safety and equipment availability ranged from 50% to 78%. The total count did not exceed the standard values, and the TVC ranged from 2 to 4 log CFU/mL. The coliform count exceeded the standard levels in some places. The study's findings indicate inadequate hygiene practices among food workers in food-preparation areas. In conclusion, further efforts are necessary to ensure safe food handling and production. This research will contribute to the development of educational programs to enhance food safety.

Introduction

Foodborne pathogens are microorganisms capable of causing infectious diseases in both animals and humans through the ingestion of contaminated food or feed. In 2021, the World Health Organization (WHO) estimated that around 600 million cases of foodborne illnesses are documented annually, and it is estimated that 33 million people die annually worldwide due to the consumption of contaminated food (WHO, 2015a). Food poisoning may occur for several reasons, including improper holding temperatures, cross-contamination, inappropriate storage conditions, unreliable food sources, frequent food handling, poor personal hygiene, improper cleaning and disinfection, and unhealthy cooking methods (WHO, 2015b). Todd (2017) conducted safety-focused food studies in the Middle East, including the Gulf countries, and concluded that foodborne illnesses are present in street and restaurant food, as well as in food prepared at home. Food delivery and dining out have emerged as significant phenomena in recent years. Fast food restaurants and cafeterias offer diverse, fresh, and flavorful food items at competitive prices (Kashyap *et al.*, 2004; Gupta *et al.*, 2011). Taha *et al.* (2020) reported that food-related businesses provide culinary services to more than 3 million residents and tourists in the city of Dubai, underscoring the dire need for safe, wholesome conditions for food preparation and service. Liu and Lee (2018) noted that the cleanliness of the restaurant itself was a major indicator of food safety. Hence, sanitary and hygienic practices must be implemented throughout the whole food production and preparation process (Rf, 1992). Undoubtedly, food safety education for food handlers in restaurants and cafes is necessary to safeguard the public and tourists and to improve public health (Todd, 2017). One way for enhancing food safety is by reaching out to food businesses and offering educational opportunities, such as a periodical meeting, or an event of some sort, such as the International Annual Food Safety Conference held in Dubai, which started in 2006, to enhance food safety knowledge, improve food safety practices in culinary businesses and to promote a global partnership focused on reducing foodborne disease prevalence on a mega scale (Dubai Municipality, 2006). In their 2018 article titled *Food Safety in the 21st Century*, Fung *et al.* (2018) stated that "food safety is a basic human right". Moreover, food safety is a scientific discipline and a critical factor that must be addressed throughout the food preparation process, including receiving raw materials, pre-processing, production, packing, and distributing food, to ensure food safety during the COVID-19 pandemic (NFI, 2003). The importance of a safe food supply arose as an exceptionally important concern during the COVID-19 pandemic (Rizou *et al.*, 2020). Lacombe *et al.* (2021) drew attention to the fact that individuals staffing food businesses are more prone to infection with SARS-CoV-2 (the virus responsible for COVID-

19) due to the long time they spend in crowded areas and in close proximity to other workers and food consumers. Such conditions facilitate the transmission of COVID-19 when infected individuals repeatedly touch their faces, mouths, noses, and eyes, and then touch food, food packaging, or food-contact surfaces. This can be attributed to the potential for COVID-19 contamination during food preparation, serving, and delivery to customers. Therefore, there is an immediate need to study food safety knowledge, attitudes, and practices (KAP) in the context of the COVID-19 pandemic. Several studies have shown that KAP has increased significantly during this public health emergency, but employees' unsafe practices may increase the risk of disease transmission (Hatabu *et al.*, 2020; Larisa *et al.*, 2020; Luo *et al.*, 2021; Ranaei *et al.*, 2020; Omar, 2020). Ensuring food safety for consumers during that period posed a significant challenge across various food establishments, particularly in fast-food restaurants.

To our knowledge, this is the first study of its sort to investigate COVID-19 pandemic food safety, quality, and acceptability practices across different fast-food establishments and traditional eateries in the United Arab Emirates (UAE). Some previous studies addressed food safety knowledge and practices in the UAR. However, this research differs from other studies in several respects. The sample size, the targeted population, and the procedures used to collect data, to name a few, are all different. For example, Al Daour *et al.* (2022) conducted a study in the UAE during the COVID-19 pandemic focusing on pregnant women's knowledge of food safety. Osaili *et al.* (2022) also conducted a study of 231 workers in the UAE who aid families in preparing food to examine the association between their food safety knowledge and age, education level, marital status, and nationality. Ababneh *et al.* (2022) studied the intentions and customer satisfaction of undergraduate students in fast-food restaurants in the UAE during COVID-19. Mostafa *et al.* (2024) addressed differences in the sample and study conditions, assessing food safety risks only for homemade ready-to-eat foods that consumers could buy online in the UAE. In addition, a previous study (Ebrahim, 2020) addressed restaurant workers in the UAE restaurants to examine the impact of food safety training on the adoption of good hygienic practices, though not during the pandemic. Additionally, none of the previous studies measured the exact practical impact of spreading knowledge and awareness among workers in food restaurants on the safety and quality of prepared foods. Meanwhile, the current study not only surveyed the safety and hygiene practices among food workers in representative food establishments in the UAE but also measured total and coliform counts (CC) on surfaces across different vendors in UAE restaurants during the COVID-19 pandemic. Therefore, this study primarily aims to critically assess the quality, safety, and acceptability of food items made and distributed by representative fast-food vendors during the COVID-19 pandemic. A secondary objective is to provide a comprehensive profile of food handlers, food materials, hygiene standards, surface sanitation, and food safety knowledge, and the safety protocols adhered to during food production, packaging, and distribution related to diverse delicacies offered by the six most famous fast-food vendors across various locations in Al Ain City, Abu Dhabi, UAE. In addition, total and CC were assessed at several locations within each vendor as a further indicator of the safety of food preparation techniques.

Materials and Methods

The technique

Six large fast-food chains that were selected in three locations in Al Ain City, Abu Dhabi, UAE, were the subjects of the research during 2021-2022. The six representative restaurants were chosen due to their regional popularity and usually have a lot of tourist visits, which makes them representative of the city's fast-food sector. In addition, the study emphasized depth rather than breadth, employing microbiological swabbing, staff surveys, and observational audits at each site to identify critical pandemic risks. Besides, limited the large-scale random sampling due to the COVID-19 pandemic, lockdowns, restaurant closures, personnel shortages, and safety precautions. The Institutional Review Board (IRB) at Al Ain University authorized the study and procedure, including the consent form, Reference number COP/AREC/AD/01. The consent form was informed, written, and discussed verbally with the participants, and the results were documented. Catering operations and food material handling practices were evaluated

and recorded with the aid of a questionnaire interview schedule. The questionnaire was in English, although Arabic is the official language of the UAE, but English is the main language in business, tourism, and education. The following aspects of the layout were documented: methods for acquiring and getting raw materials; methods for storing raw materials under various conditions; methods for preparing vegetables (soaking, washing, thawing), the cooking process, grilling, salad making, providing and keeping while serving; methods for cleaning machinery and utensils; and methods for managing leftovers. Hygiene practices (such as handwashing and glove use) and individual experiences were also documented. Using a thermometer, the temperature was tracked throughout the whole process, from pre-production to manufacture and storage. Using the same questionnaire for all restaurants, we assigned a score of 1 to the most acceptable practice and 0 to the most undesirable, as shown in the *Supplementary S1 Appendix*. The questionnaire was developed from a previously published food safety questionnaire and adapted to the objectives of our study. The questionnaire was adapted by a panel of food safety experts to assess its relevance, clarity, and comprehensiveness.

The six distinct fast-food sellers had their average scores and standard deviations computed for each assessed step. This was compared with the maximum score obtainable for that relevant operation, and the percentage score was calculated for each operation. Each food seller and each food handler was required to complete an observation checklist that had been pre-tested in order to document their personal hygiene procedures.

As a whole, all of the following were assessed (per *Supplementary S1 Appendix*): Following standard procedures, swabs were taken from various locations within vendors to determine the total microbial count and the CC. The evaluations included raw food product quality, manufacturing facility, physical facility, product storage, packaging, food handlers' personal hygiene practices, food safety knowledge, and equipment availability. In *Supplementary S1 Appendix*, you may find more information.

Microbial counts methods

The microbiological count technique for total viable count and coliform testing includes sample collection and laboratory analysis. Microbial random samples from different locations on surfaces where food is prepared and served, including the workbench, cutting board, and refrigerator, were obtained using a sterile swab moistened with buffered peptone water. Three replications with three observations from each location. Food samples were also measured. Accurate sample labeling was conducted for identification and monitoring. The samples were thereafter transported at 4 °C and examined within 24 h of collection.

Total viable count (TVC)

A series of dilutions of the swab samples with sterile diluents were conducted to get a countable number of colonies on the culture medium. Under aseptic conditions, 0.1 mL of each diluent was placed onto Plate Count Agar. The plates were incubated at 37°C for 24 to 48 h to facilitate microbial growth. Plates exhibiting 30-300 visible colonies were enumerated using the appropriate dilution factor.

Coliform count

The Membrane Filter technique and the Most Probable Number (MPN) were used for enumeration.

I. The MPN approach included preparing a series of tubes with lactose broth and varying the dilution of the swab sample. After that, the tubes were incubated for 24 to 48 h at 37 °C in order to produce gas. The presence of coliform is confirmed by the gas bubble in the lactose broth's inverted Durham's Tubes.

II. Membrane Filtration Method: To capture coliform bacteria, swab samples are passed through a membrane filter. After that, the membrane filters were moved to the Eosin Methylene Blue Agar medium, which enables the selective growth and identification of coliforms. Colonies were counted after agar plates were cultured for 24 to 48 hours at 37°C.

Statistical analysis

The data were subjected to an Analysis of Variance (ANOVA) using the Statistical Analysis System (SAS) software (2003). This was done to investigate whether there were any significant differences in all assessed features among the food sellers included in the study. All of the RCD's specifications were met. For the purpose of mean separation, the LSD test was used. $P \leq 0.05$ was used to determine the significance of the findings.

Results and Discussion

Assessment of a variety of food products at each vendor's food service location

Figure 1 illustrates the evaluation scores of various food products across Al Ain City locations. The oil products received the highest evaluation percentage, at 94%, indicating a significant difference ($p \leq 0.05$) compared with the other evaluations. In contrast, the evaluation for meat and meat products was the lowest at 78%, with significance at $p \leq 0.05$. The evaluation encompasses several parameters: meat temperatures ranging from 4 to 6°C, package cleanliness, the expiration date, and sensory properties. This result is essential for assessing the quality and safety of meat products, as numerous health concerns are associated with the consumption of meat and meat products. Furthermore, there were no significant variances at $P \leq 0.05$ among various food-serving vendors across diverse locations in the safety assessment scores of these foods. Insignificant differences were observed in the evaluation scores among dry products, milk and milk products, as well as fruits and vegetables, as illustrated in Figure 1. This result is essential for assessing the quality and safety of these products, as many pathogenic microbes can be transmitted through the consumption of contaminated milk and milk products. Abughoush *et al.* (2023) conducted a study during COVID-19 on food handlers at Jordanian fast-food restaurants at universities and concluded that the quality of milk and milk products, along with oil products, received the lowest scores compared to meat and meat products. Leading us to a conclusion that during COVID, compared to Jordanian fast-food restaurants, restaurants in the UAE dealt with oil, fruit and vegetables, and milk and milk products more cautiously compared to meat and meat products. This results in lower quality and lower food safety for meat and meat products in the United Arab Emirates. The results serve as strong indicators of the benefits associated with conducting this study during such a pandemic, and in case of any future crises. Training sessions and detailed guidelines should be provided to UAE employees in various food vendors regarding the safety and quality of food intended for direct consumption or for use in production and preparation, particularly the meat and meat products.

Assessment ratings of diverse manufacturing places (space and cleanliness) in several vendors to produce healthy food products

Insignificant differences were observed in the evaluation scores, represented as average ratios, for the ventilation and cleanliness of various locations utilized in food manufacturing, as illustrated in Figure 2. The lowest percentages of evaluation scores were recorded for the production space, and production was conducted under safe conditions. The evaluation of the preproduction step conditions necessary for safe food production was rated 100%. This includes cleaning and sanitizing raw materials, covering them, and ensuring the environment is free of objectionable odors. The evaluation percentage of the production area is 66%, encompassing production surface cleanliness, product covering, and temperature control. Furthermore, there were no significant variances at $p \leq 0.05$ among various food-serving vendors across several locations regarding space and cleanliness. The results suggest that further efforts are necessary to enhance the efficiency of safe food production. The production step requires modification and monitoring. According to Olaimat *et al.* (2022), microorganisms, including viruses, can be transmitted across the food chain from production to consumption. Hence, it was crucial to ensure safe food production during the COVID-19 pandemic.

Assessment ratings of various physical amenities, water accessibility, and waste management systems

Figure 3 shows that the ratios for water availability, physical facilities, and waste management are 88%, 38%, and 69%, respectively, with significant differences among these factors at $P \leq 0.05$. The primary issues stem from severely limited physical facilities, including inadequate lighting and ventilation, insufficient sinks and water supply, and a lack of clean equipment across vendors. Ahuja (2017) states that a good design of any restaurant or eating establishment is crucial to ensuring food safety, including lighting and facilities such as water and electricity. To reduce the risk of exposure and transmission of COVID-19 among restaurants' workers as well as customers, Guy *et al.* (2021) proposed ensuring sufficient air ventilation and cleaning. Additionally, inefficient waste management processes contribute to safety concerns. The results indicate that further efforts are necessary to enhance the safe food production process. Furthermore, there were no significant differences at $p \leq 0.05$ among food-serving locations across vendors in water availability, physical facilities, and waste management.

Effective waste management is a critical issue that must be regulated to ensure the production of safe food. Waste management encompasses various elements, including the availability of trash baskets with lids, self-closing garbage bins, disposable bags, and numerous other factors outlined in Supplementary S1 Appendix 1. Figure 3 illustrates that waste management received a medium score percentage of 69%, whereas physical facilities were rated the lowest at 38% among all evaluated vendors. The accessibility of source water and the type of water used by food vendors received the highest percentage scores among the factors, indicating a significant difference at $p \leq 0.05$. This is one of the primary factors influencing the safety of the vendors and their food products.

Assessment metrics for product storage and packaging, product evaluation, and distribution in regulated environments

As shown in Figure 4, delivery and serving of food after production received an evaluation score of 88%, while the product storage conditions and packaging received an evaluation score of 80%. The product evaluation scores were 29% for chemical, microbiological, and sensory aspects. Additionally, in controlled settings, there were small differences ($p < 0.05$) in product assessment and delivery among different vendors across different food service facilities.

Product assessment received the lowest percentage value, 32%, indicating a significant difference from the other criteria ($p \leq 0.05$). As a step, product assessment is crucial in assessing the quality and safety of food items. None of the food manufacturing vendors examined conducted chemical or microbiological evaluations of their goods before serving, except for sensory assessment. Some businesses conduct a specific kind of sensory examination. This process requires enhancement among food production vendors via collaboration with ADAFSA (Abu Dhabi Agriculture and Food Safety Authority) and the food analysis laboratories at Al Ain University.

Personal hygiene practices and food keepers' evaluation ratings

Figure 5 illustrates the proportion of scores for various factors: personal appearance at 79%, unwanted activity through work at 74%, hygienic performance at 47%, and toilet situations at 83%. Furthermore, the differences observed at $p \leq 0.05$ among various food-serving vendors regarding food handlers' and personal hygiene practices were negligible.

The lowest percentage score was recorded for the hygienic practices observed among these vendors, indicating a significant difference compared with other factors at $p \leq 0.05$. The values are crucial for understanding the hygienic practices employed by workers, which directly influence the food safety levels consumers experience. Employees who do not adhere to hygienic practices in food can transmit various pathogenic microorganisms to food. It is essential to educate employees on these practices. The results indicate that employees require additional information and knowledge about hygienic practices, including personal appearance, such as regular shaving, keeping nails short, wearing clean uniforms, and using gloves during service (*Supplementary S1 Appendix*). Additionally, certain inappropriate practices were observed

among employees during food handling and serving, including blowing their noses, combing their hair, coughing, sneezing, and cleaning their ears (*Supplementary S1 Appendix*).

Additionally, various employee activities were monitored during the evaluation, including restroom visits, cash handling, cleaning without adequate handwashing with soap, and smoking. These activities increase the likelihood that pathogenic microorganisms will be transmitted to food. Olaimat *et al.* (2022) stated that although the coronavirus is not considered a foodborne virus, it can be transmitted through inadequate food-handling hygiene. Furthermore, the study revealed that the toilet situations were highly adequate, including the availability of sanitizers, soap, and dryers, among other amenities.

Evaluation grades for equipment availability and food safety knowledge

Figure 6 shows that, out of a possible 100 points, 50% have knowledge of food safety, and 78% have access to the necessary equipment. Furthermore, there were a few variations at $p < 0.05$ among various food-providing vendors for food safety expertise and equipment availability.

The vast majority of food manufacturing vendors lack food safety training programs, such as Hazard Analysis and Critical Control Points or Good Manufacturing Practices. There is a significant difference in food safety knowledge scores compared with other factors ($p < 0.05$). As a result, this score is extremely low. This result agrees with Osaili *et al.* (2022), who conducted a study on 231 UAE workers to study their food safety knowledge, including hygiene, control of temperature, contamination, and food poisoning, and reported that UAE workers did not have adequate food safety knowledge, recommending raising the awareness of the importance of food safety training programs to workers in the United Arab Emirates. On the other hand, this issue can be remedied by holding workshops for staff members, enabling them to implement the aforementioned systems at their respective establishments. This will gradually eliminate the possibility of food contamination and reduce potential health risks to customers. This is supported by Ebrahim (2020), who conducted a study in Dubai restaurants to study the impact of food safety training sessions on the hygienic practices of their employees, and found that training actually enhances workers' performance, achieves good hygienic practices, and most importantly lowers foodborne diseases, recommending that every restaurant offer food safety training regularly. This should be a goal, especially post-COVID-19 pandemic, as Shi *et al.* (2020) stated that the COVID-19 crisis surprisingly increased people's food safety knowledge, which reflected on their behaviors.

Microbial count of the different areas in the different food production vendors located in different places in Al Ain City

Swabs were collected from different locations at various food service production vendors, and the microbial results for TVC and CC are shown in Table 1.

As shown in Table 1, the TVC for the different areas across different vendors ranges from 2 to 4 CFU/g/ml. The highest viable counts were significantly higher on the cutting boards and workbench surfaces, and the lowest on the freezer surfaces, across the different food production vendors. Such findings are less than those of other studies, such as Issa-Zacharia *et al.* (2025), conducted in university restaurants in Tanzania to evaluate food safety knowledge of workers in the food services and the microbial contamination of food contact surfaces. It was found that the table's surfaces total viable count (TVC) ranges from 2.83 to 7.13 CFU/ml. The presence of microbial loads indicates poor hygiene at these sites. There were insignificant differences between the results and the standard, but as can be seen, the results are within the maximum acceptable values. Therefore, proper cleaning techniques and the use of cleaning agents are necessary to achieve appropriate sanitation. In addition, as shown in Table 1, there are significant differences in TVC among production vendors, whereas coliform counts are not significant except for the cutting boards of the S and M vendors. These differences reflect the variations in the cleaning, sanitizing, and hygienic practices that are followed by each vendor. They also reflect the low level of food safety awareness among employees and the limited training preparation.

Most of the food handlers belonged to the low socioeconomic category, and more than 80% of the personnel

were untrained; none of the chefs had received any official training and had learned the profession by experience (Gupta *et al.*, 2011). The low percentage scores may be attributable to the aforementioned factors. Gupta *et al.* (2011) revealed that none of the workers used soap to wash their hands after smoking, eating, handling garbage, cleaning, or handling currency. All of these factors may increase the risk of cross-contamination at any food vendor. Moreover, several studies have shown a significant positive association between education and food handlers' hygiene practices in Bijapur (Udgiri and Masali, 2007). Inadequate handwashing and the neglect of sanitary towels for drying exacerbate weaknesses in hygiene management practices (Park and Lee, 2009). A study in Brazil revealed that 13 out of 15 schools (87%) were categorized as inadequate based on total scores related to layout, utensils and equipment maintenance, employee hygiene practices, quality of raw and ready-to-eat foods, production flow, food handler practices, and quality control (Santana *et al.*, 2009). These findings indicate that inadequate sanitary measures, low educational attainment, and insufficient food safety knowledge and practices are prevalent in fast-food establishments across many nations. This research concludes that urgent implementation of regular training for all food handlers is essential to prevent fast food vendors from becoming a significant public health concern.

Conclusions

A comprehensive profile of food handlers, food ingredients, hygiene practices, and surface sanitation for several foods offered by representative, well-known fast-food vendors across 6 distinct sites in Al Ain City, Abu Dhabi, UAE, was established during the COVID-19 pandemic. It is concluded from this study that the evaluation of UAE restaurants received lower scores in assessments of meat and meat products, food safety in the production stage, particularly, physical facilities, product evaluation, including chemical and microbiological assessments. Workers received lower scores for hygienic practices and for unwanted activities, as well as lower food safety knowledge. While these data provide preliminary insights, the small, non-representative sample size prevents broad generalizations beyond the participating restaurants. Notwithstanding sampling limitations, this study identifies significant gaps in the pandemic-era food safety procedures of participating restaurants, highlighting priority areas for intervention (e.g., microbiological hotspots and hand hygiene compliance). Future extensive research and customized training initiatives can benefit from these findings.

Limitations and future directions

Future work should include evaluating questionnaires to better assess their validity and consistency. As well as using a Likert or similar scale instead of the use of (one score and zero), for example, a Likert scale (e.g., 1 to 5 or 1 to 7), multiple-choice with degrees of opinion, and Semantic differential scales. In addition, more locations are required to be evaluated. Moreover, although these representative restaurants were chosen using a purposive sampling strategy, based on their high regional popularity and heavy tourist traffic, they are highly representative of the city's fast-food sector. These findings primarily apply to the participation establishments.

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Online supplementary material

Supplementary S1 Appendix. Structured checklist format tool on food safety, hygiene practices, and overall conditions of fast-food restaurants within the United Arab Emirates during the COVID-19 pandemic.

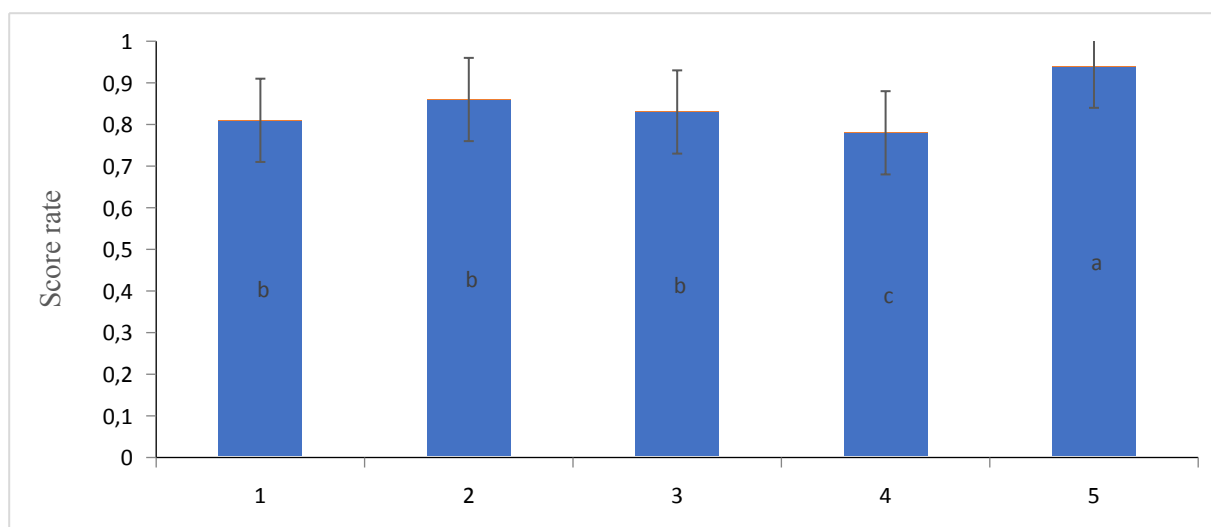


Figure 1. Evaluation scores of various food goods at all vendors' food serving sites. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) Milk and milk products, (2) Dry products, (3) Fruit and vegetables, (4) Meat and meat products, (5) Oil products. *Statistically significant at $p \leq 0.05$, if letters are different among the bars.

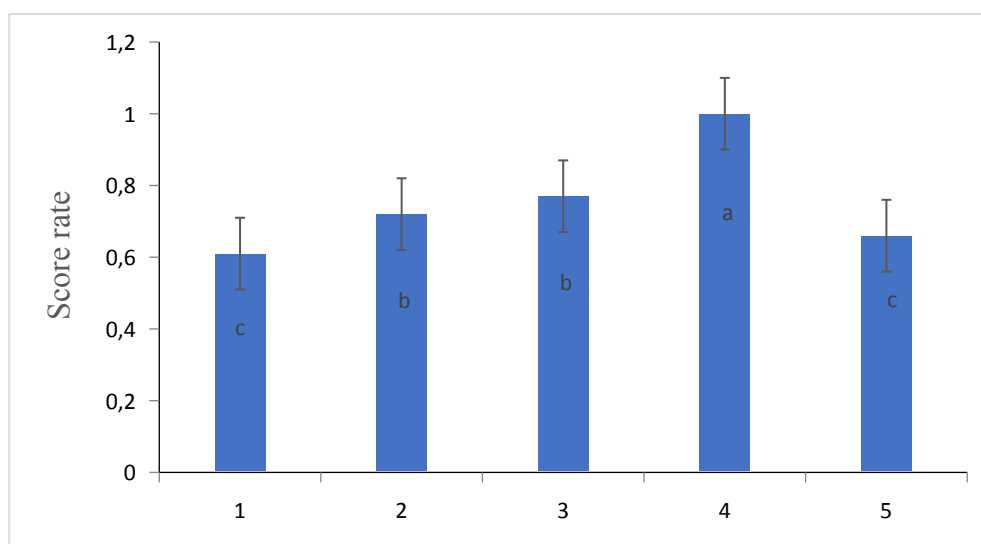


Figure 2. Assessment ratings of diverse manufacturing places (space and cleanliness) in all vendors' food serving locations to produce safe food products. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) Adequate space, (2) Clean, (3) Ventilation, (4) Preproduction safety, (5) production safety. *Statistically significant at $p \leq 0.05$ if letters are different among the bars.

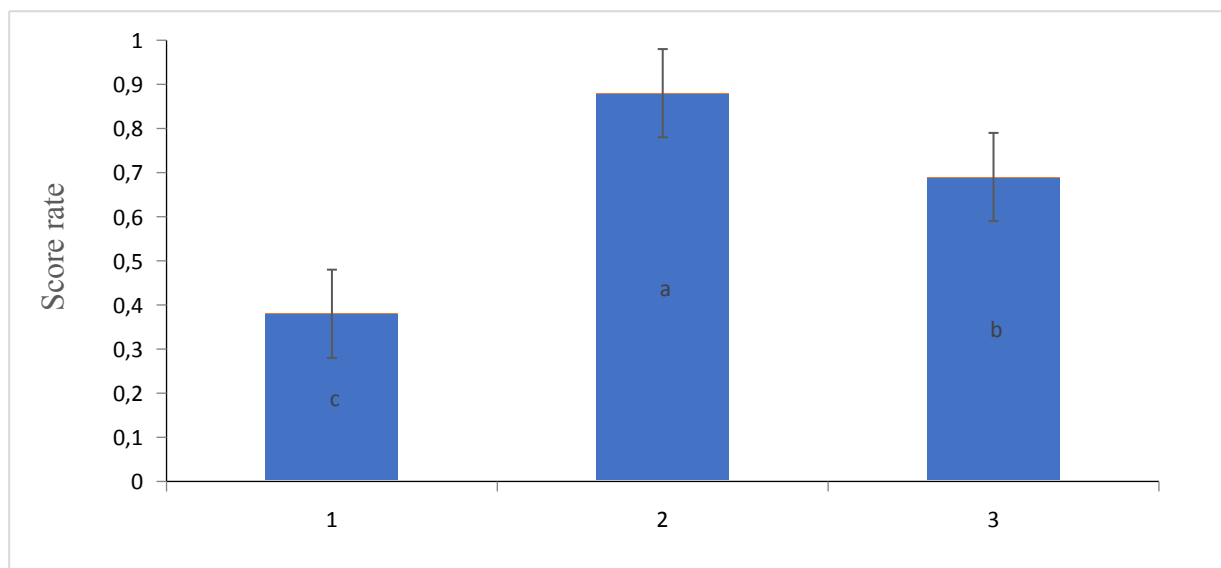


Figure 3. Evaluation ratings for various physical facilities, water availability, and waste management across food-serving locations in Al Ain city, aimed at ensuring the production of safe food products. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) physical facilities, (2) water availability, and (3) waste management. *Statistically significant at $p \leq 0.05$, if letters are different among the bars.

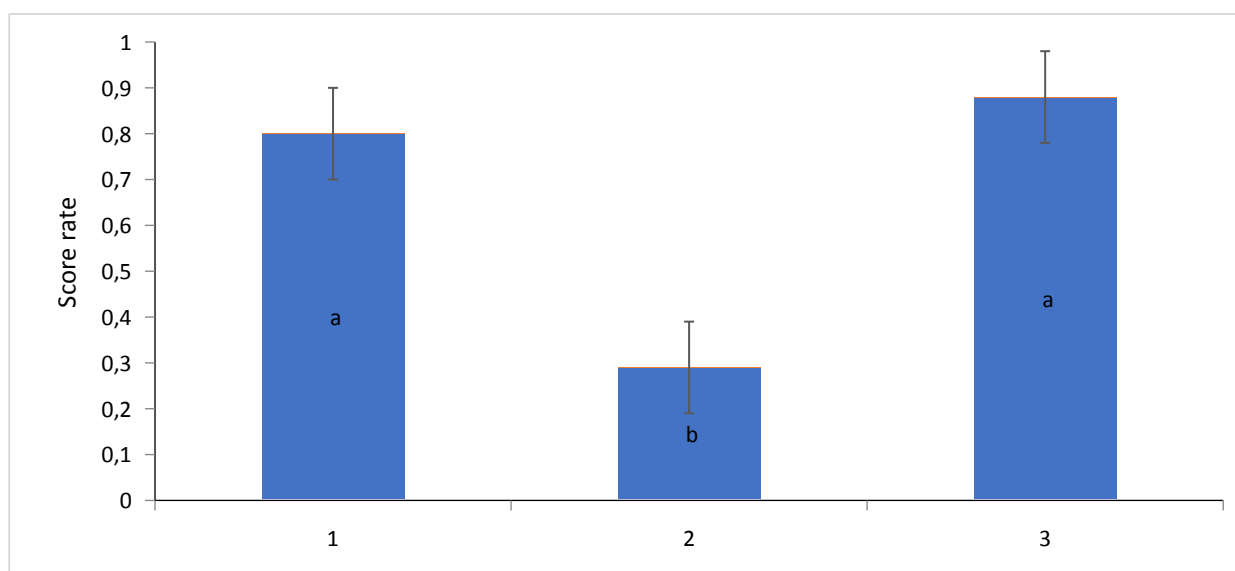


Figure 4. Assessment scores for product storage and packaging, product evaluation, and distribution under controlled conditions at all Al Ain City locations to ensure the production of safe food products. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) product storage and packaging, (2) product evaluation, (3) product distribution. *Statistically significant at $p \leq 0.05$, if letters are different among the bars.

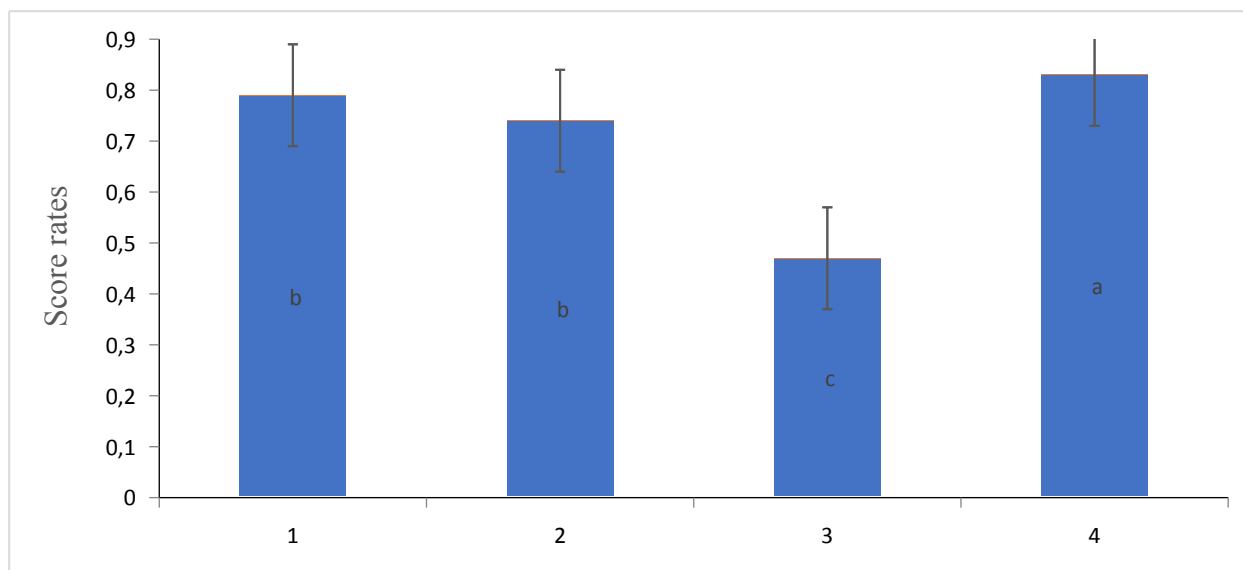


Figure 5. Evaluation scores of food handlers and personal hygiene practices in all university campuses' food serving locations to produce safe food products. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) personal appearance, (2) undesirable activity during the work, (3) hygienic practices, (4) toilet conditions. *Statistically significant at $p \leq 0.05$, if letters are different among the bars.

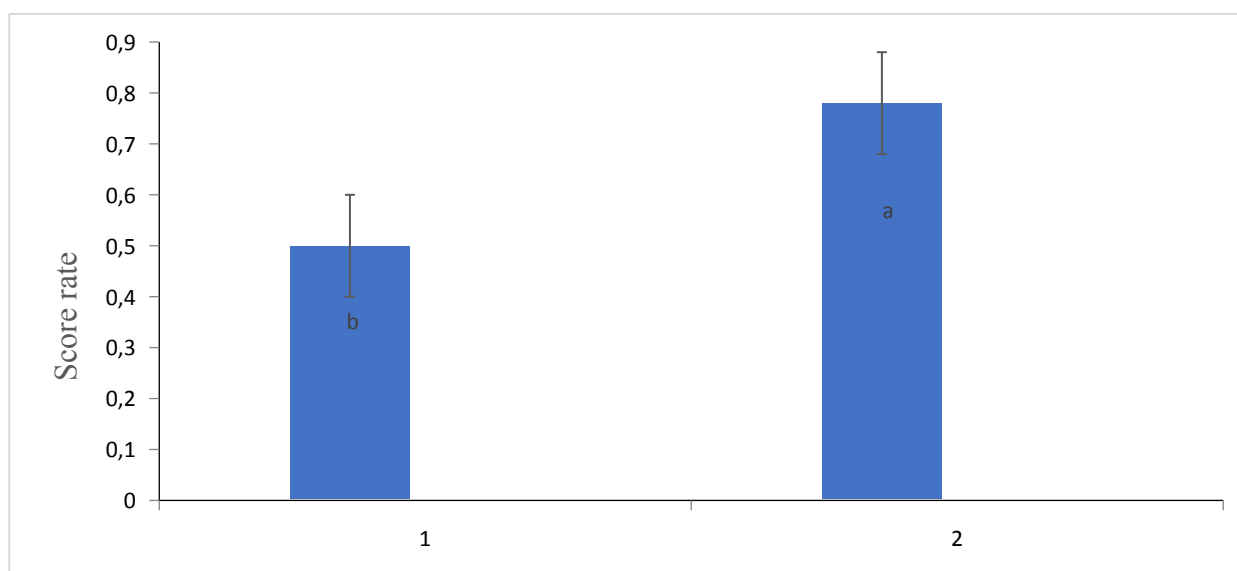


Figure 6. The results of an evaluation of food safety knowledge and equipment availability at Al Ain city sites to ensure the safe production of food items. Bars represent the mean scores (converted to percentages by multiplying raw scores by 100). Evaluated categories are defined as: (1) represents food safety knowledge, and (2) represents equipment availability according to the *Supplementary S1 Appendix*. *Statistically significant at $p \leq 0.05$, if letters are different among the bars.

Table 1. Total viable count for samples from different food production vendors and their standards in the UAE.

Location	Vendor name	Total viable count (log ₁₀ CFU/mL)	Coliform count
Work bench	Z	4.83 ^a	2.72 ^a
	B	3.76 ^b	2.46 ^a
	A	4.73 ^a	2.11 ^a
	D	3.73 ^b	2.01 ^a
	S	2.98 ^c	2.78 ^a
	M	2.06 ^c	2.41 ^a
Freezer	Z	2.11 ^c	ND
	B	2.10 ^c	ND
	A	4.41 ^a	2.2 ^a
	D	2.30 ^c	ND
	S	3.65 ^b	2.48 ^a
	M	3.82 ^b	2.24 ^a
Cutting boards	Z	4.67 ^a	2.59 ^b
	B	2.69 ^c	2.11 ^b
	A	3.79 ^b	2.28 ^b
	D	4.69 ^a	2.08 ^b
	S	4.90 ^a	4.83 ^a
	M	4.79 ^a	4.63 ^a

The letters that have been used refer to the first letter of the actual name of the food production or present at very low levels (<10 CFU/g) vendor. * National Standard UAE.S (1016:2017) issued by the Emirates Authority for Standardization and Metrology and enforced by the Abu Dhabi Agriculture and Food Safety Authority (ADAFSA). Acceptable limits for total aerobic plate count generally range between 2-4 CFU/g, and coliforms are required to be absent. *Statistically significant at $p \leq 0.05$, if letters are different among the different treatments.