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Microwave oven usability and safety: an empirical analysis of food splash and possible hazards for users

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ABSTRACT

Nowadays, microwave ovens have become a staple in every home and at public gatherings where food is needed. The popularity stems from its superior cooking performance compared to other methods. Microwaves can preserve vitamin C and other nutrients that degrade when exposed to heat better than other kitchen appliances. The effectiveness of microwave cooking has led many users to overlook the importance of using microwaves safely when preparing food. This study investigated the presence of harmful microorganisms in food splatters left inside microwave ovens. Samples were collected from six microwaves at six distinct sites, with a total of 12 swabs cultured from each microwave and tested for microbial presence. A total of 142 DNA samples were extracted, and both 16s rDNA and ITS rDNA were analyzed to identify bacteria and fungi. The sequence analysis revealed the presence of uncultured *Lactococcus* sp., uncultured *Legionella* sp., and Neottia nidus-avis bacteria, and a significant number of fungi, including *Trichosporum lignicola*, *Candida* spp., *Saccharomyces cerevisiae*, *Aspergillus pseudoglaucus*, *Paecilomyces tenuis*, *Cercophora acanthigera*, *Epicoccum nigrum*, and *Leiotrametes Latina*. The findings indicate that food splatters left in microwave ovens for several (three to four) days can harbor harmful microorganisms, such as bacteria and fungi. Findings also acknowledge the possibility of food cross-contamination. We recommend regular, thorough microwave cleaning after noticing food splashes to help prevent the spread of these microorganisms. Findings from this study will provide valuable insights into ongoing research on food safety and public health, specifically regarding microwave oven use.

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1. Introduction

Wealth does not necessarily correlate with health; therefore, the financial capacity to purchase expensive products does not guarantee their safe use.

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Any materials or products that lack proper sanitation and maintenance can directly affect user safety. Manufacturing a product is one thing; prioritizing health and safety when developing products and equipment to meet human needs is the most essential factor for any human-use product. The saying "health is wealth" underscores the importance of good health to individuals, as it often determines their productivity. To ensure human safety and good health, it is crucial to make informed food choices and maintain rigorous sanitary practices when handling food production materials. People use a microwave oven to heat or preheat food that has become too cold for consumption. Given that most people now use microwaves to preheat and heat cold food, the routine sanitization of microwaves should be a primary concern for users to ensure safe conditions. Globally, food safety remains a critical issue in food preparation and production, necessitating actions to ensure that all food is as safe as possible. The push to strengthen efforts to ensure food safety for consumption was a significant concern discussed at the May 2020 World Health Organization (WHO) meeting. It was emphasized that the efforts will motivate a global strategy and plan of action on public health, innovation, intellectual property, and preparedness against influenza (1).

Microwave oven sanitation and proper usage for daily purposes become increasingly vital. In 2016, an unacceptable and unhygienic canteen culture was reported in Malaysia, as highlighted by the Education Minister, Datuk Seri Mahdzir Khalid, who stated that a significant number of student hospitalizations were due to poor sanitary practices in consuming egg sandwiches (2).

The microwave was invented in the mid-20th century for cooking purposes. The device has now become the most famous and indispensable kitchen appliance for food preparation worldwide (3). Today, more than 90% of households own at least one microwave oven (4). Although many individuals who believe in a traditional way of life prefer to prepare daily meals on conventional cookers rather than solely depending on microwaves, the convenience of microwave cooking has led many to prioritize speed over safety.

According to the Hong Kong Centre for Food Safety, a microwave oven operates at electromagnetic frequencies between 300 and 300,000 MHz. The microwave oven is now a standard appliance in student lounges, staff offices, homes, restaurants, and other settings. It serves as a standard appliance for efficient food preparation. Over the years, numerous studies have examined the safety of using a microwave oven to heat food (5, 6, 7). However, prior research has primarily focused on radiation leakage and its potential impacts on the chemical structure of food, leading to reduced nutritional value and the leaching of carcinogenic toxins from plastics and other materials into food (8, 9).

Chandrasekaran and his colleagues (10) documented several ways in which microwave ovens function for food processing. The author mentioned cooking, drying, pasteurization, defrosting frozen foods, and food preservation. Nick Tumminello acknowledged five additional dangers associated with the use of microwave ovens for food preparation in 2013 (11). In fact, all these research findings on microwaves for food preparation emphasized the need for users to remain informed about the potential hazards of microwaving and to ensure proper sanitation practices in their kitchens (12). In fact, the WHO released an article in 2024 on food safety and concluded that every year, almost 1 in 10 people in the world fall ill after eating contaminated food, and 420,000 people die, with children under 5 years of age being the most affected (13).

According to a 1995 study by Evans et al. (12), all guests and their hosts developed symptoms of food poisoning after consuming food prepared in a microwave oven. Aligned with previous studies, Gessner and Beller at the Centers for Disease Control and Prevention documented a *Salmonella* outbreak involving approximately 40 picnic attendees, in which reheated roast pork was identified as the source. In the study, 30 individuals participated. The results indicated that men who used microwave ovens became ill, whereas none of those who used conventional ovens or skillets were affected. These findings supported O'Connor's (13) finding that microwave cooking does not consistently eliminate harmful bacteria, as microwave ovens can cook food unevenly, creating "cold spots" where bacteria may survive (9). A subsequent study suggested that while microwaving can kill weaker bacteria, it may inadvertently strengthen more resilient strains of bacteria (15).

Conversely, researchers at the University of Florida found that microwaving can eliminate germs, including viruses and bacteria. They claimed that "90-plus percent of Americans with microwaves in their kitchens have a powerful weapon against *E. coli*, *Salmonella*, and other pathogens responsible for increasing incidents of potentially deadly food poisoning and related illnesses" (16, p. 1). However, the findings concerning the efficacy of microwaving in killing microorganisms may be misleading. Although microwave ovens can effectively eliminate some pathogens, their effectiveness is not guaranteed; results may vary depending on the specific pathogens present (17). A recent study on food safety has highlighted the growing complexity of food production and processing, raising concerns about contaminants in food processes that pose significant public health risks (18).

Furthermore, any food sprays left uncleaned in microwave ovens for several days can lead to cross-contamination and the production of both pathogenic and non-pathogenic microorganisms. Common practice is for many people to leave their food uncovered, which poses a high risk of splattering inside the microwave during cooking. Kitchens, where microwaves are typically located, are recognized as environments with an inherent risk of contamination from various microorganisms (19). Consequently, it is crucial to address the potential for cross-contamination and pathogen transfer from dirt samples (splash residue) in microwave ovens that are not adequately cleaned after each use. Now that the microwave oven has been widely accepted as an alternative cooking appliance, ensuring food safety is a matter of concern at both the local and global levels. Food safety begins with agricultural production practices (such as the use of feed additives, genetically modified organisms, and pesticides) and spreads to food handling, storage, and preparation (20). It is important and necessary to investigate the safety of food preparation in microwave ovens at this time. This study hypothesizes that food splatters left in microwave ovens for 4-7 days before use will allow harmful microorganisms to thrive, which will not be eradicated during the first 10 min of heating or cooking. The study aims to determine whether the initial 10 min of cooking or heating in microwave ovens with leftover food splatters can effectively eliminate all microorganisms.

Objectives of this study including: 1) Located microwave ovens for the study, 2) The investigators took sample swabs of the food splashes in the microwave ovens, 3) Sent samples for culture, 4) Conducted rDNA analysis on samples.

2. Materials and Methods

This study was conducted in a real-world environment, in which the public actively heated their food before consumption. The materials utilized for data collection in this study are listed as follows:

- Microwave ovens
- Swabs
- Petri dishes
- Specimen Transfer Bags
- A 5mL Cary-Blair transport medium
- Hand gloves (Latex-free)

The study was conducted at one university in the Northwestern part of Indiana, United States. The PI of the research visited all student lounges two weeks before the commencement of the study, and in each lounge, a microwave oven was available. This visit allowed for a thorough familiarization with the settings and conditions of the microwave ovens.

We randomly selected six microwave ovens in six locations within the university during this preliminary phase. These selected sites represented a cross-section of the environments where students commonly use microwave ovens during lunch. We collected twelve (12) swabs from each microwave oven to ensure a comprehensive analysis of the residue present. The DNA samples collected from all the microwave ovens total seventy-two, providing a robust dataset for further examination. A 5mL Cary-Blair was used to transport the swab to the laboratory, where samples were tested for the presence of microorganisms. The dimensions of the microwave oven surfaces used in the study vary by type of microwave oven. However, we took three samples from each side: the top, bottom, right, and left sides of each microwave oven. We employed Polymerase Chain Reaction (PCR) techniques targeting the 16S rDNA and Internal Transcribed Spacer (ITS) rDNA to evaluate the microbial composition of the collected samples. This molecular biology technique enabled us to identify and analyse the presence of various bacterial and fungal species within the samples. The pictures of the microwaves showcase the conditions of the microwave ovens from which samples were collected.

We labeled and documented all swabs in a spreadsheet before being shipped for subsequent microbiological analysis. We orderly classified and labeled the swaps to ensure that each sample could be precisely tracked throughout the analysis phases. During the process, we used cetyltrimethylammonium bromide (CTAB) to separate all the specimens removed for testing. The DNA extraction method was adopted due to its effectiveness, as established in several studies on plant and microbial sources. The DNAs were further quantified using the Quantus Fluorometer. The Quantus Fluorometer is a sophisticated instrument designed to analyze nucleic acid concentrations. We identified the main factors affecting the reliability of downstream analyses by considering the quality and concentration of the DNA samples.

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2.1. Procedure

We visited the university's facilities department about one week before the start of data collection to seek formal permission from the department head for the study. This visit helped us obtain approval from the facility department and enabled us to work with facilities management. We seek permission from the facility representative to exempt the microwave ovens located across the campus from cleaning on the Friday preceding the data collection. This approach was designed to allow the microwaves to remain uncleaned for an optimal period of three or more days, ensuring that residue from previous use could accumulate for the analysis.

We started data collection on Tuesday morning, following the designated Friday when the microwave ovens were last left untouched. We arrived at the microwave locations by 8 am and patiently waited for the ovens to be used by at least two individuals. This waiting period was necessary to ensure that the collected samples reflected actual student usage conditions, thereby enhancing the data's validity. We moistened the swab with Buffered Peptone water to improve the collection of bacteria, DNA, and other cells, especially from dry areas. We immediately started sample collection. After each swab, we inserted each into the rectum to collect a sample. We then placed it in a Cary-Blair transport tube to keep the microbes alive during transport to the lab. For our safety, we used a petri dish and latex-free Synthetic Vinyl Blend Disposable Gloves during sample collection to prevent cross-contamination and ensure researcher safety.

Three swabs were taken from each side of the microwave ovens, including the top, sides, and bottom surfaces. In total, we took twelve (12) swabs from each microwave, which will help ensure a comprehensive analysis of the food splash patterns. We labeled each swab with relevant identification details and recorded them in a spreadsheet to maintain accurate, organized documentation.

All swabs collected were shipped to Mycorrhiza Biotech's microbiology laboratory for further analysis. An isolated foam shipping kit was used to transport the sample, ensuring the sample remained at the proper temperature until it arrived in the laboratory for analysis. The time elapsed from collection to delivery at the microbiology lab was approximately 24 h.

All tests were performed in the laboratory to clarify the microbial load and identify the specific organisms in the samples. All sample conditions were confirmed suitable for level III DNA-based analysis. This was done because DNA-based analysis can be used in studies to identify both common and potentially pathogenic organisms in leftover food in the microwave. The analysis is robust to exemplify the microbial landscape present in any food. Therefore, doing this helps food safety experts gain knowledge and helps unveil food safety risks.

3. Results

Table 1 shows the DNA concentrations obtained for all samples tested. This table provides a comprehensive overview of the extraction yields across the various specimens.

To adequately analyze the samples, we later employed PCR on all isolated samples using fungal ITS primers and bacterial 16S ribosomal RNA (rRNA) primers. The selected primers enabled amplification of targeted DNA regions. It also helps identify both fungal and bacterial species present in the original samples. After this process, gel electrophoresis was conducted with all PCR products. Using this technique, we were able to visualize and verify amplified DNA fragments, confirming their sizes and the success of the PCR reactions. Table 1 presents gel electrophoresis results, including relevant findings, and provides detailed insights into the microbial composition and diversity in the sampled environments.

The culture results allow easy reference and analysis of data generated by PCR and electrophoresis, aiding in concluding the presence and prevalence of specific bacterial and fungal organisms in the university's microwave ovens.

The results obtained from the analyses using ITS primers are shown in Fig. 1. Generally, to amplify specific regions of fungal DNA, facilitating the recognition and characterization of various fungal species present in splashed food samples in a microwave. ITS primers are commonly employed in molecular biology. ITS primers' usage is important in studies of fungal varieties and ecology. Fig. 1 shows the visual representation of the presence and abundance of specific fungal species within the tested samples. The details in Fig. 1 provide insight into the overall fungal load and potential pathogenic risks associated with the food leftovers analysed. The sample also shows the presence of various fungal species. The quality and type of fungi reflected in the figure show the intensity and size of these bands, with distinct patterns suggesting different species based on their specific genomic characteristics. With critical observation on the findings, based on the contamination levels from various molds, including pathogenic species, thereby informing necessary actions for food safety and hygiene.

Fig. 2 presents the gel electrophoresis results from samples analysed with bacterial 16S rRNA primers. Because the 16S rRNA gene is a preserved component of the bacterial genome, bacteria can be easily identified and classified. The results of this analysis help detect bacterial contamination in the splashed food samples. Research has proven that harmful bacteria pose significant health risks upon ingestion. Fig. 2 further shows a series of bands, each corresponding to different bacterial species or strains present in the tested samples, including food splashed in the microwave. Band-intensity variation indicated differences in bacterial load, while the presence of unexpected bands may indicate contamination with non-target bacteria. Analysing the bacterial composition of these leftover food samples is crucial for evaluating food safety risks, particularly because some bacteria may be pathogenic and contribute to foodborne illnesses.

Fig. 1 and 2 detail key information about the microbial landscape and the potential risks posed by fungi and bacteria that can grow in unclean microwave ovens after use. The graphical representations of Fig. 1 and 2 of our findings illuminate microbial contamination in food and underscore the need to maintain cleanliness and hygiene in food-preparation environments.

Table 1. DNA concentrations (ng/ul) and gel electrophoresis results of Purdue samples.

S/N	Sample ID	DNA Concentration (ng/ul)	ITS Gel Results	16S Gel Results
29	B3	0.0517	+	+
30	T3	0.473	-	-
31	T1	12	+	+
32	L2	4.07	+	+
33	B3	0.61	+	+
34	T2	2.06	+	+
35	T3	98	+	+
36	R2	lower than blank	+	+
37	R1	lower than blank	+	+
38	L2	7.9	+	+
39	L3	0.182	+	+
40	B2	0.711	+	+
41	B3	0.296	-	+
42	T2	0.432	+	+
43	T2	5.1	+	+
44	B3	0.156	-	+
45	R1	0.582	+	+
46	T2	0.0369	+	+
47	T1	0.0049	+	+
48	B1	0.0136	+	+
49	D2	lower than blank	+	+
50	R2	0.658	+	+
51	B1	0.277	+	+
52	L3	8.9	+	+
53	R1	6.4	+	+
54	T2	3.33	+	+
55	R2	10	+	+
56	B2	4.7	+	+
57	R1	0.161	+	+
58	L1	0.682	+	+
59	B2	0.156	-	+
60	D1	0.0964	+	+

61	T3	0.0724	+	-
62	B3	lower than blank	+	+
63	R3	0.379	+	+
64	L3	7.8	+	+
65	T1	3.64	+	+
66	T3	1.11	+	+
67	T2	0.0582	+	+
68	R3	0.17	+	+
69	L3	0.136	+	+
70	R3	lower than blank	+	+
71	L3	1.56	+	-
72	R2	17	+	+

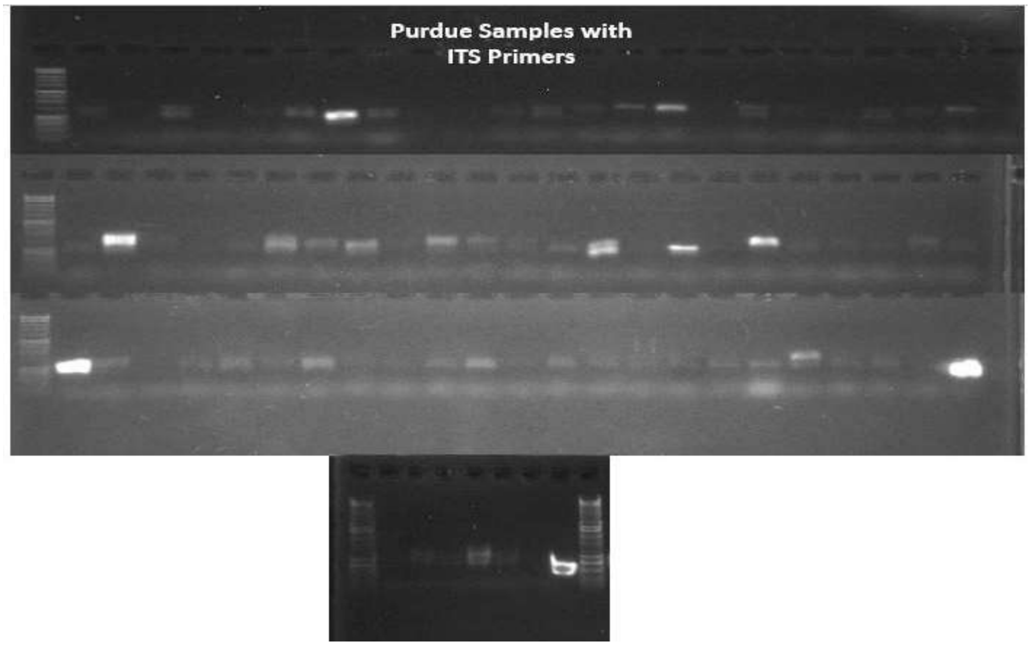

Figure 1. Gel results of samples with fungal ITS primers.

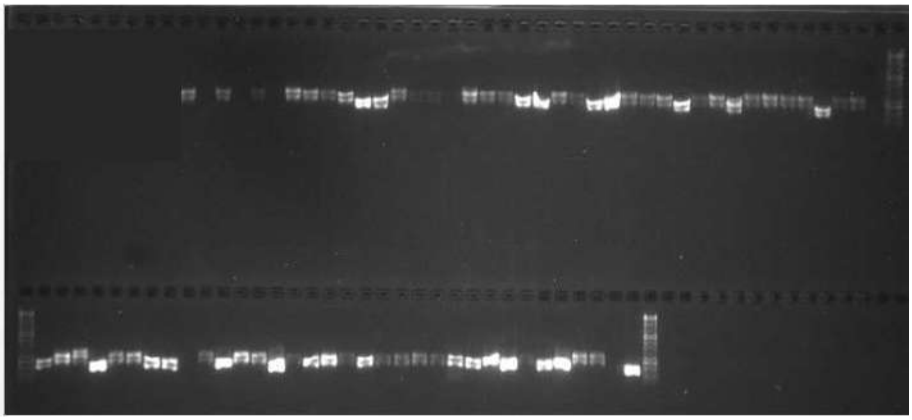

Figure2. Gel results of samples with bacterial 16S rRNA primers.

Additionally, we conducted an extensive analysis to investigate the presence of bacteria in food that had splashed in microwave ovens over four days. We identified three bacteria similar to those in the GenBank database, while others showed no similarity. The bacteria are uncultured *Lactococcus* sp., uncultured *Legionella* sp., and Neottia nidus-avis. The entities identified matched records found in GenBank, indicating a link to previously documented microorganisms; therefore, it's worth monitoring.

Later, we conducted another analysis on the internal transcribed spacer (ITS) sequences. This analysis yielded more results compared to the 16S sequences. By comparing the two approaches, we found that ITS efficiency is attributable to the extensive database of fungal sequences in GenBank. The list of fungi identified with the ITS approach includes *Trichosporum lignicola*, *Candida* spp., *Saccharomyces cerevisiae*, *Aspergillus pseudoglaucus*, *Paecilomyces tenuis*, *Cercophora acanthigera*, *Epicoccum nigrum*, and *Leiotrametes latina*.

Likewise, we observed that fungal sequence analyses showed particularly high similarity scores to existing records in GenBank. The results show that *Aspergillus pseudoglaucus* exhibited a high similarity score of 91%. Ninety-eight percent (98%) of *Leiotrametes lactinea* and *Saccharomyces cerevisiae* were found to be 87%. *Epicoccum nigrum* and *Paecilomyces tenuis* had scores of 99%, indicating close genetic similarity to those fungi in current databases. Furthermore, the *Cercophora acanthigera* score was 85% similar; likewise, *Candida* spp. represented a similarity of 99%.

In fact, the ITS sequencing technique yielded successful results, as evidenced by the large number of fungal sequences obtained from the samples that show similarity to fungal taxa in GenBank. The results revealed various microbial communities and their complexity, possibly residing in food splashes in microwave ovens. These bacteria and fungi can thrive in such environments.

4. Discussion

The kitchen is where all raw foods must pass before becoming edible. The kitchen has become an important feature of human life because of its importance within human dwellings. Activities performed in the kitchen can expose it to several harmful microorganisms. Kitchen exposure to various microorganisms makes it the second-most at-risk area, after restrooms, for contamination. Several studies have concluded that improperly managed kitchen utensils can lead to foodborne illnesses due to the growth of microorganisms in kitchen environments (19, 21, 22). The rate of microbial growth in the kitchen requires good sanitation and hygiene practices in the surrounding area. Good sanitary and hygiene practices will help reduce the risk of bacterial contamination in the kitchen. However, the reverse is the case, as many individuals have forgotten that health is wealth and have failed to maintain proper sanitary practices in the kitchen.

In this study, we examined the potential growth of microorganisms in food splashed inside a microwave oven and left there for a period of three (3) or more days before use. The findings from this study showed that any food splashed in a microwave oven and left for more than three (3) days has the potential to grow fungi and bacteria, and the pathogens can lead to significant health risks to the users.

The findings further revealed that the thermal effects produced during the initial use of the microwave for about ten min, following the four days during which the oven was left unused, are inadequate to remove all existing microorganisms. Thereby increases users' health risks and causes cross-contamination.

We also found in the study that the uneven heating distribution characteristic of microwave ovens can aggravate food cross-contamination. As documented by Cardinale and colleagues in their 2017 article, microwaves do not produce uniform heat when cooking. When food is unevenly heated, the potential for rapid bacterial growth is high; therefore, it is essential to monitor microwave cleanliness regularly, especially when splashed food is left behind. This process will help reduce or eliminate the possibility of cross-contamination, which could spread harmful microorganisms.

Our findings showed the presence of *Aspergillus* spp. in the sample. *Aspergillus* spp. is a mold commonly found in organic matter such as food remnants. This confirmed that food splashed left in a microwave for days without cleaning could grow pathogenic bacteria. Studies have confirmed the possibility of health risks associated with *Aspergillus* spp. and the target human organ. The main target organ is the human respiratory system, as documented by Dr. Eloise M. Harman, a staff physician and director of the Medical Intensive Care Unit at the Gainesville Veterans Affairs Medical Center (23). Attacks on the human lung can lead to severe conditions such as bronchopulmonary aspergillosis, necrotizing pneumonia, and aspergilloma. Harman concluded in his 2020 study on Aspergillus spp. that there is a need to act quickly to control the rapid progression of *aspergillosis* and prevent adverse lung effects (23). Likewise, (23, 25) concluded that Aspergillus spp. has a harmful effect on human lung health, affirming the fungus's role in inducing a range of pulmonary complications.

Since many individuals are allergic to various foods, the risk of cross-contamination in a microwave oven, particularly when food is splashed, warrants immediate attention, especially in public-use microwave ovens. One of our findings is the potential for food cross-contamination, which underscores the need for proper sanitary practices when using microwave ovens. Public microwave oven users should ensure the microwave is clean before use, or cover their food while cooking. Food heated in a microwave oven

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without a cover can be exposed to unintended splashes of dried particles. This finding affirms that an unclean microwave oven with food splashes after use not only exposes users to health risks but also to food allergens. One major microorganism found in the sample is the yeast *Saccharomyces cerevisiae.* It was identified in 92% of cultured DNA samples. This fungus is known to be associated with gastrointestinal discomfort such as diarrhea (26). Our findings have not only highlighted the different microorganisms that multiply in improperly sanitized kitchen appliances but also identified potential health risks associated with unclean kitchen utensils, particularly microwave ovens.

Our findings clearly reveal that many bacteria and fungi detected in the cultured sample have the potential to pose a health risk to human users of microwave ovens. The findings agree with Gizaw's 2019 research (27). Gizaw concluded in the study that unsafe food, due to bacteria, viruses, chemical substances, or parasites, has been linked to over 200 diseases, ranging from common diarrhea to cancer (27). Therefore, educating the public on proper, regular sanitary practices in the kitchen should be given high priority. These findings agree with Ojima's (21) findings. In 2002, Ojima emphasized the need for improved and more effective food safety education programs in Malaysia. The study specifically targets the safe operation and maintenance of microwave ovens.

5. Conclusion

The goal of this study is to investigate whether food left in a microwave oven for several days without use can support the growth of microorganisms that pose a health risk to users. This study identified common food safety–related public health risks associated with microwave-prepared food. Findings from this study revealed that unclean microwave ovens could spread harmful bacteria and fungi if left unused for about three to four days before use. We also investigated the possibility of cross-contamination of food when it is reheated in a microwave oven with unclean splashes. It was discovered that reheating food in a microwave oven with splashes left uncleaned and left uncovered has a high likelihood of causing cross-contamination. The findings from our study offer valuable insights into the existing literature on food safety. Findings from our study support the Centers for Disease Control and Prevention (CDC) campaign on the importance of developing procedures and proper methods to prevent *Salmonella* outbreaks associated with improper food handling practices, as outlined in their 2017 article.

We found that the first few min to ten min of use of a microwave oven do not always ensure the elimination of harmful bacteria, particularly when food splashes have been left over for extended periods. According to the literature, the presence of harmful bacteria in food poses a high risk of causing health issues for individuals who consume it. Therefore, constant and adequate sanitation of microwave ovens is recommended to ensure proper hygiene practices.

Based on our findings, we further recommend sanitation guidelines for safety and health inspection policies of public food preparation environments. For example, food cafeterias, colleges, and university student lounges. We believe implementing safety recommendations for food preparation would help minimize health risks associated with using dirty equipment. We also encourage further research in this area to understand better other common public health risks related to food safety during preparation. Specifically, more studies are needed on the effects of leftover food splashes in microwave ovens over extended periods. Findings from such a study will increase human understanding of the health implications of a nonchalant attitude toward proper cleaning habits. Such studies could significantly contribute to public education efforts focused on the importance of regular sanitation practices for microwave ovens.

We also suggest monitoring the microwave oven temperature during the first phase of use after it has been left unused for about three (3) to four (4) days with food splashes left over. By ensuring the temperature reaches an adequate level to destroy harmful organisms, users can ensure the food being prepared in the appliance is safe. All suggestions are important for protecting individual health and fostering a culture of food safety awareness in communal cooking settings. We further recommend raising public awareness of microwave oven sanitation through comprehensive educational initiatives across our schools, from elementary to higher education institutions. These initiatives could help mitigate the health risks associated with inadequate cleaning and improper food safety practices within kitchen environments.

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Author contributions

Bankole Fasanya was the principal investigator of this study. He was responsible for the study methodology, translated the laboratory report, coordinated the entire study process from start to finish, wrote, reviewed, and edited the whole manuscript. **Precious Fasanya** was responsible for data collection (from swab collection to laboratory analysis), took microwave pictures, purchased all used data-collection materials, reviewed the original manuscript draft, and generated the study idea.

Conflicts of interest

All contributing authors declared no conflicts of interest.

Data Availability

Data for the study is available upon request.

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