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Assessment of Microbial Contamination and Bacterial Characterization in Ready-to-Eat Fruits from Port Harcourt Markets, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Food safety is critical in preventing foodborne illnesses, particularly in regions where regulatory oversight may be inconsistent. This study aimed to assess the microbial contamination and characterize bacteria found in whole and sliced ready-to-eat (RTE) fruits sold in Port Harcourt, Nigeria. The study area of this research was in Port Harcourt, the capital and largest city in Rivers State, Nigeria. The study employed a simple random sampling technique, and the methodology involved collecting 30 samples of apples, cucumbers, oranges, pawpaws, and watermelons from

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six markets: Fruit Garden Market, Mile 1 Market, Mile 3 Market, Oil Mill Market, Rumuokoro Market, and Town Market. Samples were analyzed using standard microbiological techniques, including total heterotrophic bacterial count (THBC) and total coliform count (TCC). Serial dilutions and culturing were performed, and the isolates were identified through morphological and biochemical tests. Results indicated that coliforms such as *Escherichia coli*, Klebsiella spp and Enterobacter spp were isolated, and the THBC varied significantly among the markets, with the highest contamination observed in Mile 3 Market (9.50×10^4 CFU/ml) and the lowest in Town Market (7.27×10^4 CFU/ml). TCC results showed the highest coliform contamination in Rumuokoro Market (5.16×10^3 CFU/ml), likely influenced by proximity to unsanitary water sources. Watermelon had the highest contamination levels for both THBC and TCC, while cucumber showed the lowest. Variations in contamination levels were attributed to environmental factors, inadequate handling practices, and hygiene standards. The study concluded that RTE fruits sold in Port Harcourt pose significant health risks due to microbial contamination levels exceeding recommended safety thresholds. It emphasized the importance of stringent hygiene practices among vendors and better regulatory measures to prevent outbreaks. Recommendations include improved food safety training for vendors, stricter sanitation practices during handling and transportation, and regular monitoring by health authorities to ensure compliance with safety standards. Therefore, the study highlights health risks in consuming ready-to-eat fruits, supporting food safety improvements to reduce foodborne illnesses in Port Harcourt.

Keywords: Microbial contamination; ready-to-eat fruits; food safety; port Harcourt; bacterial characterization; hygiene practices.

1. INTRODUCTION

Food is essential for satisfying hunger and fulfilling the biological needs of living organisms. It plays a crucial role in Maslow's hierarchy of needs (Takgbajouah and Buscemi, 2022). Moon emphasized that food consumption reflects the fulfilment of these biological needs (Feliciano et al., 2022). Food safety refers to ensuring food will not harm consumers when properly prepared and consumed (Walaszczyk and Galińska, 2020). It involves maintaining the physical, chemical, and biological integrity of food to preserve its nutritional value (Walaszczyk and Galińska, 2020). The regulation of food safety requires vigilance from purchase to consumption (Abdulah, 2016), and one of the key goals of Healthy People 2020 is reducing infections transmitted through food, especially by major pathogens (Stenger et al., 2014). Food handlers play a critical role in ensuring food safety, as lapses in handling can cause foodborne diseases (Adane et al., 2018).

The WHO reports that 600 million people worldwide fall ill annually from contaminated food, with 420,000 deaths, while in the U.S., foodborne diseases affect 48 million people annually, leading to 128,000 hospitalizations and 3,000 deaths (WHO, 2015), with Africa and Southeast Asia experiencing the highest incidence and death rates from foodborne diseases (Adane et al., 2018). This issue persists due to unhygienic food handling and poor preservation methods, leading to contamination (WHO, 2016). Additionally, cross-contamination by food handlers further contributes to outbreaks of foodborne illnesses (Akabanda et al., 2017).

Proper food safety practices, including thorough hygiene, are essential to reducing the occurrence, morbidity, and mortality of foodborne illnesses (Vlasin-Marty et al., 2016). Foodborne pandemics are often driven by a lack of knowledge or disregard for hygiene and safety standards (Osaili et al., 2018), and marginalized populations, particularly those in food retail or service, are at higher risk of exposure to foodborne pathogens (Quinlan and Jennifer, 2013), with diarrheal diseases being the most common result of food contamination (Khairuzzaman et al., 2014).

Ready-to-eat fruits (RTEFs), such as oranges, apples, and bananas, have become popular due to their nutritional value and convenience. However, they are vulnerable to microbial contamination during harvest, postharvest processing, and handling (Lima et al., 2019), and increasing incidences of foodborne illnesses from fresh fruits have been reported (Pradhan et al., 2019). Studies have identified bacteria like Listeria monocytogenes, which can cause severe infections, especially in vulnerable populations (Bierne et al., 2018).

The nature of fruits makes them prone to microbial contamination, and poor handling practices further contribute to spoilage (Mailafia et al., 2013). Bacterial species, including Escherichia and Salmonella, are commonly associated with contaminated fruits (Wiley et al., 2013). Additionally, the use of untreated wastewater and organic manure for fruit cultivation in some regions contributes to contamination (WHO, 2015). Increased consumption of contaminated RTEFs in Nigeria has led to outbreaks of foodborne illnesses, prompting the need for proper assessment and stricter food safety measures (Pradhan et al., 2019). Therefore, this study was aimed at assessing the microbial contamination and characterization of bacteria isolated from whole and sliced ready-to-eat fruits in Port Harcourt, Nigeria.

2. METHODOLOGY

2.1 Study Area

The study area of this research was in Port Harcourt, the capital and largest city in Rivers State, Nigeria.

2.2 Study Design

The study employed a simple random sampling technique to isolate and characterize microorganisms from ready-to-eat fruits marketed in Port Harcourt, Rivers State, Nigeria. A total of 30 fruit samples, including both whole (3) and sliced (3) samples of five different types of fruits including apple, cucumber, orange, pawpaw, and watermelon were collected. These samples were purchased from six different markets: Fruit Garden Market (FGM), Mile 1 Market (M1M), Mile 3 Market (M3M), Oil Mill Market (OMM), Rumuokoro Market (RM), and Town Market (TM).

2.3 Sample Collection

All samples of whole and sliced fresh fruits were collected from six different markets in Port Harcourt using sterile polythene bags and transported in an insulated ice box to maintain temperatures between 4°C and 6°C. The samples were immediately taken to the Microbiology Laboratory Unit of Rivers State University Teaching Hospital, Port Harcourt, and analyzed within one hour of arrival. All necessary materials for analysis, including media and glassware, were sterilized and prepared before sample collection. The samples were collected from both wholesale and retail vendors between February 2022 and July 2022.

2.4 Preparation of Sample

The method by Kaur and Rai (2015) was followed. Twenty grams (20 g) of each fruit sample were weighed and transferred aseptically into sterile beakers containing 200 ml of sterile distilled water. Sliced fruits were homogenized using an electric blender, while whole fruits were rinsed, and the wash water was used as the stock for culturing. Ten-fold serial dilutions of both whole and sliced fruit stock samples were prepared using sterilized peptone water. Four test tubes, each containing 9 ml of sterilized peptone water, were used for the dilutions. The peptone water was sterilized by autoclaving at 121°C for 15 minutes. After cooling, 1 ml of stock was added to the first test tube to create a 10-fold dilution, and the process was repeated for the remaining tubes. Contamination was prevented by swabbing the workbench with 70% alcohol, working near a Bunsen flame, and using sterile materials.

2.5 Enumeration and Isolation of Microorganisms

After serial dilution, 1 ml from each of the four dilutions was aseptically dispensed into labelled Petri dishes using the spread plate method with a bent glass rod, in duplicates. Tryptic Soy Agar (TSA) was used for Total Heterotrophic Bacterial Count (THBC), and MacConkey Agar (MAC) for Total Coliform Count (TCC). TSA and MAC plates were incubated at 37°C for 24 hours. After 24 hours, bacterial colonies were counted and recorded as colony-forming units per ml (cfu/ml). The colonies were sub-cultured on Nutrient Agar to obtain pure cultures, and incubated at 37°C for 24 hours. Colony morphology, including colour, shape, and size, was examined microscopically. All experiments were conducted in duplicate to ensure reproducibility.

2.6 Purification of Isolates

When in use, each of the test isolates were first purified by sub-culturing on freshly prepared Nutrient agar using the streak method and then incubated for 24 hours at 37^{o}C. The colonies were also carefully examined using microscope for their morphological characteristics like colour, shape and size.

2.7 Phenotypic Characterization and Identification of Organisms

The isolates were identified through Gram staining, colonial morphology, and biochemical tests. Morphological characteristics observed included colony size, surface texture, shape, elevation, colour, and edge. Gram staining was used to identify bacteria, and biochemical tests conducted included citrate utilization, indole production, methyl red, Voges-Proskauer, motility, triple sugar iron agar, catalase, oxidase, sugar fermentation, urease, and coagulase (slide method), following the method of Karoki et al*.* (2018).

2.8 Antibiotic Susceptibility Profiling of the Bacterial Isolates

Bacterial isolates (1.5 x 10^8 cells/ml) were seeded aseptically onto each sterile Mueller-Hinton agar using the disc diffusion method (Taddese et al*.,* 2019). and were allowed to stand at room temperature (27 ^{0}C) for 30 minutes to allow inoculated organisms to pre-diffuse in the prepared media. The disc containing antibiotics (Basingstoke, UK) used against the isolates were: Gentamicin (GEN, 10 µg), Cefuroxime (CXM, 30 µg), Imipenem (IMI, 10 µg), Ciprofloxacin(CIP, 5µg), Levofloxacin (LEV, 5µg), Cefixime (CTX, 5µg), Ceftriaxone (CTR, 45 µg), Amoxycillin (AMX, 30 µg) were used against Gram negative rods while Gentamicin (GEN, 10 µg), Cefuroxime (CXM, 30 µg), Ciprofloxacin(CIP, 5µg), Levofloxacin (LEV, 5µg), Cefixime (CTX, 5µg), Ceftriaxone (CTR, 45 µg), Amoxycillin (AMX, 30 µg), Erythromycin (ERY, 15 µg), Azithromycin (AZN, 15 µg) and Ofloxacin (OFX, 5 µg) were also used against Gram positive cocci. All plates were placed in an incubator and allowed to stand for 24 hours at 37 ^{0}C. Zone of inhibition was measured in millimetres to meet the guidelines set by the Clinical Standard Laboratory Institute (CLSI, 2017).

2.9 Statistical Analysis

The data was analyzed statistically using SPSS software (version 23.0). Descriptive statistics, including mean and standard error, were calculated for Total Heterotrophic Bacterial Count (THBC), Total Coliform Count (TCC). A one-way Analysis of Variance (ANOVA) was performed to determine differences at a 0.05 significance level, followed by Tukey's post hoc test to assess significance between groups.

3. RESULTS

Table 1a showed that the Total Heterotrophic Bacterial Count (THBC) ranged between 7.27x10^4 CFU/ml in Town market to 9.50 x10^4 CFU/ml in Mile 3 market. This implies that the incidence of bacteria present in selected whole fresh fruits is highest in Mile 3 market followed by Mile 1 market, Oil mill market, Rumuokoro market and Fruit Garden market, while Town market had the lowest level of bacterial contamination. The results from Table 1b indicated a significant mean difference in the Total Heterotrophic Bacterial Count (THBC) among selected whole fruit sample ($F_{5,\ 84} = 4.185;\ P < .05$). Therefore, there was a significant mean difference in the Total Heterotrophic Bacterial Count (THBC) amongst selected whole fresh fruits based on the market type.

Table 2a showed the Total Coliform Count (TCC) ranged between 3.67 x10^3 CFU/ml in Town market to 5.16 x 10^3 CFU/ml in Rumuokoro market. The Total Coliform Count (TCC) showed coliform present in selected whole fresh fruits is highest in Rumuokoro market followed by Mile 1 market, Oil mill market, Mile 3 market and Fruit Garden market while Town market had the lowest level of bacterial contamination. The results from Table 2b indicates a significant mean difference in the Total Coliform Count (TCC) among selected whole fruit sample ($F_{5,\ 84} = 8.45;\ P < .05$). Therefore, there was a significant mean difference in the Total Coliform Count (TCC) amongst selected whole fresh fruits based on the market type.

Table 3a showed the Total Heterotrophic Bacterial Count (THBC) ranged between 8.81x10^3 CFU/ml in fruit garden market to 1.17 x10^4 CFU/ml in Rumuokoro market. This implies that the bacteria present in selected sliced fresh fruits was highest in Rumuokoro market followed by Mile 3 market, Town market, Oil mill market and Mile 1 market while Fruit Garden market had the lowest level of bacterial contamination. The results from Table 3b indicates that there was a significant mean difference in the Total Heterotrophic Bacterial Count (THBC) among selected sliced fruit sample ($F_{5,\ 84} = 3.107;\ P < .05$). Therefore, there is a significant mean difference in the Total Heterotrophic Bacterial Count (THBC) amongst selected sliced fresh fruits based on the market type.

Table 4a showed that the Total Coliform Count (TCC) ranged between 5.29 x 10^3 CFU/ml in

Town market and Fruit Garden to 6.67 x10^3 CFU/ml in Mile 3 market. The Total Coliform Count (TCC) shows that the incidence of coliform present in selected sliced fresh fruits is highest in Mile 3 market followed by Mile 1 market, Oil mill market and Rumuokoro market while Town market and Fruit garden market had the lowest level of bacterial contamination. The results from Table 4b indicates a significant mean difference in the Total Coliform Count (TCC) among selected sliced fruit sample ($F_{5,\ 84} = 3.81;\ P < .05$). Therefore, there was a significant mean difference in the (Total Coliform Count TCC) amongst selected sliced fresh fruits based on the market type.

Table 1a. Mean Total Heterotrophic Bacterial Count (THBC) and CFU/ml of selected whole fresh fruits based on Market type at 10^3 cfu/ml

Selected Markets	N	Mean	SD	CFU/ml
Rumuokoro	15	85.20	20.975	8.52 x 10^4
Mile 1	15	89.87	18.660	8.99 x 10^4
Fruit Garden	15	84.53	21.845	8.45 x 10^4
Oil Mill	15	85.33	18.464	8.53 x 10^4
Mile 3	15	95.00	17.985	9.50 x 10^4
Town	15	72.70	20.715	7.27 x 10^4
Total	**90**			

N = Number of samples examined

Table 1b. ANOVA Test showing the mean difference of Total Heterotrophic Bacterial Count (THBC) of whole fresh fruits among market types

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (p value)	Decision
Between Groups	8225.628	5	1645.126	4.185	.001	**Significant**,
Within Groups	68406.700	84	393.142			P < 0.05.
Total	**76632.328**	**89**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 2a. Mean Total Coliform Count (TCC) and CFU/ml of selected whole fresh fruits based on market type at 10^2 CFU/ml

Selected Markets	N	Mean	SD	CFU/ml
Rumuokoro	15	51.60	13.835	5.16 x 10^3
Mile 1	15	45.27	11.465	4.53 x 10^3
Fruit Garden	15	42.93	10.075	4.29 x 10^3
Oil Mill	15	44.13	10.261	4.41 x 10^3
Mile 3	15	37.40	7.833	3.74 x 10^3
Town	15	36.77	7.089	3.67 x 10^3
Total	**90**			

N = Number of samples examined

Table 2b. ANOVA Test showing the mean difference of Total Coliform Count (TCC) of whole fruits among market types

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (p value)	Decision
Between Groups	4517.983	5	903.597	8.454	.000	**Significant**,
Within Groups	18596.967	84	106.879			P < 0.05.
Total	**23114.950**	**89**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 3a. Mean Total Heterotrophic Bacteria Count (THBC) and CFU/ml of Selected Sliced Fresh Fruits Based on Market Type at 10^2 cfu/ml

Selected Markets	N	Mean	SD	CFU/ml
Rumuokoro	15	116.73	63.666	1.17×10^4
Mile 1	15	95.40	20.256	9.54×10^3
Fruit Garden	15	88.07	20.096	8.81×10^3
Oil Mill	15	97.47	40.442	9.75×10^3
Mile 3	15	113.73	7.839	1.13×10^4
Town	15	103.47	23.396	1.03×10^4
Total	**90**			

N = Number of samples examined

Table 3b. ANOVA Test showing the Mean difference of Total Heterotrophic Bacterial Count (THBC) of Sliced Fruits among Market Types

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (p value)	Decision
Between Groups	18413.17	5	3682.636	3.107	.010	**Significant**,
Within Groups	206243.73	84	1185.309			P < 0.05.
Total	**224656.91**	**89**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 4a. Mean Coliform Count and CFU/ml of selected sliced fresh fruits based on Market type at 10^2 CFU/ml

Selected Markets	N	Mean	SD	CFU/ml
Rumuokoro	15	55.13	18.032	5.51×10^3
Mile 1	15	61.20	17.785	6.12×10^3
Fruit Garden	15	52.93	15.697	5.29×10^3
Oil Mill	15	60.60	15.633	6.06×10^3
Mile 3	15	66.73	13.759	6.67×10^3
Town	15	52.93	10.935	5.29×10^3
Total	**90**			

N = Number of samples examined

Table 4b. ANOVA Test showing the mean difference of Total Coliform Count (TCC) of Whole Fruits among Market Types

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (p value)	Decision
Between Groups	4573.178	5	914.636	3.808	.003	**Significant**,
Within Groups	41793.067	84	240.190			P < 0.05.
Total	**46366.244**	**89**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 5a showed the Total Heterotrophic Bacterial Count (THBC) which ranged between 7.21 x10^4 CFU/ml in cucumber fruit and 1.01x10^5 CFU/ml in watermelon fruit. The Total Heterotrophic Bacterial Count (THBC) showed that the incidence of bacteria present in whole fresh fruit was highest in watermelon followed by pawpaw, apple, and orange but cucumber had the lowest level of bacterial contamination. The results obtained from Table 5b using the ANOVA indicate a significant mean difference in the Total Heterotrophic Bacterial Count (THBC) among selected whole fruit Sample ($F_{4, 175} = 11.12; P < .05$). The Tukey post hoc test in Table 5c showed that the level of bacterial contamination was significantly higher in pawpaw (8.70 ± 2.38), apple (8.39 ± 3.65) and oranges (8.36± 2.93) when compared to cucumbers (7.21 ± 3.41).

While, watermelon (10.10 ± 3.04) showed a statistically significant level of bacterial contamination when compared with the other fruits (cucumber, orange, apple and pawpaw).

Table 6a showed the Total Coliform Count (TCC) which ranged between 3.77 x10^4 CFU/ml in Cucumber fruit and 4.60 x10^4 CFU/ml in Watermelon. The Total Heterotrophic Bacterial Count shows that the incidence of bacteria present in whole fresh fruit was highest in Water Melon followed by Pawpaw, Orange, and Apple but Cucumber had the lowest level of coliform contamination. The results from Table 6b using the ANOVA indicate a significant mean difference in the Total Coliform Count (TCC) among selected whole fruit Sample ($F_{4, 175} = 2.99; P < .05$). The Tukey post hoc test in Table 6c revealed that the level of coliform contamination was significantly higher in pawpaw (4.51±2.49) and Watermelon (4.60±1.91) when compared to cucumbers (2.77±1.62). While the other post hoc comparisons among the fruits were not statistically significant.

Table 5a. Mean Total Heterotrophic Bacterial Count (THBC) and CFU/ml of selected whole fresh fruits

Selected Fruits	N	Mean	SD	CFU/ml
Watermelon	36	101.06	3.048	1.01 x10^5
Orange	36	83.39	3.650	8.34 x10^4
Apple	36	83.61	2.928	8.36 x10^4
Cucumber	36	72.11	3.409	7.21 x10^4
Pawpaw	36	87.03	2.383	8.70 x10^4
Total	**180**			

N = Number of samples examined

Table 5b. ANOVA Test showing the mean difference of Total Heterotrophic Bacterial Count (THBC) among selected whole fruit sample

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (P value)	Decision
Between Groups	15536.80	4	3884.20	11.126	.000	**Significant**,
Within Groups	61095.52	175	349.11			P < 0.05.
Total	**76632.32**	**179**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 5c. Tukey Test for ranking of Total Heterotrophic Bacterial Count (THBC) (Mean ± SE) of selected whole fruits at 10^4 CFU/ml

Fruit Sample	(Mean ± SD)
Cucumber	7.21±3.41[a]
Orange	8.39±3.65 [b]
Apple	8.36±2.93 [b]
Pawpaw	8.70±2.38 [b]
Watermelon	10.10±3.04 [c]

Each value is the mean of 2 replicates from three samples of each fruit type. Means of fruit sample in each column followed by the same letter are not significantly different (P>0.05) by Tukey's test while, fruit type having mean with different letters are Significant

Table 6a. Mean Coliform Count and CFU/ml of Selected Sliced Fresh Fruits

Selected Fruits	N	Mean	SD	CFU/ml
Watermelon	36	64.39	2.185	6.43 x 10^3
Orange	36	56.22	3.225	5.62x 10^3
Apple	36	58.56	2.449	5.85x 10^3
Cucumber	36	50.72	2.339	5.07x 10^3
Pawpaw	36	61.39	2.658	6.14x 10^3
Total	**180**			

N = Number of samples examined

Table 6b. ANOVA Test Showing the Mean Difference of Total Coliform Count (TCC) among Selected Whole Fruit Sample

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (P value)	Decision
Between Groups	1482.20	4	370.550	2.998	.020	**Significant**,
Within Groups	21632.75	175	123.616			P < 0.05.
Total	**23114.95**	**179**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 6c. Tukey Test for Ranking of Total Coliform Count (TCC) (Mean ± SE) of Selected Whole Fruits at 10^4 CFU/ml

Fruit Sample	(Mean ± SD)
Cucumber	2.77±1.62[a]
Apple	4.27±1.58 [ab]
Orange	4.35±1.46[ab]
Pawpaw	4.51±2.49 [b]
Watermelon	4.60±1.91 [b]

Each value is the mean of 2 replicates from three samples of each fruit type. Means of fruit sample in each column followed by the same letter (at least one identical letter) are not significantly different (P>0.05) by Tukey's test while, fruit type having mean with different letters (no identical letter) are statistically Significant (P<0.05)

Table 7a showed the Total Heterotrophic Bacterial Count (THBC) which ranged between 7.95 $x10^3$ CFU/ml in cucumber fruit and 1.22 $x10^4$ CFU/ml in watermelon. The Total Heterotrophic Bacterial Count showed that the incidence of bacteria present in sliced fresh fruit was highest in Water Melon followed by pawpaw, and apple, while, orange and cucumber had the lowest level of bacterial contamination. The results from Table 7b using the ANOVA indicates a significant mean difference in the Total Bacterial Count (TBC) among selected sliced Sample ($F_{4, 175} = 10.54; P < .05$).

The Tukey post hoc test in Table 7c showed that the level of bacterial contamination was significantly higher in Watermelon (12.2 ± 6.75), pawpaw (11.94 ± 6.89) and Apple (11.03± 5.51) in comparison to Oranges (8.95±3.32) and cucumbers (7.95 ± 3.02). However, no significant difference was observed in the level of bacterial contamination between pairs of watermelon, pawpaw and apple. Also, level of bacterial contamination in cucumber and orange did not show any real difference.

Table 8a showed the Total Coliform Count (TCC) which ranged between 5.72 $x10^3$ CFU/ml in cucumber fruit and 6.43 $x10^3$ CFU/ml in watermelon. The total Coliform Count shows that the coliform contamination present in sliced fresh fruit was highest in watermelon followed by pawpaw, orange and apple but cucumber had the lowest level of coliform contamination. The results from Table 8b using the ANOVA indicate a significant mean difference in the Total Coliform Count (TCC) among selected sliced fruit sample ($F_{4, 175} = 4.021; P < .05$). As a result of this, Tukey test was used for ranking the mean and for measuring the pairwise difference among selected fruit sample. The Tukey post hoc test in Table 8c revealed that the level of coliform contamination was significantly higher in pawpaw (6.14± 2.65) and Watermelon (6.43± 2.18) when compared to cucumbers (5.07± 2.33). While the other post hoc comparisons among the fruits were not statistically significant.

4. DISCUSSION

This study aimed to evaluate the microbial contamination and bacterial characterization of whole and sliced ready-to-eat fruits from various markets in Port Harcourt, Nigeria. The Total Heterotrophic Bacterial Count (THBC) varied across the different markets, ranging from 7.27 x 10^4 CFU/ml in Town market to 9.50 x 10^4 CFU/ml in Mile 3 market. The findings indicated that bacterial contamination was highest in Mile 3 market, followed by Mile 1, Oil Mill, Rumuokoro, and Fruit Garden markets, with Town market showing the lowest levels of contamination. The higher contamination in Mile 3 market may be attributed to poor sanitary conditions and the proximity of Mile 3 park, where frequent visitors could contribute to contamination through contact with food products. Other factors, such as poor handling, vending sites, and the use of unclean materials during fruit processing, were also considered potential contributors to contamination.

Table 7a. Mean Bacteria Count and CFU/ml of selected sliced fresh fruits.

Selected Fruits	N	Mean	SD	CFU/ml
Watermelon	36	122.06	6.750	1.22×10^4
Orange	36	89.56	3.319	8.59×10^3
Apple	36	110.33	5.513	1.10×10^4
Cucumber	36	79.50	3.024	7.95×10^3
Pawpaw	36	110.94	6.897	1.10×10^4
Total	**180**			

N = Number of samples examined

Table 7b. ANOVA Test showing the mean difference of Total Heterotrophic Bacterial Count (THBC) among selected sliced fruit sample

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (P value)	Decision
Between Groups	43619.24	4	10904.811	10.541	.000	**Significant**,
Within Groups	181037.66	175	1034.501			P < 0.05.
Total	**224656.91**	**179**				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 7c. Tukey Test for ranking of Total Heterotrophic Bacterial Count (THBC) (Mean ± SE) of selected sliced fruits at 10^3 CFU/ml

Fruit Sample	(Mean ± SD)
Cucumber	7.95±3.02[a]
Orange	8.95±3.32 [a]
Apple	11.03±5.51 [b]
Pawpaw	11.94±6.89 [b]
Watermelon	12.2±6.75 [b]

Each value is the mean of 2 replicates from three samples of each fruit type. Means of fruit sample in each column followed by the same letter are not significantly different (P>0.05) by Tukey's test while, fruit type having mean with different letters are significant

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Apple	36	58.56	2.449	5.85×10^3
Cucumber	36	50.72	2.339	5.07×10^3
Pawpaw	36	61.39	2.658	6.14×10^3
Total	**180**			

N = Number of samples examined

Table 8b. ANOVA Test showing the mean difference of Total Coliform Count (TCC) among selected sliced fruits sample

Sources of Variation	Sum of Squares	Df	Mean Square	F	Sig. (P value)	Decision
Between Groups	3902.80	4	975.700	4.021	.004	**Significant**,
Within Groups	42463.44	175	242.648			P < 0.05.
Total	46366.24	179				

Key: Df = Degree of freedom, F = F value, P = P value, Sig. = Significance, Between groups = Different fruit sample from the markets, Within groups = The same fruit samples from the markets

Table 8c. Tukey Test for ranking of Total Coliform Count (TCC) (Mean ± SE) of Selected Sliced Fruits at 10^3 CFU/ml

Fruit Sample	(Mean ± SD)
Cucumber	5.07±2.33[a]
Apple	5.85 ±2.45 [ab]
Orange	5.62 ±3.22[ab]
Pawpaw	6.14±2.65 [b]
Watermelon	6.43±2.18 [b]

Each value is the mean of 2 replicates from three samples of each fruit type. Means of fruit sample in each column followed by the same letter (at least one identical letter) are not significantly different (P>0.05) by Tukey's test while, fruit type having mean with different letters (no identical letter) are statistically Significant (P<0.05)

Regarding coliform bacteria, the Total Coliform Count (TCC) ranged from 3.67 x 10^3 CFU/ml in Town market to 5.16 x 10^3 CFU/ml in Rumuokoro market. The highest coliform contamination was observed in Rumuokoro market, which may be due to the nearby Ntawogba creek, where improper sanitation practices could lead to increased bacterial contamination. The study also revealed significant contamination of whole fruits, with watermelon showing the highest bacterial load (1.01 x 10^5 CFU/ml), followed by pawpaw, apple, and orange, while cucumber had the lowest contamination.

Analysis of variance (ANOVA) for whole fruits revealed significant differences in contamination levels, with watermelon exhibiting notably higher bacterial counts than other fruits. The Tukey post hoc test confirmed that watermelon had significantly higher bacterial contamination compared to cucumber, orange, apple, and pawpaw. These findings align with previous studies by Afreen and Ahmed (2019), which also reported high bacterial contamination in watermelon. However, the contamination levels in this study were lower than those reported by Ajijolakewu and Salaudeen (2015) and Ajiboye and Emmanuel (2021) in Nigeria, as well as studies from Oman (Al-Kharousi et al., 2016).

The study further examined coliform contamination among the fruits, showing the highest Total Coliform Count (TCC) in watermelon, followed by pawpaw, orange, and apple, with cucumber having the lowest contamination. These results were consistent with a study by Mahfuza et al. (2016), which also identified watermelon as having higher coliform counts due to its proximity to soil and potential exposure to manure and contaminated irrigation water.

5. CONCLUSION

This study identified various bacteria associated with street-vended fruits like apples, cucumbers, oranges, pawpaws, and watermelons in Port Harcourt. The findings highlight the potential health risks posed by consuming these ready-to-eat fruits. Bacterial counts, including total heterotrophic and coliform counts, exceeded recommended safety standards, suggesting these fruits may transmit pathogens to consumers. The study emphasizes the need for vendors to improve hygiene practices, including proper handwashing, use of clean water, and sanitary food handling. Contamination likely stems from farms, improper food processing, and environmental factors. Additionally, the presence of antibiotic-resistant strains raises public health concerns. Therefore, street-vended fruits in Port Harcourt pose significant health risks, and enhanced sanitation measures are essential to ensure food safety and prevent disease outbreaks. Some bacteria were found to be antibiotic-resistant, further highlighting the need for better handling and processing methods to mitigate contamination risks.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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