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DOI: https://doi.org/10.18593/evid.36507

***Saúde***

# Gas chromatography-mass spectrometry profile and antibacterial efficacy of fixed oils from Moringa oleifera, Ficus exasperata, and Theobroma cacao against pathogens isolated from street-vended foods

## *Perfil por GC–MS e eficácia antibacteriana de óleos fixos de Moringa oleifera, Ficus exasperate e Theobroma cacao contra patógenos isolados de alimentos vendidos em vias públicas*

Olumide Oluyele (PhD)[1], Vivian Adetola Adejayan (BSC)[1], Ayomikun Isaac Obagbemi[1], Amaka Vivian Obasi (BSC)[1], Oluwole Opeyemi Owoyemi (PhD)[2], Adebola Tosin Gbadamosi (MSC)[1]

*[1] Department of Microbiology, Faculty of Science, Adekunle Ajasin University Akungba-Akoko, Nigeria; [2] Department of Microbiology, School of Life Sciences, Federal University of Technology, Akure Nigeria.*

Olumide Oluyele (PhD)*
olumide.oluyele@aaua.edu.ng, olumideoluyele@gmail.com
https://orcid.org/0000-0003-1810-4986

Vivian Adetola Adejayan (BSC)
Vivianadetola20@gmail.com
https://orcid.org/0009-0002-3818-3466

Ayomikun Isaac Obagbemi
ayomikunbagbem34@gm.com
Orcid not available

Amaka Vivian Obasi (BSC)
amakachia@gmail.com
https://orcid.org/0009-0007-0470-8224

Oluwole Opeyemi Owoyemi (PhD)
oluwoleowoyemi@gmail.com
https://orcid.org/0000-0002-8286-822X

Adebola Tosin Gbadamosi (MSC)
odchris88@gmail.com
https://orcid.org/0009-0003-1942-8218

*Corresponding author: full mailing address – olumide.oluyele@aaua.edu.ng; olumideoluyele@gmail.com

**Abstract**: Street-vended foods are frequently associated with microbial contamination, a major cause of foodborne illnesses. Plants, with their diverse chemical constituents, offer valuable sources of bioactive compounds with antimicrobial potential. This study evaluated the *in vitro* inhibitory activity of oils derived from *Moringa oleifera* seeds, *Theobroma cacao* pods, and *Ficus exasperata* leaves against antibiotic-resistant bacteria isolated from street-vended foods. A total of 48 food samples were randomly collected from eight vendors and analyzed using standard microbiological methods. Antibiotic susceptibility testing was performed by the disc diffusion technique, while fixed oils were extracted using Soxhlet apparatus and assessed for antibacterial activity through agar-well diffusion. Phytochemical constituents were identified using gas chromatography–mass spectrometry (GC–MS). Among the food samples, fufu recorded the highest bacterial load ($3.5 \times 10^4$–$7.5 \times 10^6$ cfu/g). The predominant isolates were *Escherichia coli, Salmonella* spp*., Bacillus* spp*., Staphylococcus aureus,* and *Enterococcus faecalis. Bacillus* spp*. and Salmonella* spp. exhibited the highest resistance among Gram-positive and Gram-negative isolates, respectively. The oils showed strong inhibitory activity, with zones of 15.0 ± 0.6 mm for *T. cacao* against *Bacillus* spp., 15.0 ± 0.6 mm for *F. exasperata* against *Bacillus* and *Salmonella typhi,* and 14.0 ± 0.6 mm for *M. oleifera* against *Streptococcus* spp. GC–MS analysis revealed the presence of fatty acids, sterols, and aromatic hydrocarbons as major constituents of the oils. The findings indicate that these plant-derived oils possess significant *in vitro* inhibitory potential against foodborne antibiotic-resistant pathogens and could serve as promising natural antimicrobial sources.

**Keywords**: Street-vended foods, Antibiotic-resistant bacteria, Fixed oil, *Moringa oleifera*, *Ficus exasperata*, *Theobroma cacao*.

**Resumo**: Alimentos vendidos em vias públicas estão frequentemente associados à contaminação microbiana, constituindo uma importante causa de doenças transmitidas por alimentos. As plantas, devido à diversidade de seus constituintes químicos, representam fontes valiosas de compostos bioativos com potencial antimicrobiano. Este estudo avaliou a atividade inibitória *in vitro* de óleos derivados de sementes de *Moringa oleifera*, vagens de *Theobroma cacao* e folhas de *Ficus exasperata* contra bactérias resistentes a antibióticos isoladas de alimentos vendidos em vias públicas. Um total de 48 amostras de alimentos foi coletado aleatoriamente de oito vendedores e analisado por métodos microbiológicos padronizados. O teste de suscetibilidade a antibióticos foi realizado pela técnica de difusão em disco, enquanto os óleos essenciais foram extraídos utilizando aparelho de Soxhlet e avaliados quanto à atividade antibacteriana por meio do método de difusão em ágar por poços. Os constituintes fitoquímicos foram identificados por cromatografia gasosa acoplada à espectrometria de massas (GC–MS). Entre as amostras analisadas, o fufu apresentou a maior carga bacteriana ($3{,}5 \times 10^4$–$7{,}5 \times 10^6$ UFC/g). Os principais isolados foram *Escherichia coli*, *Salmonella spp*., *Bacillus spp*., *Staphylococcus aureus* e *Enterococcus faecalis*. *Bacillus spp*. e *Salmonella spp*. apresentaram os maiores níveis de resistência entre os isolados Gram-positivos e Gram-negativos, respectivamente. Os óleos demonstraram forte atividade inibitória, com halos de 15,0 ± 0,6 mm para *T. cacao* contra *Bacillus spp*., 15,0 ± 0,6 mm para *F. exasperata* contra *Bacillus spp*. e *Salmonella typhi*, e 14,0 ± 0,6 mm para *M. oleifera* contra *Streptococcus spp*. Os principais compostos identificados por GC–MS incluíram benzeno, 1,2,3-trimetil; dodecano; ácido cis-11-eicosanoico; ácido octadecanoico; e ácido n-hexadecenoico. Os resultados indicam que esses óleos de origem vegetal possuem significativo potencial inibitório in vitro contra patógenos alimentares resistentes a antibióticos, podendo constituir fontes promissoras de agentes antimicrobianos naturais.

**Palavras-chave**: Alimentos vendidos em vias públicas, Bactérias resistentes a antibióticos, Óleo fixo, *Moringa oleifera*, *Ficus exasperata*, *Theobroma cacao*.

**Recebido:** 14/10/2024 | **Aceito:** 06/02/2026 | **Publicado:** 26/06/2026
**Editor:** Marcos Freitas Cordeiro

## INTRODUCTION

Street-vended foods (SVF), also referred to as street foods, are “foods and beverages prepared and/or sold by vendors in streets and other public places for immediate consumption or consumption at a later time without further processing or preparation” (WHO, 1996). They are popular because they are accessible, affordable, tasty, and convenient to produce. These foods are typically prepared from raw ingredients such as cereals, seafood, meat, nuts, and spices. Street food vending has a long history and is widespread in many countries, especially in low- and middle-income nations. Its growth is expected to continue due to increasing global population, urbanization, and changing consumer preferences (WHO, 2019). It also provides an important source of income for many low-income individuals, particularly women (Adeosun et al., 2022; Mazi et al., 2023).

While street-vended foods are essential for urban food supply and social interaction, they are frequently associated with microbial contamination—a major global public health challenge contributing significantly to foodborne diseases (Amare, 2019). Foodborne diseases remain a major health concern, particularly in developing countries, due to poor hygiene practices and limited awareness about food safety. In recent years, foodborne outbreaks have intensified owing to globalization and the active international trade of food products. According to the World Health Organization, contaminated food causes approximately 600 million cases of foodborne diseases and 420,000 deaths worldwide each year (WHO, 2024). Common illnesses associated with ready-to-eat foods include diarrhoea, dysentery, food poisoning, and hepatitis A (Fadahunsi et al., 2018; Kubde et al., 2016; Somda et al., 2018). Unhygienic practices such as inadequate sanitation at vending sites, poor water access, and improper waste disposal further contribute to pathogen transmission and health risks linked to street-vended foods.

The increasing prevalence of antibiotic-resistant foodborne bacteria underscores the urgent need for alternative treatment options, especially in resource-limited settings (Amare et al., 2019). The growing resistance problem is undermining the efficacy of conventional antibiotics, threatening to return global healthcare to a pre-antibiotic era.

Among plant-derived products, oils have gained increasing attention as potential sources of natural antimicrobial agents. These oils comprise diverse bioactive constituents, including triglycerides, fatty acids, terpenoids, phenolics, and other secondary metabolites, which collectively contribute to their wide range of pharmacological properties (Matera et al., 2023; Rey et al., 2023). Oils from medicinal plants have been reported to possess antimicrobial, antioxidant, hematopoietic and immunomodulatory activities, suggesting their potential usefulness as complementary agents in managing infectious diseases (Li et al., 2021; Oluyele et al., 2022; Oluyele et al., 2025a; Valdivieso-Ugarte et al., 2019).

Several medicinal plants are known to yield oils with diverse therapeutic applications. *Moringa oleifera* (locally known as Zogale in Hausa, Ewe igbale in Yoruba, and Okwe oyibo in Igbo) is a widely distributed medicinal plant found in tropical and subtropical regions. Traditionally, it is used to treat ailments such as stomach disorders, ulcers, poor vision, and joint pain. The plant exhibits antimicrobial, anti-inflammatory, antioxidant, and antitumor properties (Al-Asmari et al., 2015; Aondo et al., 2018). Its seeds are rich in macronutrients and secondary metabolites, including flavonoids, which enhance its medicinal and nutritional value (Singh et al., 2009).

*Theobroma cacao* (commonly called Cocoa and known locally in Nigeria as Koko in Yoruba, Kaka in Hausa, and Okoko in Igbo) is an evergreen tree of the Malvaceae family. It produces a variety of compounds such as theobromine, flavonoids, and aromatic terpenoids (Scapagnini et al., 2014). Cocoa pods contain significant levels of polyphenols, while the seeds are rich in psychoactive alkaloids like theobromine and caffeine. These contribute to its well-known antioxidant and aphrodisiac properties, as well as mood-enhancing effects through compounds like phenylethylamine (Zimmermann & Ellinger, 2020).

*Ficus exasperata* (commonly called Sandpaper tree, and locally known as Eepin in Yoruba, Anwerenwa in Igbo, and Kapa-kapa in Hausa) has a variety of traditional uses across Africa and Asia. In many communities, its leaves are used for polishing wood and stabilizing palm oil by reducing saponins and foaming while enhancing carotenoid content. Medicinally, various parts of the plant are used to manage a broad range of ailments including ophthalmic, oral, urinary, cardiac, skin, and respiratory infections, as well as for wound healing and pain relief (Bafor & Igbinuwen, 2009; Deepa et al., 2018).

Understanding the bacteriological quality of ready-to-eat foods is essential for identifying safety concerns and designing effective disease-prevention strategies. In Akungba-Akoko, street-vended foods are widely consumed by residents, students, and low-income earners due to their affordability and accessibility. However, the microbiological safety of these foods remains poorly documented.

This study therefore aimed to determine the bacteriological profile and antimicrobial susceptibility patterns of bacteria isolated from vended ready-to-eat foods in Akungba-Akoko. It also evaluated the antibacterial efficacy and GC–MS profile of fixed oils derived from *Moringa oleifera* seeds, *Theobroma cacao* pods, and *Ficus exasperata* leaves against antibiotic-resistant foodborne bacteria.

## METHODS

### *Collection and Processing of food samples*

A total of **48 street-vended food samples** were randomly purchased from **eight independent vendors** located across **different zones within Akungba-Akoko, Ondo State, Nigeria.** The food types included *Jollof rice, Fufu, Fried yam, Fried fish, Moi-moi, Semo, Kulikuli,* and *Dodo* (six samples per food type).

**Inclusion criteria:** Ready-to-eat foods purchased directly from active vendors operating in open vending environments during peak sales periods.

**Exclusion criteria:** Pre-packaged, reheated, or visibly spoiled foods were excluded.

Samples (approximately 100 g each) were aseptically collected using sterile spatulas into **sterile, labeled polyethylene containers.** The samples were immediately placed in **insulated cool boxes (4–8 °C)** and transported within **1 hour** to the **Microbiology Laboratory, Adekunle Ajasin University, Akungba-Akoko,** for microbiological analysis. Ten grams of each homogenized food sample was added to 90 mL of sterile distilled water, followed by **six-fold serial dilution** (Amare et al., 2019). Using the **pour plate method**, 1 mL aliquots from each dilution were plated in duplicates on **Nutrient agar, MacConkey agar, and Eosin Methylene Blue (EMB) agar** and incubated at **37 °C for 24 hours**. Total viable counts were determined, and discrete colonies were purified by sub-culturing. Pure isolates were maintained on **double-strength Nutrient Agar slants at 4 °C** for further use.

### *Identification of isolates*

Preliminary characterization of the bacterial isolates was based on Gram staining, morphological and cultural characteristics. Further characterization was carried out with various biochemical tests viz: catalase, citrate utilization, urease, indole, oxidase, Voges-prokauer, methyl-red, motility, triple sugar iron, starch hydrolysis, and sugar fermentation tests (Olotu et al., 2020; Oluyele et al., 2023).

### *Antibiotic Susceptibility testing*

The susceptibility of the isolates to commercially available antibiotics were determined using the disc diffusion method. The bacterial colony was suspended into sterile Mueller–Hinton broth, and standardized using McFarland's turbidity standard. The standardized suspension was then inoculated onto the solidified agar plate, and the antibiotic-treated disc was aseptically tapped on the inoculated plate. The disc containing the antibiotic was allowed to diffuse through the solidified agar, resulting in the formation of an inhibition zone after the overnight incubation at 37 °C for 24 hrs. Thereafter, the size of the inhibition zone formed around the antibiotic disc was measured (Oluyele & Oladunmoye 2017).

### *Collection of Plant Materials and Plant Oil Extraction*

*Moringa oleifera* seeds and *Ficus exasperata* leaves were sourced from the Akungba-Akoko environs, while *Theobroma cacao* pods were obtained from a farm in Lasia. The plant materials were authenticated by a botanist at the Department of Plant Science and Biotechnology, Adekunle Ajasin State University, Akungba-Akoko, Nigeria. The extraction process followed the procedure described by Fagbemi et al. (2021) with slight modifications. Precisely weighed samples of *M. oleifera* (634.4 g), *T. cacao* (680.6 g), and *F. exasperata* (671.7 g) were air-dried, pulverized, and extracted separately using an n-hexane solvent (analytical grade, ≥99.0%, Sigma-Aldrich) in a Soxhlet apparatus fitted with a condenser and a 250 mL round-bottom flask. For each plant material, 200 mL of n-hexane was used per extraction cycle, and the process was maintained at the boiling point of n-hexane (≈68 °C) for 6–8 hours until the solvent in the siphon tube became clear, indicating exhaustive extraction. The solvent-oil mixture obtained was concentrated by distillation to recover the solvent, followed by drying at 40 °C in a water bath to constant weight. Complete removal of the solvent was confirmed by the absence of solvent odor and stable extract weight after two consecutive measurements. The dried oils were stored in airtight amber glass bottles at 4 °C until further analysis. The yield of the plant oils extracted was using the formula:

$$\text{Oil yield (w/w \%)} = \frac{\text{Weight of extracted oil (g)}}{\text{Weight of pulverized plant material (g)}} \times 100$$

## GAS CHROMATOGRAPHY MASS SPECTROMETRIC ANALYSIS (GCMS) OF EXTRACTED OILS

The chemical composition of the extracted oils was analyzed using a Shimadzu GC–MS system (QP2010 Ultra, Kyoto, Japan) equipped with a fused silica capillary column (Rtx-5MS; 30 m × 0.25 mm i.d., 0.25 µm film thickness). High-purity helium (99.999%) was used as the carrier gas at a constant flow rate of 1.0 mL/min. The injector temperature was set at 250 °C, and 0.5 µL of each oil sample, diluted in n-hexane, was injected in split mode (1:5). The oven temperature was initially held at 60 °C for 2 min, ramped to 180 °C at 3 °C/min, then to 300 °C at 10 °C/min, and held for 10 min. The interface and ion source temperatures were maintained at 280 °C, and ionization was performed in electron impact (EI) mode at 70 eV. The quadrupole mass analyzer scanned ions in the m/z range of 40–500 Da, and detection was achieved by an electron multiplier detector. Identification of compounds was based on comparison of their mass spectra with those in the NIST 14 and Wiley libraries and by calculating their retention indices (RI) relative to a homologous series of n-alkanes (C7–C28) analyzed under identical conditions. Only compounds showing a match factor (MF) of ≥85% and consistent retention time (RT) and RI values with reference data were reported. Data acquisition and processing were carried out using GC–MS Postrun Analysis software (LabSolutions, Shimadzu) (Teneva et al., 2019).

### *Susceptibility Testing of Extracted Oils*

Antibacterial activity of the extracted oils was evaluated using the agar-well diffusion method as described by Oluyele and Oladunmoye (2017), with slight modifications. Mueller–Hinton agar (MHA) was prepared and sterilized according to the manufacturer's instructions, poured into sterile Petri dishes, and allowed to solidify. Each test bacterial isolate was standardized to 0.5 McFarland turbidity (≈1 × $10^8$ CFU/mL) and uniformly swabbed onto the surface of the agar using sterile cotton swabs. Wells of 8 mm diameter were aseptically bored into the agar with a sterile cork borer. Test solutions of the oils were prepared by dissolving each oil in 0.5% (v/v) dimethyl sulfoxide (DMSO) to obtain a working concentration of 100 mg/mL. From this solution, 50 µL was carefully dispensed into each well. Plates were left at room temperature for 30 minutes to allow diffusion before incubation at 37 °C for 24 hours. The diameters of the inhibition zones were measured in millimeters (mm), and all assays were carried out in triplicate (n = 3) to ensure reproducibility. A separate well containing only 0.5% DMSO served as a negative control, and preliminary tests confirmed that 0.5% DMSO exhibited no inhibitory effect on the bacterial isolates.

### *Determination of Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration*

The antimicrobial activity of the test oils was assessed using the microdilution method in a 96-well (Li et al., 2019). Stock solutions (1000 mg/mL) of each oil were prepared in 0.5% (v/v) DMSO. Twofold serial dilutions were made in Mueller–Hinton broth (MHB) to obtain final concentrations of 100, 50, 25, 12.5, 6.25, and 3.125 mg/mL in a 96-well microtiter plate. Each well received 100 µL of the oil dilution and 100 µL of standardized bacterial suspension (≈$1 \times 10^6$ CFU/mL). Plates were incubated at 37 °C for 24 hours. Bacterial growth was assessed by measuring turbidity at 600 nm using a spectrophotometer (Beckman Model 35). The MIC was defined as the lowest concentration of oil showing no visible growth or significant turbidity increase relative to the negative control. For MBC determination, a loopful of culture from wells showing no visible growth was streaked onto sterile MHA plates and incubated at 37 °C for 24 hours. The lowest concentration at which no bacterial colonies appeared was recorded as the MBC.

### *Data Analysis*

Experiments were conducted in triplicate, and the data obtained were expressed as mean ± standard error of the mean (SEM). Data from the antibacterial assays were analyzed using IBM SPSS Statistics version 25.0 (IBM Corp., Armonk, NY, USA). Differences between groups were assessed using One-Way ANOVA, followed by Tukey´s post-hoc test. Results were considered statistically significant at $p < 0.05$.

## RESULTS

### *Colony count and Bacterial profile of Street-vended food samples in Akungba*

In this investigation, nine (9) different types of commonly vended ready to eat food samples were examined for bacterial contamination. Results showed that all the food samples were contaminated with varying levels of bacterial loads. Table 1 shows the variations in bacterial presence and the bacterial count in the food samples. *Bacillus* spp had the highest frequency of occurrence and *Lactococcus* spp had the lowest occurrence. Fufu had the highest bacterial count range of $3.5 \times 10^4$ – $7.5 \times 10^6$ cfu/g while Yam showed the lowest count of $1.0 \times 10^4$ - $4.0 \times 10^6$ cfu/g.

### *Antibiotics Susceptibility Patterns of Bacterial Isolates from Street-vended foods*

Table 2 shows the antibiotic susceptibility profile of bacterial isolates from the food samples. *Bacillus* spp elicited the highest level of resistance while *Enterococcus faecalis* portrayed the lowest level of resistance to the antibiotics employed for Gram positive bacteria. For Gram-negative bacterial isolates, *Salmonella* spp showed the highest level of resistance, while *Shigella* spp showed the lowest resistance.

### *Percentage Yields and Antibacterial Activities of Oils from* ***T. cacao, M. oleifera,*** *and* ***F. exasperata*** *Against Bacterial Isolates from Street-vended Foods*

The oil yields obtained from the extraction process was 6.81%, 13.61%, and 8.71%, for *T. cacao, M. oleifera,* and *F. exasperata* respectively, the results are depicted in Figure 1. As presented in Table 3, the oils demonstrated appreciable activities against the test organisms with the highest inhibition zone recorded as 15 mm for *T. cacao* against *Bacillus* spp, and against *Bacillus* and *Salmonella typhi* for *F. exasperata;* while a zone of 14mm was the highest recorded for *M. oleifera* against *Streptococcus* spp. The minimum inhibitory concentration of the oils against the test organisms ranged between 25 to 50 mg/mL across the board. The results are depicted in Table 4.

### *GC-MS Identified Compounds in the Fixed Oils from* ***T. cacao, M. oleifera,*** *and* ***F. exasperate***

The results of the GC-MS analyses of the oils are presented in Tables 5 to 7. Amongst the compounds identified, in *T. cacao* oil Benzene, 1,2,3-trimethyl- (36.05%), Dodecane (21.97%), Benzene, 1,2,4-trimethyl- (8.22%) were the most abundant; while cis-11-Eicosanoic acid (35.7%), Octadecanoic acid (20%) and n-Hexadecenoic acid (12.24%) were predominant in *M. oleifera*; and Benzene, 1,2,3-trimethyl- (31.77%), Undecane (21.11%), Benzene, 1,2,4-trimethyl- (6.48%), Decane, 4-methyl- (4.73%) were found to be the most abundant in *F. exasperata* oil.

Table 1
Colony count and types of bacteria isolated from street-vended foods in Akungba-Akoko

| Food Sample | Bacterial load range (cfu/g) | Isolated bacteria |
|---|---|---|
| Fried rice | 1.0 × 104 - 7.0 × 106 | Bacillus spp, Streptococcus spp, Enterococcus faecalis, Clostridium spp |
| Moi moi | 1.5 × 104 - 4.5 × 106 | Bacillus spp, Shigella spp. |
| Dodo | 1.6 × 104 - 4.0 × 106 | Streptococcus spp, Salmonella spp, Bacillus spp |
| Fufu | 3.5 × 104 - 7.5 × 106 | Streptococcus spp Bacillus spp, Bacillus spp, Clostridium spp Lactobacillus spp. |
| Yam | 1.0 × 104 - 4.0 × 106 | Lactococcus spp |
| Jollof rice | 1.0 × 104 - 5.6 × 106 | Escherichia coli, Salmonella spp |
| Kuli kuli | 1.1 × 104 - 4.0 × 106 | Staphylococcus aureus, Bacillus spp |
| Beans | 1.0 × 104 - 6.0 × 106 | Bacillus spp, Salmonella spp., |
| Fish | 1.0 × 104 - 7.0 × 106 | Escherichia coli |

Table 2
Phenotypic resistance profile of bacterial isolates from street-vended foods in Akungba-Akoko

| Test organisms | Resistance profile |
|---|---|
| Bacillus cereus | ST, NB, CH, APX, RD, AMX |
| Bacillus subtilis | ST, NB, CH, APX, RD, AMX |
| Streptococcus spp | NB, APX, RD, AMX |
| Staphylococcus aureus | NB, CH, APX, RD, AMX |
| Salmonella typhi | PN, CEP, OFX, NA, PEF, CN, AU, SXT |
| Lactobacillus spp | ST, NB, CH, APX, RD, AMX |
| Shigella dysenteriae | PN, NA, PEF, AU, CPX, SXT |
| Enterococcus faecalis | NB, E, APX, AMX |
| Clostridium perfringens | NB, CH, E, LEV, CN, APX, RD, AMX |
| Lactococcus spp | ST, NB, CH, E, LEV, CN, APX, RD |
| Escherichia coli | PN, CEP, OFX, NA, CPX, CN, AU, SXT |

Legend: ST- Streptomycin, APX- Ampiclox, CPX- Ciprofloxacin, E- Erythromycin, AMX- Amoxicillin, NB- Novobiocin, LEV- Levofloxacin, CN- Gentamycin, CH- Chloramphenicol, RD- Rifampin, CPX- Ciprofloxacin, SP- Streptomycin, SXT- Septrin, CN- Gentamycin, PN- Ampicillin, CEP- Ceporex, PEF- Pefloxacin, OFX- Tarivid, AU- Augmentin, NA- Nalidixic acid

Figure 1
Yields of Oils from T. cacao, M. oleifera, and F. exasperata

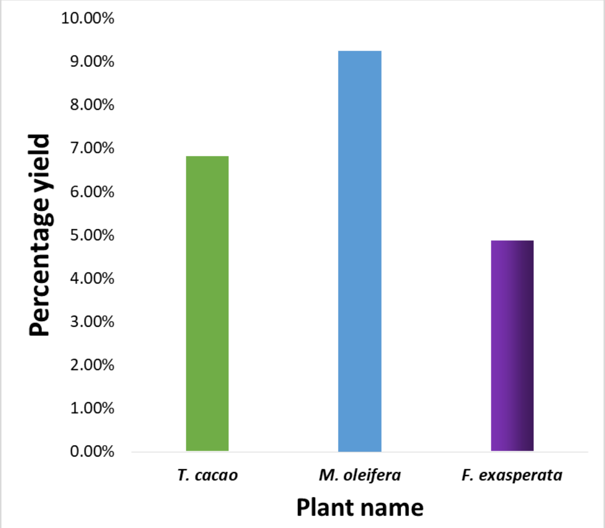

Table 3
Antibacterial Activities of Fixed Oils from T. cacao, M. oleifera, and F. exasperata against Bacterial Isolates from street-vended foods

| Test organism | Zone of inhibition (mm) | | |
|---|---|---|---|
| | T. cacao | F. exasperata | M. oleifera |
| Bacillus cereus | 15 ± 0.6 | 14 ± 0.5 | 13 ± 0.5 |
| Bacillus subtilis | 15 ± 0.7 | 15 ± 0.6 | 13 ± 0.5 |
| Streptococcus spp | 10 ± 0.4 | 13 ± 0.6 | 14 ± 0.6 |
| Staphylococcus aureus | 10 ± 0.5 | 10 ± 0.4 | 13 ± 0.5 |
| Salmonella typhi | 10 ± 0.4 | 15 ± 0.7 | 0 ± 0.0 |
| Lactobacillus spp | 15 ± 0.7 | 8 ± 0.3 | 13 ± 0.5 |
| Shigella dysenteriae | 10 ± 0.4 | 10 ± 0.5 | 10 ± 0.4 |
| Enterococcus faecalis | 10 ± 0.4 | 13 ± 0.6 | 10 ± 0.4 |
| Clostridium perfringens | 10 ± 0.4 | 10 ± 0.4 | 0 ± 0.0 |
| Lactococcus spp | 13 ± 0.5 | 13 ± 0.5 | 0 ± 0.0 |
| Escherichia coli | 10 ± 0.5 | 13 ± 0.6 | 13 ± 0.5 |

Table 4
Minimum Inhibitory Concentration of Oils from T. cacao, M. oleifera, and F. exasperata against Bacterial Isolates from Street-vended foods

| Organisms | Concentration (mg/mL) | | |
|---|---|---|---|
| | T. cacao | F. exasperata | M. oleifera |
| Bacillus subtilis | 25 | 50 | 50 |
| Bacillus cereus | 50 | 25 | 50 |
| Streptococcus spp | 50 | 25 | 50 |
| Salmonella typhi | 25 | 50 | 50 |
| Staphylococcus aureus | 50 | 50 | 25 |
| Lactobacillus spp | 50 | 50 | 50 |
| Shigella dysenteriae | 50 | 50 | 50 |
| Enterococcus faecalis | 50 | 50 | 50 |
| Clostridium spp | 50 | 25 | 50 |
| Lactococcus spp | 50 | 25 | 25 |
| Escherichia coli | 50 | 50 | 25 |

Table 5
GC–MS Identified Compounds in Moringa oleifera Oil Extract

| Peak # | Peak Area (%) | Compound Name |
|---|---|---|
| 1 | 0.75 | Nonane, 3-methyl- |
| 2 | 0.87 | 1,1-Bicyclohexyl, 2-methyl-, trans- |
| 3 | 0.34 | Cyclohexane, 1-methyl-4-(1-methylethylethy)- |
| 4 | 9.12 | 1,2,3-Trimethylbenzene |
| 5 | 5.43 | Undecane |
| 6 | 2.07 | 1,2,4-Trimethylbenzene |
| 7 | 1.24 | Decane, 4-methyl- |
| 8 | 0.71 | Cyclohexane, butyl- |
| 9 | 0.76 | Benzene, 1-ethyl-2,3-dimethyl- |
| 10 | 0.73 | Decahydronaphthalene |
| 11 | 1.06 | Dodecane |
| 12 | 0.34 | 4-Caranone |
| 13 | 0.38 | Naphthalene, decahydro-2-methyl- |
| 14 | 3.03 | cis-9-Hexadecenoic acid |
| 15 | 12.24 | n-Hexadecenoic acid |
| 16 | 1.88 | Ethyl hexadecanoate |
| 17 | 35.71 | cis-11-Eicosanoic acid |
| 18 | 20.00 | Octadecanoic acid |
| 19 | 0.96 | cis-13-Eicosenoic acid |
| 20 | 1.54 | 9-Eicosanoic acid |
| 21 | 0.49 | Docosanoic acid |
| 22 | 0.34 | Squalene |

Table 6
GC–MS Identified Compounds in Ficus exasperata Oil Extract

| Peak # | Peak Area (%) | Compound Name |
|---|---|---|
| 1 | 3.11 | Nonane, 3-methyl- |
| 2 | 3.16 | Bicyclo[3.1.0]hexan-2-one, 5-(1-methylethyl)- |
| 3 | 1.43 | Cyclohexane, 1-methyl-4-(1-methylethyl)-, cis- |
| 4 | 31.77 | 1,2,3-Trimethylbenzene |
| 5 | 21.11 | Undecane |
| 6 | 6.48 | 1,2,4-Trimethylbenzene |
| 7 | 4.73 | Decane, 4-methyl- |
| 8 | 2.71 | Cyclohexane, butyl- |
| 9 | 1.09 | 1-Decanol, 2-octyl- |
| 10 | 1.40 | 1-Octadecanesulphonyl chloride |
| 11 | 1.15 | Benzene, 1-methyl-3-propyl- |
| 12 | 2.67 | Benzene, 1-ethyl-2,3-dimethyl- |
| 13 | 2.91 | Naphthalene, decahydro-, trans- |
| 14 | 1.18 | 2-Methyltetracosane |
| 15 | 1.19 | Decane, 3-methyl- |
| 16 | 1.08 | Carveol |
| 17 | 4.68 | n-Dodecane |
| 18 | 1.31 | 2-Methyldecahydronaphthalene |
| 19 | 1.47 | Naphthalene, decahydro-2-methyl- |
| 20 | 0.58 | Cyclohexane, pentyl- |
| 21 | 0.28 | 2,2-Dimethyl-6-methylene-1-[3,5-dihydroxy-1-pentenyl]cyclohexan-1-perhydrol |
| 22 | 1.05 | γ-Sitosterol |
| 23 | 0.98 | 9,19-Cyclolanost-23-ene-3,25-diol |
| 24 | 0.80 | 4,22-Stigmastadiene-3-one |
| 25 | 1.68 | β-Hydroxy-5-cholen-24-oic acid |

Table 7
GC–MS Identified Compounds in Theobroma cacao Oil Extract

| Peak # | Peak Area (%) | Compound Name |
|---|---|---|
| 1 | 3.28 | Nonane, 3-methyl- |
| 2 | 3.36 | Bicyclo[3.1.0]hexan-2-one, 5-(1-methylethyl)- |
| 3 | 36.05 | 1,2,3-Trimethylbenzene |
| 4 | 21.97 | Dodecane |
| 5 | 8.22 | 1,2,4-Trimethylbenzene |
| 6 | 4.85 | Decane, 4-methyl- |
| 7 | 3.30 | Benzene, 1-ethyl-2,3-dimethyl- |
| 8 | 3.13 | Decahydronaphthalene |
| 9 | 4.47 | Undecane |
| 10 | 1.59 | Naphthalene, decahydro-2-methyl- |
| 11 | 0.75 | Campesterol |
| 12 | 1.83 | Stigmasterol |
| 13 | 3.80 | β-Sitosterol |
| 14 | 0.93 | Cholest-5-en-3-ol, 24-propylidene-, (3β)- |
| 15 | 0.58 | Thunbergol |
| 16 | 0.64 | 4,22-Stigmastadiene-3-one |
| 17 | 1.25 | 9(11)-Dehydroergosteryl benzoate |

## DISCUSSION

Food plays an essential role in sustaining human life but can also act as a vehicle for disease transmission when contaminated by pathogenic microorganisms. Foodborne pathogens are among the leading causes of global morbidity, with significant public health and economic impacts (Bintsis, 2017; Buliyaminu, 2016). This study investigated the antimicrobial activity of fixed oils from *Theobroma cacao*, *Ficus exasperata*, and *Moringa oleifera* against multidrug-resistant (MDR) bacteria isolated from street-vended foods in Akungba-Akoko.

The detection of diverse bacterial genera, including both Gram-positive and Gram-negative species in this study, underscores the high microbial burden of these foods and highlights the potential risks associated with inadequate hygiene during preparation and storage. The isolates recovered were similar to those reported in other studies (Teklit & Tadesse, 2016), with *Bacillus* spp. being the most frequently occurring, detected in six of the samples. *Escherichia coli, Salmonella* spp., *Clostridium* spp., and *Streptococcus* spp. were found in at least two food types, while *Lactobacillus* spp. and *Lactococcus* spp. occurred less frequently. The high frequency of *Bacillus* and *Clostridium* spp.—particularly in fufu and fried rice—suggests the potential for toxin-mediated food poisoning due to post-processing contamination.

Among the various microorganisms found in the gastrointestinal system are facultative anaerobes such as *Enterococcus, Lactobacillus,* and *Lactococcus*, which were also isolated in this study (Quera et al., 2005). Many of these lactic acid bacteria (LAB) are categorized as probiotics and are typically commensal, without significant pathogenic potential (Cortés-Sánchez et al., 2015). However, their presence in ready-to-eat foods indicates lapses in hygiene during handling, preparation, or storage. The occurrence of *Streptococcus* spp. in fried rice, dodo, and fufu further indicates contamination through respiratory droplets or skin lesions from handlers. Respiratory carriers may disseminate streptococci through sneezing or coughing, while contaminated hands can easily introduce these organisms into food (Katzenell et al., 2001). Similarly, the isolation of *Shigella* spp. from moi-moi and *Enterococcus faecalis* from fried rice, as well as *E. coli* and *Salmonella* spp. from jollof rice, fish, and dodo, reflects fecal contamination and poor hygienic practices

**among food vendors. These organisms are well-known etiological agents of diarrhoea, gastroenteritis, fever, and abdominal cramps in exposed individuals. The detection of *Staphylococcus aureus* in kuli-kuli also points to poor personal hygiene, improper storage facilities, and low-quality raw materials, as previously observed by Edeh (2012).**

**The high bacterial counts observed, particularly in moist foods such as fufu, likely reflect extensive handling and prolonged holding at ambient temperatures conducive to microbial growth. Conversely, the lower counts in yam and kuli-kuli may be attributed to their low moisture content, which restricts bacterial proliferation. Similar findings have been reported in other street food studies linking poor sanitation, water quality, and storage conditions to elevated microbial loads (Kariuki et al., 2017; Mostafa et al., 2018). These results emphasize the need for improved food hygiene practices, vendor education, and regular health inspections to prevent outbreaks of foodborne illnesses.**

**Antimicrobial resistance (AMR) has emerged as one of the most pressing global health challenges, threatening the effective treatment of infectious diseases and undermining decades of medical progress (Awolope et al., 2020; Oluyele et al., 2025b; Osei et al., 2024). The increasing prevalence of resistant bacteria in food systems presents an added public health concern, as contaminated foods can act as reservoirs and transmission vehicles for resistant strains (**Okaiyeto et al., 2024; **Samtiya, 2022). In this study, the antibiotic resistance profiles observed—Gram-positive isolates resistant to novobiocin, chloramphenicol, and amoxicillin, and Gram-negative isolates resistant to ampicillin, nalidixic acid, and augmentin—reflect global trends in the dissemination of AMR through food chains.**

Plants have served as vital sources of medicinal compounds since ancient times. The multifunctional properties of their diverse phytoconstituents make them valuable candidates for pharmacological exploration and the discovery of new therapeutics (Oluyele et al., 2025b). In this study, the fixed oils extracted from *Moringa oleifera, Ficus exasperata,* and *Theobroma cacao* exhibited measurable antimicrobial activity against antibiotic-resistant bacterial strains, with inhibition zones ranging from 8 to 15 mm. These findings suggest that the oils contain bioactive compounds capable of suppressing microbial growth even in multidrug-resistant (MDR) organisms. The observed variation in antimicrobial efficacy may be attributed to differences in phytochemical composition, extraction efficiency, and the intrinsic susceptibility of target organisms (Oluyele, 2025). GC–MS profiling of the oils revealed several bioactive constituents—including β-sitosterol, n-hexadecenoic acid, octadecanoic acid, squalene, and stigmasterol—previously reported to possess antimicrobial and membrane-disrupting properties (Alawode et al., 2021; Patra, 2012; Rahman et al., 2014). Fatty acids such as palmitic and oleic acids can destabilize bacterial membranes and interfere with essential enzyme systems (Obukhova & Murzina, 2024), while sterols and terpenoids enhance membrane permeability and attenuate pathogenicity (Lapshin et al., 2025; Raza et al., 2023; Swamy et al., 2017). The synergistic interaction among these phytochemicals likely underpins the antimicrobial potential observed in the present study. The presence of low-molecular-weight aromatic hydrocarbons and linear alkanes, such as trimethylbenzenes, dodecane, and undecane, may be associated with the non-polar nature of the extraction solvent and the thermal conditions employed during Soxhlet extraction. Similar profiles have been reported in GC–MS analyses of hexane-extracted plant fixed oils, where co-extraction of volatile and semi-volatile hydrocarbons may occur.

**Comparatively, essential oils from these plants differ significantly in composition and potency. For example, *M. oleifera* essential oil contains volatile compounds such as 1,4-bis(trimethylsilyl)benzene and 11-octadecenoic acid methyl ester, whereas *F. exasperata* essential oil is dominated by 1,8-cineole, (E)-phytol, and p-cymene (Sonibare et al., 2006). Similarly, T. cacao pyrolysis bio-oil primarily contains 9,12-octadecadienoic acid (Adjin-Tetteh et al., 2018). These differences demonstrate the influence of extraction methods and solvent polarity on the yield and profile of bioactive constituents. Essential oils,**

**rich in volatile terpenoids, typically exhibit stronger antimicrobial effects than fixed oils, which are composed mainly of long-chain fatty acids and esters. The moderate activity observed for the fixed oils in this study may therefore reflect their lower volatility and differing modes of action.**

**Comparable findings have been reported for** *Phoenix dactylifera* **seed essential oil, which exhibited broad-spectrum activity against several MDR bacteria, with inhibition zones of 14.33–31.33 mm and MICs between 3.91–125 µg/mL (Oluyele, 2025). This supports the potential of plant-derived oils as reservoirs of multifunctional antimicrobial agents. However, the relatively lower inhibition values obtained here highlight the influence of extraction solvent and compound polarity on biological activity.**

**Overall, the antimicrobial potential of the fixed oils suggests possible applications as natural preservatives or complementary therapeutics against foodborne pathogens. Nonetheless, certain limitations should be acknowledged: the study was restricted to a single geographical area and employed only in vitro assays. Future research should explore in vivo models to assess safety, bioavailability, and therapeutic efficacy, and include comparative analyses using essential oils and diverse extraction methods.**

**In conclusion, oils extracted from** *M. oleifera*, *T. cacao*, **and** *F. exasperata* **exhibited measurable antimicrobial activity against foodborne MDR pathogens, supporting their potential as alternative antimicrobial agents. Their bioactivity is likely driven by a combination of fatty acids, sterols, and terpenoids. Further studies integrating chemical standardization, toxicity profiling, and formulation development are warranted to establish their suitability for practical or clinical applications.**

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