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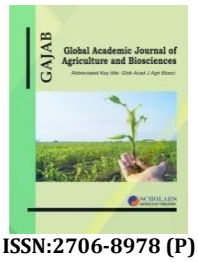

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Original Research Article

Phytomedicinal Potential of Mentha Arvensis *(Mint leaves)* and Cymbopogon Citratus *(Lemongrass)* Essential Plant Extracts against Virulent Proteus Hauseri and Providencia Stuartii

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Abstract: Medicinal plants have long played a vital role in sustaining life on Earth. *Mentha arvensis* (mint leaves) and *Cymbopogon citratus* (lemongrass) were collected under sterile conditions and transported to the laboratory at Usmanu Danfodiyo University, where they were air-dried for 3 weeks. Plant biomass was ground into powder using a mechanical grinder at a 10:90 ratio. Fresh samples were processed for preservation and deposition in the herbarium. The plant biomass was soaked with analytical-grade reagents obtained from Joechem Ventures in Rivers State, Nigeria. After removal of the solvent by standard Soxhlet extraction, the extract underwent physicochemical, proximate, and antimicrobial analyses. Bacterial isolates were obtained from virulent samples collected from slaughterhouse effluent in Badagry, Lagos State, and identified by 16S rRNA gene sequencing of genomic extracts. The well-in-agar approach was used to assess antibacterial potency. *Mentha arvensis* and *Cymbopogon citratus*, commonly known as mint leaves and lemongrass, respectively, had accession numbers ECU-FS-EE01 and ECU-FS-EE02. Phytochemical components such as flavonoids, alkaloids, phenols, tannins, and glycosides were identified in the leaves of both plants used in the study, and steroids were confirmed in Mentha arvensis. The crude lipid, fiber, and protein contents of Mentha *arvensis* were 3.12%, 5.83%, and 4.39% w/w, respectively, while those of *Cymbopogon citratus* were 3.69%, 8.21%, and 4.03% w/w, respectively. The biomass yields of *Mentha arvensis* leaves were 3.18, 5.08, and 6.33 g/w in water, ethyl ether, and n-hexane, respectively, while those of *Cymbopogon citratus* were 4.67, 6.17, and 6.445 g/w in the same solvents. The mint leaf extract exhibited optimal activity against the isolates, with *Proteus hauserii* identified as the most resistant and *Providencia stuartii* as the most sensitive to the ethyl ether extract. Synergistic evaluation indicated that a 70:30 mixture of mint leaves and lemongrass in ethyl ether exhibited the strongest synergy against the bacterial isolates. There is a need for academia to develop a robust library of pharmaceutical preparations to combat virulent bacteria that commonly interact with humans and their ecosystems.

Keywords: Antibacterial Synergy, *Mentha Arvensis*, *Cymbopogon Citratus*, Agar Well Diffusion, Phytomedicinal Potency.

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1.0 INTRODUCTION

Phytomedicine has existed for ages because plants have provided solutions to humanity's unending health challenges. Plants have been identified as possessing both dietary and medicinal attributes (Sada *et al.,* 2023). The evolution and design of drug discovery still have a strong grip on the bioactive phytochemicals, whether as indigenous or cultivated plant species. The recovery and application of crude plant extracts, or the regulation of traditional medicine, have posed several challenges to the acceptance and transition to purified plant-derived products, including misuse and abuse, dosage and administration, and side effects (Aliu *et al*., 2025). Investments and interventions by funding agencies in the development of novel products have suffered setbacks in recent times due to low clinical acceptability indices and complex and protocol design for compound purification (Zeng *et al*., 2022).

Mentha species are herbs in the family Lamiaceae, native to Africa, Australia, and India. They are perennial plants ranging from 40 to 120 cm in height (Ahmad *et al.,* 2020). The popular varieties are Mentha *arvensis*, *M. piperita*, and *Mentha spicata*, which are native to Nigeria and widely used in toothpaste production (Hudz *et al.,* 2023). It is an aromatic plant of diverse value. It is used in flavoring, dyes, and cosmetics. The food and beverage industries have explored the plant and its extract in the production of teas and herbal formulations (Świątek *et al*., 2024). This herb has found applications in the pharmaceutical, medical, and food sectors because its extract has the potential to treat headache, nausea, and vomiting. The use of Mentha sp. as a culinary additive is a folk remedy for digestive disorders and ulcerative conditions (Amtaghri *et al*., 2024). The plant has been used for its antibacterial, antifungal, and antiviral properties in the treatment of gastrointestinal infections. Phytochemicals include limonene, dihydrocarvone, and 1,8-cineole; Daiya *et al*., (2026) reported that the mint extract possesses antiseptic, antipyretic, antispasmodic, antimicrobial, rubefacient, and anti-aging properties.

Lemongrass, also known as *Cymbopogon citratus*, is a common medicinal plant in the Poaceae family (Luang-In *et al*., 2024). It is a tall, tufted grass with a characteristic aroma attributed to its rich phytochemical profile; it is a clumping perennial, invasive plant with strong adaptability to adverse conditions (Gebashe *et al*., 2020). The phytochemical components of lemongrass and its extracts include beneficial phytomedical geometric isomers, especially limonene and myrcene, which have been reported to exhibit antagonistic and antinutrient effects (Cortes-Torres *et al*., 2023). It is widely cultivated in several parts of Africa, America, and Asia; it is also used for domestic and nutraceutical purposes, such as tea production, food and feed supplements, and culinary spice production (Riar *et al*., 2024). This is because the plant is rich in Vitamins A, B, and C, as well as minerals such as calcium, iron, and potassium, which are needed as dietary supplements. The pharmacological benefits of the plant include anti-inflammatory, analgesic, antioxidant, gastrointestinal, and anti-colorectal cancer potential (Mukkavilli *et al*., 2026). The antimicrobial activities of lemongrass oil have been shown to antagonize *Staphylococcus epidermidis*, *Enterococcus faecalis, Escherichia coli,* and *Klebsiella pneumoniae*, acting mainly by inactivating peptidoglycan function and inducing efflux pump activity (Alsakhawy *et al*., 2024). The present study evaluated the antimicrobial activity of solvent extract of *Mentha arvensis* (Mint leaves) *and Cymbopogon citratus* (Lemongrass) *against* virulent *Proteus hauserii and Providencia stuartii*.

2.0 MATERIALS AND METHODS

Collection and Identification of Plant Species

The fresh leaves of lemongrass and mint were harvested at Marmaron Tonka Irrigation lands along Sokoto-Bodinga Road, in Bodinga Local Government Area of Sokoto State, Nigeria, while the georeferenced location of the plant was obtained using a mobile device. The plant part was excised, sampled, and a sterile bag was used to collect and transport the leaves and stem to the Austino laboratory at Alakahia, by the University of Port Harcourt Teaching Hospital main gate, Port Harcourt, Rivers State, Nigeria (Gebashe *et al*., 2020).

Identification of the Plant

The plant was transported to the herbarium of the Department of Biological Science, Usmanu Danfodiyo University, Sokoto. The plants were air-dried and treated with a pesticide to prevent insect attacks. The accession number was obtained after the plant, its fruits, and seeds were archived in the drawers, while pictures of the plants were used to further authenticate their identity.

Preparation and Extraction of the Plant Obtained from Lemon Grass and Mint Leave

The modified method of Jha and Sit, (2022) was employed at this stage of the work, where the leaves and stems of the plants were air-dried at room temperature (25 ± 2˚C) for six weeks; the plant biomass was placed in a desiccator and reweighed until the weight was constant. The plant was pulverized using a cleaned mechanical blender. The yield was determined using conventional arithmetic methods while biomass was loaded in a 2-L glass jar containing 80% of diethyl ether, n-hexane and sterile water, 20% plant biomass, while a headspace of 20% of the container was sealed with a cotton plug, and

left to stand for 4 days while it was shaken intermittently to homogenize the solvent, the solvent was strained using a sterile mesh supported with a Whatmann filter paper.

The solvent was extracted from the plant broth using a Soxhlet extractor at the Central laboratory, Usmanu Danfodiyo Sokoto State, Nigeria. The plant biomass slurry was prepared at the concentrations used in the study.

Phytochemical Analysis of Plant Extracts
Determination of Crude Flavonoid Content

The colorimetric methods used aluminum chloride as the analyte: an aliquot of about 50 µg was diluted with 0.5 mL of absolute methanol, vortexed, made up to 1 mL, then thoroughly mixed with 4 mL of distilled water and 0.3 mL of standard sodium hydroxide. About 0.3 mL of aluminum chloride was reacted with 2 mL of NaOH, and the reaction mixture was then made up to 10 mL with distilled water. The spectrophotometer was set to 510 nm using a Shimadzu UV-Vis spectrophotometer; the crude catechin content was extrapolated from an established standard curve as a catechin content equivalent per unit cell biomass.

Determination of Tannins

The Folin-Denis method, according to Agroindustries AOAC (2013), was used for the test; 1 mL of extract was reacted with 20 mL of 20% sodium carbonate; the mixture was vortexed; the solution was diluted to 100 mL with deionised water and left for 20 minutes. The standard curve for tannin in 100 mL was derived from spectrometric readings at 760 nm.

Determination of Saponins

An aliquot of the plant extracts was added to 100 mL of isopropyl alcohol; the debris was strained through a fine mesh; 40% magnesium carbonate was prepared, and 20% was added to the filtrate, which was then strained again to remove debris. One milliliter of the filtrate (colourless) was mixed with 2 mL of iron chloride in a beaker; the volume was adjusted, and the final volume was made up to 50 mL. The colorimetric value was determined at 380 nm, and the saponin content was deduced from the standard curve over the range 0-10 nm. m.

Ash Content

The *Mentha arvensis* and *Cymbopogon citratus* leaves were charred at a low temperature and cooled; the ash was cooled in a dessicator and re-weighed. The moisture was driven off prior to ashing at 600^0C in a muffle furnace. Mathematically deduced Ash value (%) = $\frac{W_2\ x\ 100}{W_1}$ Where: w_1 = weight of sample (g) w_2 = weight of ash (g)

Crude Fiber

The *Mentha arvensis* and *Cymbopogon citratus* Leaves were pre-hydrolyzed using nitric acid methods as presented by Agbaji *et al*., (2021)

Crude Protein

The Macro-Kjeldahl method was employed to determine the protein content of the substrate using 2.0 g of leaves from *Mentha arvensis* and *Cymbopogon citratus*, which were digested with 20 mL of concentrated H_2SO4 (Agbaji *et al*., 2021).

Total Available Carbohydrate (TAC)

Ten grams (10g) of the *Mentha arvensis* and *Cymbopogon citratus* leaves were measured, reacted, and protein was determined using the Anthrone approach (AOAC, 2000).

Moisture Content

The hot-air oven method was used to determine this. The *Mentha arvensis* and *Cymbopogon citratus* leaves were air-dried as presented by Agbaji *et al*., (2021).

Crude Fat

The fat and oil content of the *Mentha arvensis* and *Cymbopogon citratus* leaves was determined by introducing about 2.0 g of the dry samples into an ether-extracting thimble and placing it in a Soxhlet reflux flask connected to a round-bottomed flask of known weight.

Collection of Test Organisms

The molecularly identified test organisms were collected from Microbiology Laboratory at Usmanu Danfodiyo University, Sokoto. Virulent Gram-positive microorganisms and fungal strains were obtained from the laboratory. The isolates obtained were *Providencia stuartii* and *Proteus hauseri.*

Preparation of Inoculum Standardization

The method of Effiong *et al*., (2026) was adopted in preparing the inoculum. Here, 18-hr-old cultures of the bacterial isolates were grown on nutrient agar (HiMedia), while the fungal isolates were obtained after three (3) days of incubation on Sabouraud dextrose agar. The 0.1 MacFarland standard was used to determine the concentration of the isolates during their log phase of growth. The microbial cultures were dislodged, washed into a sterile container, and used to standardize the inoculum size.

Antimicrobial Assay

The Well-in Agar approach was adopted for susceptibility testing, with the plant extract dispensed into the agar well. The test organism was first swabbed onto sterile Mueller-Hinton agar plates,

after which a sterile cork borer was used to make wells, and the various concentrations of the plant extract were dispensed into the wells. The plates were monitored after 24 hours (Wali *et al*., 2022).

3.0 RESULTS AND DISCUSSION

3.1 Deposition and Accession Number of the Plants for the Study

The plants used in the study, *Mentha arvensis* and *Cymbopogon citratus,* commonly known as mint leaves and lemongrass, respectively, were deposited in the Departmental herbarium under accession numbers ECU-FS-EE01 and ECU-FS-EE02 as presented in Table 1. These accession numbers were assigned after the plants were confirmed to have been dried and treated with an appropriate preservative to deter attacks by insects and rodents.

3.2 The Phytochemical Evaluation of Plants *Mentha Arvensis* and *Cymbopogon Citratus*

The phytochemical composition of the plants is presented in Table 2 below; components such as flavonoids, alkaloids, phenols, tannins, and glycosides were identified in the leaves of *Mentha arvensis* and *Cymbopogon citratus* used in the study. Both samples also did not show the presence of saponins, while the presence of steroids in the Mentha arvensis was confirmed during the study.

3.3 Proximate Composition of the *Mentha Arvensis* and *Cymbopogon Citratus* Leaves

The results presented in Table 3.0 show the proximate composition of the leaves of *Mentha arvensis* and *Cymbopogon citratus*. The moisture content was 75.64% w/w and 64.2% w/w for *Mentha arvensis* and *Cymbopogon citratus*, respectively; the ash content was 2.91% and 2.27%; the crude lipid, fiber, and protein contents of *Mentha arvensis* were 3.12%, 5.83%, and 4.39% w/w. The composition of *Cymbopogon citratus* was 3.69%, 8.21%, and 4.03%.

3.4 Extracts Yield of *Mentha Arvensis* and *Cymbopogon Citratus*

The results presented in Table 4 show the yields of the solvent and non-solvent extracts, as the study compared extraction protocols using both solvents and non-solvents. The study conducted and revealed that the *Mentha arvensis* extract from 500g of the leaves of the plant identified that the net weight of 3.18, 5.08, and 6.33 gw/w while *Cymbopogon citratus* had 4.67, 6.17, and 6.445 for water, ethyl-ether and n-hexane.

Table 1: Accession and Deposition of Plant in Herbarium

s/n	Scientific name	Common name	Accession Number
1	*Mentha arvensis*	Mint leaves	ECU-FS-EE01
2	*Cymbopogon citratus*	Lemongrass	ECU-FS-EE02

Table 2: Phytochemical Composition of the *Mentha arvensis* and *Cymbopogon citratus* Leaves

Parameters	Plant leaves	
	Mentha arvensis	***Cymbopogon citratus***
Flavonoids	+	+
Alkaloids	+	+
Saponins	-	-
Phenols	+	+
Tannins	+	+
Steroids	-	+
Glycosides	+	+

Table 3: Proximate composition of dried leaves biomass from *Mentha arvensis* and *Cymbopogon citratus*

Parameter	***Mentha arvensis***	***Cymbopogon citratus***
	Concentration (%w/w)	
Moisture	75.64	64.2
Ash	2.91	2.27
Crude lipid	3.12	3.69
Crude Fibre	5.83	8.21
Crude Protein	4.39	4.03
Total Available Carbohydrates	8.11	17.6

Table 4: Yield per solvent extract of the *Mentha arvensis* and *Cymbopogon citratus* leaves

Plant	Water	Ethyl-ether	n-hexane
Mentha arvensis wt/500 g	3.18	5.08	6.33
Cymbopogon citratus wt/500 g	4.67	6.17	6.45

3.5 The Molecular Identity of the Bacterial Isolates Employed as Test Isolates

The identities of the bacterial isolates obtained during the study were confirmed by sequencing 16S genomic DNA from isolates previously identified by biochemical tests as *Klebsiella* spp. and *Proteus* sp. The genomic extracts were amplified and analyzed, and the isolates were identified as Providencia stuartii and Proteus hauseri, with similarity indices of 99% and 100%, respectively, to the previously identified and deposited FASTA amplicons on GenBank. The phylogenetic tree shows that the tested isolates have 100% similarity to those compared on the phylotree platform, as presented in Table 5 and Figure 1.

3.6 Antimicrobial Susceptibility of the *Proteus Hauserii and Providencia Stuartii* to the Ethyl Ether Extract of *Mentha Arvensis* and *Cymbopogon Citratus*

The antimicrobial effect of the ethyl ether extract of *Mentha arvensis* showed that the zones of inhibition for *Proteus hauserii* at 100 mg/L, 200 mg/L, 300 mg/L, 400 mg/L, and 500 mg/L were 10 mm, 13 mm, 20 mm, and 18 mm, respectively, while those for *Providencia stuartii* were 20 mm, 22.0 mm, 24.0 mm, and 26 mm. The control showed no zone of inhibition, as presented in Table 6. The antimicrobial susceptibility of the test isolates to the ethyl ether extract of *Cymbopogon citratus* is presented in Table 7. The zones of inhibition for *Proteus hauserii,* as previously defined, were 11.0 mm, 13 mm, 13.0 mm, 20.0 mm, 18 mm, and 23 mm, while those for *Providencia stuartii* were 4.0 mm, 7.0 mm, 10.0 mm.

3.7 Antimicrobial Susceptibility of the *Proteus Hauserii and Providencia Stuartii* to the N-Hexane Extract of *Mentha Arvensis* and *Cymbopogon Citratus*

The antimicrobial or antagonistic activity of plant extracts from *Mentha arvensis* and *Cymbopogon citratus* against virulent bacterial isolates. The isolate *Proteus hauserii* showed zones of inhibition of 4.3 mm, 4.5 mm, 6.5 mm, 7.0 mm, and 9.0 mm for n-hexane extracts at concentrations of 100 mg/L to 500 mg/L, while the isolate *Providencia stuartii* showed zones of inhibition of 6.0 mm, 7.0 mm, 7.0 mm, 10.0 mm, and 17.0 mm in Table 8. The n-hexane extracts of the *Cymbopogon citratus* were identified to have zones of inhibition of 8.0 mm, 8.6mm, 9.4mm, 10.2 mm, and 12.7 mm, while the control had no zone of inhibition, as presented in Table 9.

3.8 Synergistic Evaluation of the Extract of *Cymbopogon Citratus* and *Mentha Arvensis* Using

The synergistic interaction of the extracts with the virulent bacterial isolates, concentrations of *Cymbopogon citratus*: *Mentha arvensis* 80:20, 70: 30, 50:50, 30:70 and 20:80. The zone of inhibition showed 16 mm, 25mm, 20 mm, 27.5 mm and 22.4 mm while *Providencia stuartii* it was 18, 21 mm, 28.5 mm, 26.5 mm, 15.5 mm while the evaluation of the n-hexane extract for the proportion of the plant extracts obtained had 17 mm, 19mm, 16.2 mm, 19.5mm and 20.7 mm was reported in Table 11.

Table 5: Molecular identity indices of the test bacterial isolates

Bacterial Isolates	Biochemical identity of isolates	Phylogenetic %	GenBank Accession Number
Providencia stuartii	*Klebsiella* sp.	99	PZ43438008
Proteus hauserii	*Proteus* sp	100	PZ438007.1

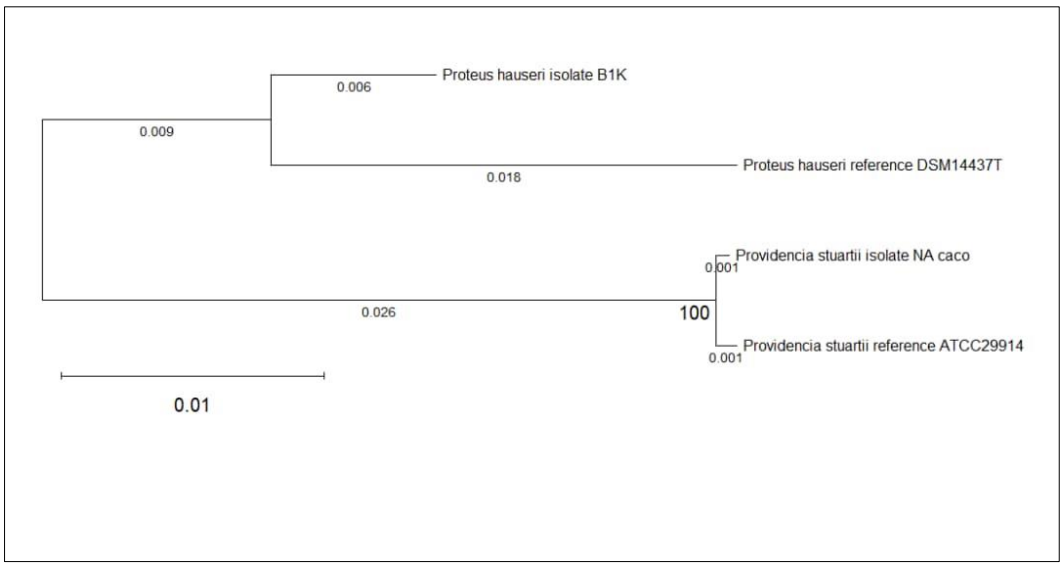

Fig. 1: Phylogenetic tree of showing the evolutionary relatedness of the test isolate

Table 6: Antimicrobial susceptibility of *2*against *Mentha arvensis* leave extract using ethyl-ether

	Zone of Inhibition in mm					
Isolates	**100 mg/L**	**200 mg/L**	**300 mg/L**	**400 mg/L**	**500 mg/L**	**Ctr**
Proteus hauserii	10.0	13.0	13.0	20.0	18.0	0.0
Providencia stuartii	20.0	22.0	24.0	24.0	26.0	0.0

Table 7: Antimicrobial susceptibility of *Proteus hauserii and Providencia stuartii* against *Cymbopogon citratus* leaves extract using ethyl-ether

	Zone of Inhibition in mm					
Isolates	**100 mg/L**	**200 mg/L**	**300 mg/L**	**400 mg/L**	**500 mg/L**	**Ctr**
Proteus hauserii	11.0	13.0	20.0	18.0	23.0	0.0
Providencia stuartii	4.0	7.0	10.0	37.0	35.0	0.0

Table 8: Antimicrobial susceptibility of *Proteus hauserii and Providencia stuartii* against *Mentha arvensis* leave extract using n-hexane

	Zone of Inhibition in mm					
Isolates	**100 mg/L**	**200 mg/L**	**300 mg/L**	**400 mg/L**	**500 mg/L**	**Ctr**
Proteus hauserii	4.3	4.5	6.5	7.0	9.0	0.0
Providencia stuartii	6.0	7.0	7.0	10.0	17.0	0.0

Table 9: Antimicrobial susceptibility of *Proteus hauserii and Providencia stuartii* against *Cymbopogon citratus* leaves extract using n-hexane

	Zone of Inhibition in mm					
Isolates	**100 mg/L**	**200 mg/L**	**300 mg/L**	**400 mg/L**	**500 mg/L**	**Ctr**
Proteus hauserii	8.0	8.6	9.4	10.2	12.7	0.0
Providencia stuartii	3.0	3.5	5.0	8.0	13.0	0.0

Table 10: Synergistic study of the *Cymbopogon citratus* and *Mentha arvensis leaves extracts using ethyl ther* on *Proteus hauserii and Providencia stuartii*

	Zone of Inhibition in mm					ctr
Isolates	**80:20**	**70:30**	**50:50**	**30:70**	**20:70**	
Proteus hauserii	16	25	20.2	27.5	22.4	0.0
Providencia stuartii	18	21	28.5	26.5	15.5	0.0

Table 11: Synergistic study of the *Cymbopogon citratus* and *Mentha arvensis leaves extracts using n-hexane* on *Proteus hauserii and Providencia stuartii*

	Zone of Inhibition in mm					ctr
Isolates	**80:20**	**70:30**	**50:50**	**30:70**	**20:00**	
Proteus hauserii	17	19	16.2	19.5	20.7	0.0
Providencia stuartii	11	15	13.5	16.5	19.5	0.0

4.0 DISCUSSION OF FINDINGS

The phytochemical composition of plants and their products is a bedrock to their application in medicine. These chemical compounds vary significantly among plant species and even within the same taxa; the evaluation of the plants showed that flavonoids, alkaloids, phenols, tannins, and glycosides were present in the leaves of *Mentha arvensis* and *Cymbopogon citratus*. These findings corroborate those of Daiya *et al*., (2026), who identified key chemical components, including alkaloids, flavonoids, and phenols. Furthermore, Amtaghri *et al*., (2024) reported that the extracts contain additional phytochemical components, such as limonene and dihydrocarvone, which enhanced their curative activities against numerous disorders. Their application in the food and drug formulation may strongly agree with the previous study by Świątek *et al*., (2024), whose study further buttresses the proportion of phenolic compounds as a major source track to the aromatic and chilling feel that resonates with its patron as culinary additives in many industrial, commercial, and domestic uses (Prakash *et al*., 2025). The report by Hassan *et al*., (2025) found that the phenolic composition of the leaves can be harnessed for a number of industrial purposes, with significant potential for turnover. Tannins and flavonoids are indicators of the antioxidant, antimicrobial, and anti-inflammatory potentials (Chagas *et al*., 2022; Mora *et al*., 2022). However, saponins and alkaloids contribute to disrupting the peptidoglycan layer of microbes as an inactivation protocol (Efimova and Ostroumova, 2021).

The proximate composition of organic compounds has been identified as a direct indicator of a material's nutritional composition; the crude lipid, fibre, and protein contents of Mentha arvensis were 3.12%, 5.83%, and 4.39% w/w, respectively. The composition of *Cymbopogon citratus* was 3.69%, 8.21%, and 4.03%. The previous work of Qanash *et al*., (2023) corroborates the findings of this present study, as their investigation reported over 5% yield with over 80% total carbohydrate content, while Pal *et al*., (2026) agreed very strongly with the findings of the present study, with a TAC of 89.26% with a crude lipid of 1.80%. Sulieman *et al*., (2011) reported that mint leaves contained moisture 76.01%, fibre 2.1%, ash 3.48%, protein 1.75%, fat 3.20%, and carbohydrates 14.46%. In a related study.

Maslov *et al*., (2022) identified that a 70% ethanol-water mixture is used for the extraction of plant parts; the choice of solvent is critical in extracting organic and inorganic compounds, especially pharmacological compounds; polar phytoactive substances are extracted using water, ethanol, and methanol, which can extract cyanins, flavonoids and cyanins while lipophilic components like the terpenoid while binary solvents such as ethanol-water mixtures may extract a good number of phytoactive components (Tzanova *et al*., 2020; Siddiqui *et al*., 2024). Furthermore, Suryanita *et al.,* (2024), these results indicate higher extraction efficiency, suggesting that the methods used in this study were more effective at extracting active compounds. Meanwhile, extract yields using the UAE method were 28.1% with 60% ethanol, 1.62% with n-hexane (the lowest), and 25.35% with 70% ethanol. Chang *et al*., (2041) found that ethanol alone has a lower extraction potential than aqueous extraction. The synergistic combination of water and ethanol showed better extraction performance (Plaskova and Mlcek, 2023).

The antimicrobial effect of the ethyl ether extract of *Mentha arvensis* showed that the zones of inhibition for *Proteus hauserii* at 100 mg/L, 200 mg/L, 300 mg/L, 400 mg/L, and 500 mg/L were 10 mm, 13 mm, 20 mm, and 18 mm, respectively, while those for *Providencia stuartii* were 20 mm, 22.0 mm, 24.0 mm. Similarly, Sulaiman *et al*., (2023) reported that spearmint oil exhibited antibacterial activity against *Escherichia coli,* with inhibition zones of 17mm and 15mm at the higher and lower concentrations, respectively, which corroborates the findings of the present study. These findings concurred with the work of Lixandru *et al*., (2010), who stated that spearmint oil exhibited considerable inhibitory activity against *E. coli*. Furthermore, the virulent isolates *Proteus hauserii* and *Providencia stuartii* are Gram-negative bacteria which are similar in morphology to the *E. coli*. These findings were in tandem with the report of Khanal *et al*., (2020) whose ethanolic extract did not show a significant activity on *Salmonella typhi*, *Staphylococcus aureus*, *Pseudomonas aeruginosa* and *Escherichia coli*; they further asserted that the extraction protocol using ethanol may not have extracted the bioactive compounds need to induce the antibacterial activity. The activity of the n-hexane extract on the virulent bacterial isolate *Proteus hauserii* at the 500 mg/L could be premised on the ability of the extract to induce both metabolic inhibition and inhibit the efflux mechanism of the test isolates.

5.0 CONCLUSION AND RECOMMENDATIONS

The study found that the plant extracts prepared with the study's solvents were considerably higher than those of aqueous extracts. The presence of phytoactive and phytochemical components, such as saponins, glycosides, and alkaloids, was identified during the study. The antimicrobial activity of the ethyl ether extract was significantly greater than that of the n-hexane extract, suggesting that the ethyl ether extract was the appropriate protocol for isolating polar and non-polar components. The isolate *Proteus hauserii*, which has been linked to life-threatening systemic and gastrointestinal infections, was more sensitive to the extracts than *Providencia sturtii*. The combined studies of the extracts showed greater synergism in inhibiting bacterial metabolism. The study recommends that the antimicrobial activity of *Mentha arvensis* and *Cymbopogon citratus* could provide a roadmap for treating invasive diseases and infections contracted in daily life. The scientific community must be encouraged to delve deeper into the extract's metagenomic impact on the microflora across various environmental matrices, rather than focusing solely on clinical isolates, as has been done in previous studies. The study further observed that the pharmacological and physicochemical components overlap, suggesting that both plants could serve as complementary additives in the design of a curative mixture to combat Gram-negative infections arising from gastrointestinal infections associated with consuming contaminated food.

Conflict of Interest: The authors declare no competing interests regarding this study.

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