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# Enhancing Public Health: Evaluating Ginger, Garlic, and Turmeric Extracts as Natural Antibacterial Preservatives in Water Treatment

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**ABSTRACT**

Plant extract has antibacterial properties due to their bioactive components, and effective against a wide variety of bacteria causing diseases. This study is carried out to determine the antibacterial efficacy of Ginger, Garlic and Turmeric extract on common waterborne pathogens isolated from Rivers State University as a way of enhancing public health. A total of eight (8) borehole, stream and well water samples were collected in a sterile container from Mgboshimini/Agip and subjected to standard bacteriological procedure. A total of seven (7) bacteria were identified belonging to six (6) genera and they include, *Pseudomonas, Bacillus, Micrococcus, Klebsiella, Escherichia coli* and *Serratia*. The spices were purchased and the extraction of crude extracts of was carried out using a standard method. The extracts were prepared into different concentrations (100%, 50%, 25%, 12.5%, 6.25%, 3.125%, 1.563%) and impregnated on sterile discs for antimicrobial susceptibility testing. The total heterotrophic bacterial count ranged from 4.3±0.8, 4.3±2.9 to 4.6±3.9 for well water, borehole and stream water. Total coliform count ranged from 1.8±0.9 to 4.6± 2.9 for borehole and well water and faecal coliform count ranged from 0.0±0.0 to 2.4±1.4 borehole and stream water respectively. There was no significant difference ($p \geq 0.05$) in the total heterotrophic bacteria and faecal coliform count and there was a difference ($p \leq 0.05$) in the total coliform count. The antibacterial activity of turmeric on the bacterial isolates showed inhibitory properties on all the bacterial isolates at 100% and 50% concentration but at 25% it has effect on *E. coli* and *Klebsiella*. At 12.5%, 6.25%, 3.125% and 1.563% it had no effect on all the bacterial isolates. The minimal inhibitory concentration (MIC) indicated that *Bacillus, Serratia, Micrococcus* and *Pseudomonas* had an MIC at 100% while *E. coli* and *Klebsiella* with MIC at 25%. The antibacterial activity of garlic on the bacterial isolates revealed that at 100%, 50%, 25%, and 12.5% garlic had inhibitory property on all the bacterial isolates. At 6.25%, it was only effective on *Serratia, Micrococcus, Staphylococcus, E. coli* and *Klebsiella*. At 3.125% garlic extract inhibit the growth of only *Micrococcus*. MIC revealed that *Bacillus* and *Serratia* had an MIC at 12.5%, *Pseudomonas* had an MIC at 25% while *Micrococcus, Staphylococcus, E. coli and Klebsiella* had an MIC at 6.25%. Ginger exhibited inhibitory on all the bacterial isolates at 100%, 50%, 25%, 12.5%. At 6.25% it was only effective *on Bacillus, Serratia, Micrococcus, Staphylococcus* and *E. coli*. At 3.125% it was only effective on only *Micrococcus*. The MIC of ginger on the bacterial isolates showed that *Bacillus, Serratia* and *Micrococcus* had an MIC at 6.25% but *Pseudomonas* and *Klebsiella* had an MIC at 25% while *E. coli* had an MIC at 12.5%. Due to the antibacterial properties demonstrated by the spices it is recommended that they should be used for the treatment of infections.

## INTRODUCTION

The provision of potable water is a critical public health issue in developing nations, especially Nigeria. High population density in tertiary institutions strains hydraulic infrastructure, leading to contamination of water sources with enteric pathogens like *Escherichia coli* and *Salmonella* species (Osisiogu et al., 2024). These contaminants are significant contributors to waterborne disease outbreaks in academic communities. Conventional treatment with synthetic antibiotics has become less effective due to the rise of multidrug-resistant (MDR) bacterial strains, resulting in increased morbidity, mortality, and healthcare costs (Abd El-Kalek & Mohamed, 2022). Thus, there is an urgent need for sustainable, bio-based antimicrobial alternatives.

Aquatic ecosystems support a wide range of biological communities, including both macro-fauna and complex microbial assemblages (Kumar et al., 2021). While many microorganisms play vital roles in ecological processes such as nutrient cycling, chemical decomposition, and symbiotic digestion, certain taxa are significant human pathogens (Ammon et al., 2023; Abdulzahra & Mohammed, 2024). The contamination of water bodies with pathogens is often linked to fecal pollution from anthropogenic or zoonotic sources. Given the logistical and financial limitations in monitoring all waterborne pathogens, microbiological assessments typically employ indicator organisms, particularly fecal coliforms, to evaluate sanitary quality and indicate the potential presence of enteric pathogens (Krauss & Griebler, 2021).

To address the shortcomings of ineffective antibiotic treatments, recent investigations have shifted focus to the secondary metabolites derived from medicinal plants (Nascimento et al., 2020). Spices, categorized by the US Food and Drug Administration as aromatic vegetable substances primarily employed for flavoring, are gaining recognition for their therapeutic properties (Abdulzahra & Mohammed, 2024). In contrast to synthetic additives like butylated hydroxytoluene (BHT), plant-based extracts are typically considered Generally Recognized As Safe (GRAS) and exhibit high public bio-acceptability (Biswas *et al.,* 2023).

Plants such as *Zingiber officinale* (ginger), *Allium sativum* (garlic), and *Curcuma longa* (turmeric) are rich in bioactive compounds, including gingerols, allicin, and curcumin, respectively (Karuppiah & Rajaram, 2012). These phytochemicals, which comprise flavonoids, phenolics, alkaloids, and sulfur-containing compounds, exert antimicrobial effects through various mechanisms. These include disruption of the bacterial cytoplasmic membrane, inhibition of enzymatic activity, and interference with nucleic acid synthesis (González-Lamothe et al., 2019; Biswas et al., 2023).

Previous research has established the broad-spectrum efficacy of botanical extracts against resilient pathogens such as *Staphylococcus aureus* and *Pseudomonas aeruginosa* (Al-Zahrani et al., 2016). As many waterborne isolates, including species of *Vibrio* and *Klebsiella*, show increasing resistance to conventional antibiotics (WHO, 2017), it is crucial to validate the effectiveness of *Zingiber officinale*, *Allium sativum*, and *Curcuma longa*.

This study aims to evaluate the potential of ginger, garlic, and turmeric extracts as bio-preservatives and supplementary antimicrobial agents for water treatment. The specific objectives include quantifying microbial load in water samples through Total Heterotrophic Bacterial (THB), total coliform, and fecal coliform counts; isolating and identifying waterborne bacteria using phenotypic, morphological, and biochemical characterization; and determining the Minimum Inhibitory Concentration (MIC) and antibacterial efficacy of ginger, garlic, and turmeric extracts against the identified isolates in comparison with standard antibiotics.

## MATERIALS AND METHODS

### Sample Collection

A total of eight (8) borehole, stream and well water samples were collected from Mgboshimini/Agip Estate and the samples were labelled properly, put in ice-chest and transported aseptically to the Department of Microbiology Laboratory for further bacteriological analysis in Rivers State University.

### Microbiological Analysis

### Enumeration and Isolation of Bacteria

One millitre (1ml) was dispensed in 9ml of normal saline subjected to a ten-fold serial dilution with a dilution factor ranging from $10^1$ to $10^4$. An aliquot (0.1ml) of the appropriate dilutions was spread plated in duplicates onto Nutrient Agar and incubated at 37ºC for 24hours, during which the colonies formed on the plates were morphologically described.

### Characterization and Identification of the Bacterial Isolates

To identify the bacterial isolates, morphological characteristics and biochemical test were performed on the pure isolates. Suspected bacterial growth was then cultivated on freshly prepared nutrient agar plates to monitor for growth. To confirm bacteria, tests including Gram Staining, Motility test, and biochemical ones like Oxidase, Methyl red, Oxidase, Voges Proskaur, Sugar fermentation, Motility and Citrate Utilization test were performed. The results were compared to the ABIS online identification tool to identify the bacteria of interest (Stoica and Sorescu, 2012; Thomas *et al.,* 2021).

### Gram Staining

Gram-positive and Gram-negative bacteria are differentiated using the Gram staining technique. Initially, a smear was prepared from a 24-hour bacterial culture on a grease-free glass slide, which was properly labelled. This was accomplished by placing one to two drops of distilled water on the slide and emulsifying it with a loopful of the bacterial culture. The smear was then air-dried and heat-fixed by passing the slide briefly under a Bunsen burner flame three times.

Following this, the smear was flooded with the primary stain, crystal violet, for 60 seconds and rinsed gently with tap water. The next step involved flooding the smear with Lugol's iodine for 60 seconds, followed by another rinse with tap water. The slides were then decolorized with 95% ethanol for 30 seconds and rinsed once more with tap water. The counterstain, safranin, was applied for 30 seconds and the slide was rinsed again. Finally, the slide was allowed to air dry on a rack. The stained smear was examined microscopically using an oil immersion lens (100x magnification). Bacteria that retained the crystal violet stain appeared purple or violet, indicating Gram-positive status, while those that took up the safranin appeared pink or red, indicating Gram-negative status.

### Biochemical Tests

### Oxidase Test (Filter Paper Method)

This test is used to identify microorganisms, cytochrome oxidase (important in the election transport chain). It is commonly used to distinguish between oxidase positive and oxidase negative. A small portion of the isolate (24 hours cultured) was smeared in part of the filter paper impregnated with freshly prepared oxidase reagent. The reaction was observed within 10 seconds to see if there's any colour change. Deep purple coloration appearing within 5 to 10 seconds indicates a positive reaction. A weak positive appeared with 10 to 60 seconds and a negative reaction was indicated by a none colour change (Shields & Cathcart, 2010; Disegha. & Appah, 2025).

**Catalase Test (Slide Method)**

This test is used to identify organism that produce the enzyme, catalase. This enzyme detoxifies hydrogen peroxide by breaking it down into water and oxygen gas. A sterile wire loop was used to transfer a loop full of the organism to a grease free slide, emulsified with small distilled water. One drop of hydrogen peroxide (6%) was added and observed for effervescence within 3 seconds. The production of air bubbles indicates a positive result (Elkins *et al*., 1999).

**Methyl Red Test**

The test is used to identify bacteria producing stable acid by mechanism of mixed acid fermentation of glucose. Seventeen (17) grams of methyl Vogues-Proskauer (MRVP) broth was suspended in distilled water 5ml of the MRVP broth were distributed into each test tubes and autoclaved at 121°C for 10 minutes. A loop full of the test organisms were inoculated into the broth and incubated for 48 hours. After incubation, 2 to 5 drops of methyl red indicator were added to the culture. Positive indicates red colour and Negative indicates yellow colour.

**Indole Test**

This test was used to ascertain the ability of some microbes to hydrolyze the amino acid tryptophan to produce Indole. Tryptophan is made available by tryptone in the medium of 10ml of peptone water and dispensed in test tubes and sterilized by autoclaving. It was allowed to cool before inoculation isolates into sterile broth. The broth culture was incubated at 37°c for 48 hours after which 0.5ml Kovacs's reagent was added into rack of the culture tests tubes, the test tubes were shaken and allowed to stand for 15 minutes. Positive result shows a red colour at the surface of the medium and negative result showed no red Colour at the surface of the medium.

**Voges-Proskauer Test**

This test was used to detect acetone (an important physiological metabolite excreted by many microorganisms) in a bacteria broth culture. A loop-ful of the test organism was inoculated into MRVP broth and incubated for 24 hours. After incubation, about (10 drops of α–naphthal and (10 drops) of potassium hydroxide were added into the broth culture and was shaken and allowed to stand for 15 minutes. Positive result indicated a pink or red colour at the surface of the medium and negative results indicated a copper colour at the surface of the medium (Navena and Joy, 2014).

**Citrate Utilization Test**

Citrate utilization test is possible only if the organisms are capable of fermenting citrate. Using a slant, inject Simon's citrate agar gently on the slant by slightly touching the tip of the needle to the colony, which is about 18-24hours old. In the citrate medium, organism require more time to grow. The solution is incubated at 37°c for 24 hours. Positive result indicates a colour change from green to blue while negative result indicates no color change.

**Sugar Fermentation Test**

This test was carried out to determine whether the organisms could ferment a particular sugar. Phenol red broth with addition of the specific sugar (glucose, fructose, lactose) was used for the test. Test tubes were filled to 4 to 5ml with Phenol red sugar broth and Durham tubes inserted into each of them. The test medium was autoclaved at 121$^{o}$ C for 15 minutes to sterilize and also drive the broth into the inverted Durham tubes. Some sugars like lactose and maltose were autoclaved for only 3 minutes to avoid breakdown arising from autoclaving. After cooling, each test tube was aseptically inoculated using sterile wire loop and then incubated at 35 to 37$^{o}$C for 24 hours. Tubes were observed for colour change to yellow (positive result-acid production) or no colour change; remains red (negative result-no acid production). Furthermore, bubbles in the Durham tubes indicated gas production whereas, lack of bubbles indicated no gas production.

**Motility Test**

The presence or absence of flagella on the bacterial isolates was assayed using the motility test. The presence of flagella on bacteria confers the ability to be motile and functions as an adhesion component of the bacteria during invasion of a host cell (Charkraborty & Nishith, 2008). The test was done by stab-inoculating the bacterial isolate into an emulsified nutrient agar medium in a test tube with a sterile needle. The tube was incubated at 37$^{o}$C for 24 hours following the method of Charkraborty and Nishith, 2008. Results were reported considering whether the isolate migrated away from the stab line or not.

**Preservation of Pure Culture**

The pure cultures of bacterial isolates after subculture were preserved in 10% (v/v) glycerol suspension at -4$^{o}$C as a cryo-preservative agent to prevent the deterioration of the pure cultures for further analysis.

**Collection of the Plants Materials**

Collection of plants Ginger (*Zingiber officinale*), garlic (*Allium sativum*) and Turmeric (*Cucuma longa*) were bought randomly from vendors in Mgboshimini and Agip

Estate markets. The spices were collected in clean polyethylene bags and were transported to the microbiology laboratory, Department of Microbiology, Faculty of Science, Rivers State University, Nigeria. The spices were identified by Professor E. C. Chuku of the Plant Science and Biotechnology Department as Ginger (*Zingiber officinale*), garlic (*Allium sativum*) and Turmeric (*Cucuma longa*).

### Preparation of Crude Extracts of Ginger, Garlic and Turmeric.

The ginger, garlic and Turmeric were prepared as described by Kibiti and Afolayan (2015). In this method, these spices were rinsed with sterile distilled water, air dried, and ground to homogenous powder using a sterile blender (sterilized with 96% ethanol).

### Preparation of Various Concentrations of the Extracts

The concentrations of the extracts were prepared by dissolving 100 mg of the oily residue with 1 ml of dimethyl sulfoxide to give a stock concentration of 100 mg/ml. After which, two-fold serial dilution was determined using the stock to obtain sequential concentrations of 50, 25, 12.5, 6.25, 3.125 and 1.5625 mg/ml. A 50 µl of the various concentrations were impregnated on perforated discs. These discs were dried and used to test for antibacterial activity.

### Antimicrobial Susceptibility of Extracts

The antimicrobial susceptibility of the extract was carried out using the disc diffusion method. The extract-impregnated discs containing the various concentrations were aseptically placed on the surfaces of the Mueller-Hinton agar plates which had been inoculated with isolates of bacterial isolates which had been standardized using the 0.5 McFarland. The plates were incubated at 37°C for 24 hours (CLSI, 2019).

### Determination of minimum inhibitory concentration

Minimum inhibitory concentrations (MICs) of the extracts on the isolates were determined as described by Ogbonna *et al*. (2013). The extracts were diluted ranging from 50, 25,12.5, 6.25, 3.125 and 1.5625 mg/ml concentrations. One ml of the 0.5 McFarland standardized isolate was transferred into test tubes containing 2 ml of the various extract concentrations. The control contained only the extract without any bacterial isolates. Test tubes that were not turbid represented the minimal inhibitory concentration. Experiments were done in duplicates to corroborate the results.

### Data Analysis

The data obtained was analyzed using analysis of variance (ANOVA) to test for significance and where differences occur, Duncan multiple range test was used to separate the means using the Statistical Package for Social Science (SPSS) version 27.

## RESULTS

The results of this study provide a comprehensive analysis of the bacterial population in water samples collected from different sources, including borehole, stream, and well water. The total heterotrophic bacterial count (THB), total coliform count (TCC), and total fecal coliform count (TFC) were assessed to evaluate the microbiological quality of the water, revealing significant variations among the samples. The study identified eight bacterial isolates, including Escherichia coli, Serratia, Bacillus, Pseudomonas, Micrococcus, Klebsiella, and Staphylococcus, highlighting the potential health risks associated with contaminated water sources. Furthermore, the antibacterial efficacy of natural extracts from turmeric, garlic, and ginger was investigated, establishing their effectiveness at various concentrations against the identified bacterial isolates. The findings underscore the importance of analyzing water quality and exploring natural alternatives for antibacterial treatment, contributing to enhanced public health outcomes.

### Colonial/Biochemical and Prevalence of the Bacterial Isolates from the Water Samples

The results of characterization of the bacterial isolates revealed their colonial/morphological characteristics such as size, colour, elevation, shape, margin, transparency and biochemical test (Indole, Catalase, Methyl red, Voges Proskauer, Sugar fermentation, Oxidase, Citrate) are shown in **appendix I**. A total of eight (8) bacterial isolates were identified from the water sample and they include, *Escherichia coli, Serratia, Bacillus, Pseudomonas, Micrococcus, Klebsiella and Staphylococcus*.

### Mean Bacterial Population of the Water Samples

The result of the bacterial population from the water samples is revealed in **table 1**. The total heterotrophic bacterial count ranged from 4.3±0.8, 4.3±2.9 to 4.6±3.9 for well water, borehole and stream water. Total coliform count ranged from 1.8±0.9 to 4.6±2.9 for borehole and well water. The faecal coliform count ranged from 0.0±0.0 to 2.4±1.4 borehole and stream water respectively. Generally, it was observed that there was no significant difference ($p \geq 0.05$) in the total heterotrophic bacteria and faecal coliform count and there was a difference ($p \leq 0.05$) in the total coliform count.

**Table 1: Mean Bacterial Population from the Water Samples from Mgboshimini/Agip**

| Sample | THB $x10^4$ CFU/ml | TCC $x10^3$ CFU/ml | TFC $x10^2$ CFU/ml |
|---|---|---|---|
| **Borehole** | 4.3±2.9[a] | 1.8±0.9[a] | 0.0±0.0[a] |
| **Stream water** | 4.6±3.9[a] | 3.1±0.6[ab] | 2.4±1.4[a] |
| **Well water** | 4.3±0.8[a] | 4.6±2.9[b] | 1.8±0.9[a] |
| **P-value** | 0.987 | 0.047 | 0.114 |

***Means with different alphabet along the column shows a significant difference ($p \leq 0.05$)
KEY: THB- Total heterotrophic Bacteria count, TCC-Total coliform count, TFC-Total faecal coliform count

**Effect of Turmeric Extract/Minimal Inhibitory Concentration on Bacterial Isolates**

The antibacterial activity of turmeric on the bacterial isolates showed that turmeric had inhibitory properties on all the bacterial isolates at 100% and 50% concentration but at 25% it has effect on *E. coli* and *Klebsiella* with zone of inhibition of 10mm. at 12.5%, 6.25%, 3.125% and 1.563% turmeric had no effect on all the bacterial isolates. The minimal inhibitory concentration (MIC) indicated that *Bacillus*, *Serratia, Micrococcus* and *Pseudomonas* had an MIC at 100% while *E. coli* and *Klebsiella* with MIC at 25% concentration of extract of turmeric (Table 2 and 3).

**Table 2: Effect of Turmeric Extract on Bacterial Isolates from Water Samples Mgboshimini/Agip**

| **Organisms** | Concentrations (%)/Zones of Inhibition(mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **100** | **50±0.3** | **25** | **12.5** | **6.25** | **3.125** | **1.563** |
| ***Bacillus* spp** | 15±0.5 | 12±0.4 | 0 | 0 | 0 | 0 | 0 |
| ***Serratia* spp** | 14±0.4 | 10±0.4 | 0 | 0 | 0 | 0 | 0 |
| ***Micrococcus* spp** | 10±0.3 | 8±0.1 | 0 | 0 | 0 | 0 | 0 |
| ***Staphylococcus* spp** | 17±0.5 | 10±0.5 | 0 | 0 | 0 | 0 | 0 |
| ***Pseudomonas* spp** | 12±0.6 | 8±0.5 | 0 | 0 | 0 | 0 | 0 |
| ***Escherichia coli*** | 20±0.3 | 18±0.6 | 14±0.3 | 10 | 0 | 0 | 0 |
| ***Klebsiella* spp** | 18±0.2 | 16±0.4 | 14±0.3 | 10 | 0 | 0 | 0 |

**Table 3: The Minimal Inhibitory Concentrations of Turmeric on Bacterial Isolates from Water Samples in Mgboshimini/Agip**

| **Organisms** | **Concentrations (%)** | | | | | | |
|---|---|---|---|---|---|---|---|
| | **100** | **50** | **25** | **12.5** | **6.25** | **3.125** | **1.563** |
| ***Bacillus* spp** | - | + | + | + | + | + | + |
| ***Serratia* spp** | - | + | + | + | + | + | + |
| ***Micrococcus* spp** | - | + | + | + | + | + | + |
| ***Staphylococcus* spp** | - | + | + | + | + | + | + |
| ***Pseudomonas* spp** | - | + | + | + | + | + | + |
| ***Escherichia coli*** | - | - | - | + | + | + | + |
| ***Klebsiella* spp** | - | - | - | + | + | + | + |

**Effect of Garlic Extract/Minimal Inhibitory Concentration on Bacterial Isolates**

The antibacterial activity of garlic on the bacterial isolates revealed that at 100%, 50%, 25%, and 12.5% garlic had inhibitory property on all the bacterial isolates. At 6.25%, it was only effective on *Serratia*, *Micrococcus*, *Staphylococcus*, *E. coli* and *Klebsiella*. At 3.125% garlic extract inhibit the growth of only *Micrococcus* with zones of inhibition of 12mm. The minimal inhibitory concentration (MIC) revealed that Bacillus and Serratia had an MIC at 12.5%, Pseudomonas had an MIC at 25% while Micrococcus, Staphylococcus, E. coli and Klebsiella had an MIC at 6.25% concentration of extract of garlic (Table 4. and 5).

**Table 4: Effect of Garlic Extract on Bacterial Isolates from Water Samples Mgboshimini/Agip**

| Organisms | Concentrations (%)/Zones of Inhibition(mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **100** | **50** | **25** | **12.5** | **6.25** | **3.125** | **1.563** |
| ***Bacillus* spp** | 25±11 | 20±12 | 18±12 | 15±0.4 | 0 | 0 | 0 |
| ***Serratia* spp** | 22±10 | 20±13 | 18±13 | 14±0.6 | 12±0.3 | 0 | 0 |
| ***Micrococcus* spp** | 25±12 | 20±10 | 18±0.9 | 16±0.7 | 14±0.1 | 12±0.3 | 10±0.4 |
| ***Staphylococcus* spp** | 20±13 | 24±11 | 20±0.7 | 16±0.5 | 14±0.2 | 0 | 0 |
| ***Pseudomonas* spp** | 18±10 | 16±13 | 14±0.8 | 10±0.5 | 0 | 0 | 0 |
| ***Escherichia coli*** | 26±11 | 20±14 | 18±0.9 | 16±0.3 | 14±0.3 | 0 | 0 |
| ***Klebsiella* spp** | 24±11 | 20±12 | 18±0.8 | 16±0.6 | 14±0.4 | 0 | 0 |

**Table 5: The Minimal Inhibitory Concentrations of Garlic on Bacterial Isolates from Water Samples in Mgboshimini/Agip**

| Organisms | Concentrations (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **100** | **50** | **25** | **12.5** | **6.25** | **3.125** | **1.563** |
| ***Bacillus* spp** | - | - | - | - | + | + | + |
| ***Serratia* spp** | - | - | - | - | + | + | + |
| ***Micrococcus* spp** | - | - | - | - | - | + | + |
| ***Staphylococcus* spp** | - | - | - | - | - | + | + |
| ***Pseudomonas* spp** | - | - | - | + | + | + | + |
| ***Escherichia coli*** | - | - | - | - | - | + | + |
| ***Klebsiella* spp** | - | - | - | - | - | + | + |

**Table 6: Effect of Ginger Extract on Bacterial Isolates from Water Samples Mgboshimini/Agip**

| Organisms | Concentrations (%)/Zones of Inhibition(mm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **100** | **50** | **25** | **12.5** | **6.25** | **3.125** | **1.563** |
| ***Bacillus* spp** | 24±12 | 20±12 | 18±13 | 16±0.2 | 14±0.5 | 0 | 0 |
| ***Serratia* spp** | 26±14 | 22±14 | 20±12 | 16±0.4 | 14±0.6 | 0 | 0 |
| ***Micrococcus* spp** | 24±15 | 20±12 | 18±10 | 16±0.4 | 14±0.7 | 12 | 0 |
| ***Staphylococcus* spp** | 20±12 | 18±10 | 16±12 | 14±0.3 | 12±0.8 | 0 | 0 |
| ***Pseudomonas* spp** | 18±15 | 16±10 | 14±0.7 | 12±0.5 | 0 | 0 | 0 |
| ***Escherichia coli*** | 24±12 | 22±14 | 20±0.9 | 18±0.7 | 10±0.5 | 0 | 0 |
| ***Klebsiella* spp** | 20±10 | 16±10 | 140.4 | 10±0.8 | 0 | 0 | 0 |

**Effect of Ginger Extract/Minimal Inhibitory Concentration on Bacterial Isolates**

Ginger exhibited inhibitory on all the bacterial isolates at 100%, 50%, 25%, 12.5% concentration of the extract. At 6.25% it was only effective on *Bacillus, Serratia, Micrococcus, Staphylococcus* and *E. coli*. At 3.125% it was only effective on only *Micrococcus* with zone of inhibition of 12mm. The minimal inhibitory concentration (MIC) of ginger on the bacterial isolates showed that *Bacillus, Serratia, Micrococcus* had an MIC at 6.25% but *Pseudomonas* and *Klebsiella* had an MIC at 25% while *E. coli* had an MIC at 12.5% concentration of extract of ginger (Table 6 and 7).

**Table 7: The Minimal Inhibitory Concentrations of Ginger on Bacterial Isolates from Water Samples in Mgboshimini/Agip**

| Organisms | Concentrations (%) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 100 | 50 | 25 | 12.5 | 6.25 | 3.125 | 1.563 |
| ***Bacillus* spp** | - | - | - | - | - | + | + |
| ***Serratia* spp** | - | - | - | - | - | + | + |
| ***Micrococcus* spp** | - | - | - | - | - | + | + |
| ***Staphylococcus* spp** | - | - | - | - | + | + | + |
| ***Pseudomonas* spp** | - | - | - | + | + | + | + |
| ***Escherichia coli*** | - | - | - | - | + | + | + |
| ***Klebsiella* spp** | - | - | - | + | + | + | + |

## DISCUSSION

The antibacterial properties of turmeric, garlic and ginger is as a result of the presence of phytochemicals which are secondary metabolites present in plants. These phytochemicals could influence the antimicrobial activities of the plants (Naphtali *et al*., 2020).

Turmeric extract exhibited the weakest antibacterial activity among the three extracts tested and inhibition zones were generally small and absent at lower concentrations for several isolates. Only *Escherichia coli* and *Klebsiella* spp. showed appreciable inhibition (20 mm and 18 mm, respectively, at 100% concentration). Correspondingly, the MIC values indicated that relatively high concentrations were required to inhibit growth across most isolates. This finding aligns with previous reports that curcumin, the major bioactive component of turmeric, often demonstrates limited antibacterial potency in crude extract form due to poor aqueous solubility and bioavailability, requiring high concentrations to achieve inhibition (*Odo et al.*, 2023). Mechanistically, curcumin has been shown to disrupt bacterial membranes, generate reactive oxygen species (ROS), and interfere with virulence and biofilm formation, although its activity is frequently modest in agar diffusion assays (Akarchariya *et al*., 2017).

Garlic extract demonstrated the strongest and broadest spectrum of activity. Large inhibition zones were observed against *E. coli* (26 mm), *Klebsiella* spp. (24 mm), *Bacillus* spp. (22 mm), and *Micrococcus* spp. (20 mm) at 100% concentration, with activity persisting even at lower concentrations. The minimal inhibitory concentration values further confirmed garlic's potency, as inhibition was achieved at relatively low extract concentrations. These findings are in tandem with a wide body of literature highlighting the antimicrobial properties of allicin and other sulfur-containing compounds in garlic (Abidullah *et al*., 2021). Allicin in particular has been shown to exert bactericidal effects by reacting with thiol groups in bacterial enzymes, thereby disrupting essential metabolic pathways (Shang *et al*., 2004). The broad activity observed here, especially against Enterobacteriaceae (*E. coli*, *Klebsiella*), reinforces garlic's reputation as one of the most potent natural antimicrobials.

Ginger extract displayed intermediate antibacterial activity compared with garlic and turmeric. inhibition zones were substantial against *E. coli* (22 mm), *Klebsiella* (20 mm), and *Pseudomonas* spp. (18 mm) at 100% concentration. The minimal inhibitory concentration results indicate moderate inhibitory potential, with lower concentrations effective against *E. coli* and *Klebsiella*. These findings are supported by earlier studies reporting antimicrobial effects of gingerols, shogaols, and other phenolic compounds in ginger extracts (Rahmani *et al*., 2014; Park *et al*., 2008). These bioactive constituents are believed to disrupt bacterial cell membranes and interfere with protein synthesis, contributing to bacteriostatic and bactericidal effects. Importantly, the moderate but consistent activity observed here suggests ginger could complement other plant extracts in antimicrobial formulations (Akani & Barika, 2018). Furthermore, among the three extracts, *E. coli* and *Klebsiella* were the most susceptible, showing consistent inhibition at multiple concentrations. In contrast, *Pseudomonas* spp. exhibited relative resistance, with smaller zones and higher minimal inhibitory concentrations. This resistance pattern is consistent with the known intrinsic defense mechanisms of *Pseudomonas*, including efflux pumps, low membrane permeability, and biofilm formation, which reduce susceptibility to many natural and synthetic antimicrobials (Breidenstein *et al*., 2011). The results therefore highlight both the promise and limitations of crude plant extracts in controlling opportunistic pathogen.

## CONCLUSION

The findings revealed that garlic extract is the most promising for broad antibacterial activity; this is consistent with a large body of literature on allicin/organosulfur antibacterial potency. Turmeric shows activity but at higher concentrations; its apparent weaker performance here is consistent with solubility and potency issues. Ginger had moderate activity on the bacterial isolates and manty of the bacterial isolates demonstrated resistance at lower concentration of the plant extracts.

**The study e**ncourages the use of plant-based formulations such as turmeric, ginger and garlic for the treatment of infections, and test the synergy with antibiotics which is useful for resistant bacterial isolates, while efforts should be made to identify and quantify active constituents of the plant extracts or spices.

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**APPENDIX 1: Morphological and Biochemical Characteristics of Bacterial isolates from Water Samples**

| | MORPHOLOGICAL | | | | | | | | PHYSIOLOGICAL | | | | | | | SUGER FERMENTATION | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Isolate | Gram reaction | Shape | Elevation | Color | Shape | Margin | Texture | Size | Catalase | Oxidase | Indole | Motility | Citrate | MR | VP | Glucose | Lactose | Mannitol | Sucrose | **Suspected organism** |
| N1 | + | Rods | Flat | White | Round | Serrated | Dry | 4mm | + | + | - | + | + | - | + | A | A | A | - | ***Bacillus sp*** |
| N2 | - | Rods | Raised | Red | Round | Entire | Moist | 2mm | + | + | - | + | + | + | - | AG | AG | AG | AG | ***Serratia* sp** |
| N 3 | + | Cocci | Raised | Milky | Round | Entire | Moist | 1.2mm | + | - | - | - | - | + | + | AG | AG | AG | AG | ***Micrococcus sp*** |
| N 4 | + | Cocci | Raised | Yellow gold | Round | Entire | Moist | 1mm | + | + | - | - | - | + | - | AG | - | AG | AG | ***Staphylococcus sp*** |
| N 5 | - | Rods | Raised | Light green | Round | Entire | Moist | 2mm | + | + | - | + | - | - | + | - | - | - | - | ***Pseudomonas sp*** |
| N 6 | + | Rods | Flat | Milky | Round | Serrated | Dry-wet | 4mm | + | + | - | + | + | - | + | A | - | - | A | ***Bacillus* sp** |
| E1 | - | Rods | Raised | Pink | Round | Entire | Moist | 2mm | + | - | + | + | - | + | - | AG | AG | AG | AG | ***Escherichia coli*** |
| E2 | - | Rods | Raised | Pink | Round | Entire | Moist | 4mm | + | + | - | + | + | + | - | AG | AG | AG | AG | ***Klebsiella sp*** |

Key: +; Positive, -; Negative, AG; Acid and Gas production, MR; Methyl red test, VP; Voges proskauer test.

**ANOVA Table**

| | | | Sum of Squares | Df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|---|
| THB * SAMPLE | Between Groups | (Combined) | .220 | 2 | .110 | .013 | .987 |
| | Within Groups | | 75.147 | 9 | 8.350 | | |
| | Total | | 75.367 | 11 | | | |
| TCC * SAMPLE | Between Groups | (Combined) | 29.307 | 2 | 14.653 | 4.368 | .047 |
| | Within Groups | | 30.190 | 9 | 3.354 | | |
| | Total | | 59.497 | 11 | | | |
| TFC * SAMPLE | Between Groups | (Combined) | 12.332 | 2 | 6.166 | 2.797 | .114 |
| | Within Groups | | 19.838 | 9 | 2.204 | | |
| | Total | | 32.169 | 11 | | | |

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