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Harnessing the antibacterial potentials of *Allium sativum* (garlic), *Allium cepa* (onions) and *Zingiber officinale* (ginger) extracts against multidrug-resistant bacterial strains

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ABSTRACT

The increasing resistance of bacterial pathogens to conventional antibiotics has heightened interest in exploring natural alternatives with potential antimicrobial properties. Plants such as *Allium sativum* (garlic), *Allium cepa* (onion), and *Zingiber officinale* (ginger) have long been recognized for their medicinal qualities, including antibacterial activity against a wide range of pathogens. These plants are rich in bioactive compounds, such as allicin in garlic, sulfur-containing compounds in onions, and gingerols in ginger, which contribute to their notable antimicrobial effects, making them valuable in combating virulent bacterial agents. This study aimed to evaluate the antibacterial activities of *A. sativum* (garlic), *A. cepa* (onion), and *Z. officinale* (ginger) against virulent bacterial agents. Antibacterial testing was conducted using clinical isolates of *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella typhi* obtained from the National Veterinary Research Institute (NVRI), Vom, Plateau State. Plant materials were extracted using the maceration method with solvents of varying polarities: n-hexane, ethyl acetate, methanol, and water. Phytochemical screening was performed using standard methods. Antibacterial activity was assessed using the agar well diffusion method, while minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) were determined via the broth dilution method using a 96-well microtiter plate with resazurin as a growth indicator. The extraction yield revealed the following: aqueous extract (*A. cepa*, highest yield: 54.50 g), methanol extract (*A. cepa*, highest yield: 104.40 g), ethyl acetate extract (*Z. officinale*, highest yield: 5.30 g), and hexane extract (*A. cepa*, highest yield: 21.00 g). Phytochemical screening identified secondary metabolites, including tannins, flavonoids, alkaloids, steroids, cardiac glycosides, carbohydrates, saponins, phenols, anthraquinones, and terpenoids. The bacterial strains were most susceptible to methanol and ethyl acetate extracts of *A. cepa* and *Z. officinale*, while they showed the least susceptibility to aqueous and hexane extracts of *A. sativum* and *Z. officinale*. *S. aureus* demonstrated the highest susceptibility across all extract concentrations (100–500 mg/mL), whereas *E. coli* and *S. typhi* exhibited variable susceptibility patterns. The minimum bactericidal concentration (MBC) for *E. coli* was 300 mg/mL for the aqueous extract of *A. sativum*. For *S. typhi*, the MBC was observed for aqueous and ethyl acetate extracts of *A. sativum* and the aqueous extract of *A. cepa*. All plant extracts demonstrated broad-spectrum antibacterial activity against the tested pathogenic bacteria. These findings confirm that the test plants contain valuable secondary metabolites with antibacterial potential, supporting their use in the treatment of bacterial infections.

Keywords: Antibacterial activities, virulent agents, antimicrobial resistance, phytochemistry.

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INTRODUCTION

Resistance to antibiotics among bacteria causes hundreds of thousands of deaths annually. Globally, drug-resistant diseases are responsible for at least 700,000 deaths each year, a figure projected to rise to 10

million deaths per year by 2050. A particularly serious concern is the growing number of bacteria resistant to commonly used antibiotics, including last-resort drugs like vancomycin (Shapawee et al., 2020). The rapid spread of resistance genes worldwide highlights the urgent need for international cooperation to address this global public health crisis (Kumar et al., 2017; Kumar and Jena, 2017).

One type of resistance is natural insusceptibility, known as innate resistance. This is a constant trait of a species, strain, or group of bacteria. Certain microorganisms are inherently insensitive to specific antibiotics due to factors such as the absence of a receptor for the antibiotic, low binding affinity, cell wall impermeability, or the production of enzymes (Holmes et al., 2016). Addressing drug resistance in microorganisms requires innovative strategies, including increasing research into medicinal plants as sources of antimicrobial agents.

The indiscriminate use of antibiotics has often led to side effects and the development of resistance in pathogens, underscoring the need to explore alternative approaches for combating infectious diseases (Pandey and Agnihotri, 2015). In this context, discovering plant-derived antimicrobials as reliable sources of antibiotics has garnered significant attention from the scientific community (Kumar et al., 2017). The primary objectives should include reducing infection rates, optimizing antimicrobial use, and ensuring sustainable investment in combating antimicrobial resistance. A strategic focus on medicinal plants and the therapeutic knowledge of indigenous populations can contribute significantly to reducing antimicrobial resistance (AMP). Medicinal plants are recognized as valuable sources of bioactive compounds with potential antimicrobial properties (Uttpal et al., 2019).

Medicinal plants have been used for thousands of years to treat various infectious and non-infectious diseases worldwide (Block, 2010). Among these, ginger (*Zingiber officinale*) from the Zingiberaceae family is notable for its strong aromatic and medicinal properties (Yadufashije et al., 2020). Ginger is widely available, affordable, and contains numerous phenolic compounds, such as paradol, gingerols, zingerone, and shogaols, which exhibit significant antimicrobial effects against various resistant microbes, including bacteria, fungi, and viruses, with minimal toxicity (Okiki et al., 2015). Ginger has been reported to have both prophylactic and therapeutic properties for infections and ailments, such as colds, fever, menstrual pain, joint pain, nausea, bloating, indigestion, respiratory infections, sore throat, skin infections, kidney and bladder infections, constipation, dysentery, and intestinal inflammations (Arshad et al., 2014; Okiki et al., 2015; Mahmoud et al., 2016).

Garlic (*Allium sativum*) from the Alliaceae family, which includes onions, shallots, and leeks, has been used medicinally for centuries across many cultures (Huzaifa et al., 2014). Garlic is believed to help prevent heart diseases, including atherosclerosis, high cholesterol, and hypertension, and to improve immune function while inhibiting the development of cancer cells (Ponmurugan and Shyamkumar, 2012). In Nigeria, garlic is used in homeopathic medicine to treat abdominal discomfort, diarrhea, and respiratory infections, and it is also employed as a topical antimicrobial agent (Jaber and Al-Mossawi, 2007; Timbo et al., 2006).

Onion (*Allium cepa* L.), another member of the Alliaceae family, is among the oldest cultivated plants used both as food and for medicinal purposes (Martins, 2016). Onion bulbs are widely used for culinary purposes and therapeutic applications, while the leaves, stalks, and roots also have medicinal uses. The ethnomedicinal benefits of onions include positive effects on the circulatory system, such as acting as a diuretic, preventing atherosclerosis by lowering LDL cholesterol, and reducing blood clot formation during tissue injury. Onions also have antihyperglycemic properties for managing diabetes and antifungal and antibacterial effects (Guarrera and Savo, 2013; Hannan et al., 2010).

Despite the diverse bioactive compounds found in these plants, there is limited understanding of how solvent choice affects the extraction of the most active compounds. Therefore, this study was designed to evaluate how solvents with different polarities influence the yield of bioactive compounds and their potential antibacterial activities against multi-resistant bacteria.

MATERIALS AND METHODS

Study area

The study was conducted from January 2021 to September 2022 at the Drosophila Laboratory: Fungal Pathogens and Plant Bioactive Compounds, Department of Plant Science and Biotechnology, University of Jos, Nigeria.

Preparation of crude extracts

Collection of plant parts

A total of 100 kg of fresh onion, garlic, and ginger were purchased from the Farin Gada Market in Jos North Local Government Area, Plateau State, Nigeria.

Extraction of plant parts

Plant extracts were prepared using the maceration method based on solvent polarity, utilizing n-hexane, ethyl acetate, and distilled water**,** respectively, as described in the Harborne (1984) method of solvent partition coefficients in their graded forms.

Determination of percentage yield

The percentage yield of the crude extracts was determined for each solvent as described by Parekh and Chanda (2007). The percentage yield was calculated using the following formula:

$$\text{Percentage yield} = \frac{\text{Weight of plant extract before extraction}}{\text{Weight of plant extract after extraction}} \times 100$$

Phytochemical screening

The plant extracts were analyzed for their phytochemical constituents to determine the presence of alkaloids, saponins, tannins, flavonoids, carbohydrates, steroids, anthraquinones, cardiac glycosides, and terpenoids using standard phytochemical screening methods as described by Sofowora (2008) and Trease and Evans (2002).

Test for alkaloids

The test was conducted following the method reported by Trease and Evans (2002). A 0.5 g sample of each extract was stirred with 5 ml of 1% aqueous HCl on a steam bath. The mixture was then filtered using Whatman filter paper No. 42 (125 mm). Subsequently, 1 ml of the filtrate was treated with 2–3 drops of Mayer's reagent, while another 1 ml was treated with Dragendorff's reagent. The formation of turbidity or precipitation with either reagent indicated the presence of alkaloids.

Test for saponins

The test was performed using the method outlined by Trease and Evans (2002). A 0.5 g sample of each fraction was dissolved in 25 ml of distilled water and filtered using Whatman filter paper No. 42 (125 mm). An additional 10 ml of distilled water was added, and the mixture was shaken vigorously to observe the formation of a stable, persistent froth. The froth was then mixed with 3 drops of olive oil and shaken. The formation of an emulsion confirmed the presence of saponins.

Test for tannins

The test was performed following the method described by Edeoga et al. (2005). A total of 0.5 g of the fractions was stirred with 10 mL of distilled water and filtered using Whatman filter paper No. 42 (125 mm). To the filtrate, a solution of ferric chloride was added. The appearance of a blue-black, green, or blue-green precipitate indicates the presence of tannins.

Test for authraquinones

The detection of anthraquinones was conducted using Borntrager's test, as described by Sofowora (2008). A total of 0.5 g of each fraction was placed in a dry test tube, and 5 mL of chloroform was added. The mixture was shaken for 5 minutes, and then filtered. The filtrate was mixed with an equal volume of 100% ammonia solution and shaken. The appearance of a pink, violet, or red color in the ammoniacal (lower) layer indicates the presence of free anthraquinones.

Test for cardiac glycoside

The test was performed following the method described by Sofowora (2008). A total of 100 mg of the extracts was dissolved in 70% alcohol and filtered. Approximately three drops of lead subacetate were added to the filtrate, which was then filtered again. The resulting filtrate was extracted with 10 mL of chloroform in a separating funnel and concentrated to dryness. The residue was dissolved in 1 mL of glacial acetic acid containing one drop of ferric chloride solution. This mixture was underlaid with 1 mL of concentrated sulfuric acid. The formation of a brown ring at the interface indicates the presence of a deoxysugar, characteristic of cardenolides.

Test for steroid and terpenes

The test was performed following the method reported by Trease and Evans (2002). A total of 100 mg of each extract was dissolved in chloroform, and 1 ml of acetic anhydride was added, followed by the addition of two drops of concentrated sulfuric acid. The appearance of a pink color that changes to bluish-green upon standing indicates the presence of steroids and terpenes.

Test for flavonoids

The test was conducted according to the method described by Sofowora (2008). A total of 0.5 g of the extract was dissolved in 30 ml of distilled water, stirred, and filtered using Whatman filter paper No. 42 (125 mm). To 10 ml of the filtrate, 5 ml of 1M dilute ammonia solution was added, followed by 10 ml of concentrated sulfuric acid. The formation of a yellow precipitate that disappears upon standing indicates the presence of flavonoids.

Additionally, 5 ml of dilute ammonia was added to 5 ml of the extract, followed by 5 ml of concentrated sulfuric

acid. The appearance of a yellow color confirms the presence of flavonoids.

Test for carbohydrates

The test was performed according to the method reported by Sofowora (2008). A total of 0.5 g of the extract was dissolved in 30 ml of distilled water and filtered using Whatman filter paper No. 42 (125 mm). A few drops of Molisch reagent were added, followed by the careful addition of 1 ml of concentrated sulfuric acid down the side of the inclined test tube, ensuring the acid formed a layer beneath the aqueous solution without mixing. The presence of a reddish or violet ring at the interface of the two layers indicates the presence of carbohydrates.

Preparation and reconstitution of plant extracts

The plant extracts of *Allium sativum*, *Allium cepa* and *Zingiber officinale* were reconstituted by dissolving them in 10% DMSO (Dimethyl Sulfur-oxide) solvent, following the modified method described by Abiy and Berhe (2016). Two grams of each plant extract were dissolved in 4 mL of 30% DMSO to prepare a stock solution at a concentration of 500 mg/mL. Serial dilutions were then performed to obtain working concentrations of 400 mg/mL, 300 mg/mL, 200 mg/mL and 100 mg/mL. The reconstituted extracts were stored at 2–8°C under refrigerated conditions until used for the experiment.

Source of the microorganisms

Clinical isolates of *Escherichia coli*, *Staphylococcus aureus*, and *Salmonella typhi* were obtained from the National Veterinary Research Institute (NVRI), Vom, Plateau State. The organisms were collected as suspensions in nutrient broth (NB), cultured on nutrient agar, and subjected to Gram staining for re-identification.

Antimicrobial susceptibility testing

Agar well diffusion technique for susceptibility testing

The antibacterial susceptibility test was performed using clinical isolates of *E. coli*, *S. aureus*, and *S. typhi* following the agar well diffusion technique described by Nair and Chanta (2005). Inocula were prepared from subcultures of the bacteria as follows: 4 to 5 colonies of each isolate were emulsified in sterile nutrient broth, and the turbidity was adjusted to match the 0.5 McFarland standard. The sterile swab method was used to evenly inoculate the nutrient agar (NA) plates.

Wells approximately 6 mm in diameter were aseptically punched into the agar using a sterile cork borer (five wells per plate). Each well was filled with 100 µl of various concentrations of the plant extracts. The plates were left undisturbed for 30 minutes to allow the extracts to diffuse into the agar before being incubated at 37°C for 24 hours. Zones of inhibition were measured to the nearest millimeter (mm).

Determination of Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC)

The MIC and MBC were determined using the broth dilution method in 96-well plates, with resazurin dye as a growth indicator. A significant color change after 24 hours of incubation at 37°C was recorded to indicate the presence or absence of bacterial growth, as described by the Clinical and Laboratory Standards Institute (2006).

Data analysis

All data were collected in triplicate and subjected to analysis of variance (ANOVA) using GraphPad Prism software (version 8). A significant difference in the mean zone of inhibition was accepted at $p \leq 0.05$. Results are presented as means ± standard errors of the mean in graphical format.

RESULTS

Percentage (%) yield of plant extracts of garlic, onion, and ginger

The results for the percentage yield of the extracts from garlic, onion, and ginger using four different solvents based on polarity are presented in Table 1. The data reveal that the aqueous extracts of garlic and ginger had the highest yields, at 12.60% and 7.80%, respectively, whereas the methanol extract of onion showed the highest percentage yield of 34.80%. It was also observed that for all three plants, the ethyl acetate extracts had the lowest yields, measuring 0.10%, 0.76%, and 1.77% for garlic, onion, and ginger, respectively.

Phytochemical screening of the extracts of garlic, onion, and ginger

The phytochemical screening results of the garlic, onion, and ginger extract fractions demonstrated distinct patterns of bioactive compound presence across the various solvents, reflecting differences in solubility and extraction efficiency (Table 2). Methanol extracts (ASM,

Table 1. Percentage (%) yield of plant extracts of garlic, onion and ginger.

Organism	Extract fractions			
	Aqueous	Methanol	Ethylacetate	Hexane
A. sativum	12.60	4.17	0.10	4.00
A. cepa	18.17	34.80	0.76	1.50
Z. officinale	7.80	6.17	1.77	7.00

Table 2. Phytochemical screening of the plant extracts of garlic, onion and ginger.

Phytochemicals	Plants extracts											
	ASH	ACH	ZOH	ASEA	ACEA	ZOEA	ASM	ACM	ZOM	ASAQ	ACAQ	ZOAQ
Alkaloids	-	-	-	+	-	+	+++	+++	+++	+	+	+
Saponins	-	-	-	-	-	-	-	+	-	-	-	+
Tannins	-	++	-	-	++	-	-	+	-	-	+	-
Flavonoids	-	+	-	+	+	+	++	++	+++	-	+	++
Carbohydrates	+	+++	+	+++	+	+	++	+++	+++	-	-	-
Steroids	++	++	+++	++	++	+++	+	+	+	-	-	-
Terpenes	-	-	-	-	-	-	-	-	+	-	-	-
Anthraquinones	-	-	-	-	-	++	-	-	-	-	-	+
Cardiac glyscosides	++	+	++	-	-	++	-	-	++	-	-	+

Key: **ASH** – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

ACM, ZOM) showed the highest diversity of phytochemicals, with a strong presence of alkaloids, flavonoids, and carbohydrates, highlighting methanol's ability to extract a broad spectrum of compounds.

Ethyl acetate fractions (ASEA, ACEA, ZOEA) also exhibited notable bioactivity, with moderate to high levels of flavonoids and steroids but relatively fewer alkaloids and tannins, indicating a preference for less polar compounds. Aqueous extracts (ASAQ, ACAQ, ZOAQ) displayed limited phytochemical diversity, containing primarily alkaloids and occasional flavonoids and cardiac glycosides, reflecting water's selectivity for polar compounds.

Hexane extracts (ASH, ACH, ZOH) showed the least phytochemical presence, consistently detecting only steroids, indicating hexane's limited capacity to extract polar bioactive compounds.

Antibacterial susceptibility trend across 100 mg/ml plants extract

The results of the antibacterial activities of the different plant extracts are presented in Figures 1 to 5, covering concentrations from 100 mg/mL to 500 mg/mL. The results indicate that onion exhibited the highest antibacterial activity against the test organisms, followed by garlic, while ginger showed the least activity among the extracts tested.

Staphylococcus aureus was the most susceptible organism to all onion extracts, with zones of inhibition ranging from 6 ± 1.41 mm to 24 ± 0.78 mm for methanol extracts and from 6 ± 0.00 mm to 20 ± 0.49 mm for ethyl acetate extracts. Similarly, the ethyl acetate extract of ginger showed the highest inhibitory effect, followed by the methanol extract. *S. aureus* was the most susceptible to both extracts, with zones of inhibition ranging from 3 ± 1.13 mm to 15 ± 1.25 mm for the ethyl acetate extract and 1 ± 0.00 mm to 13 ± 0.36 mm for the methanol extract.

Similarly, both methanol and ethyl acetate extracts of garlic demonstrated inhibitory effects on the test organisms in a concentration-dependent manner.

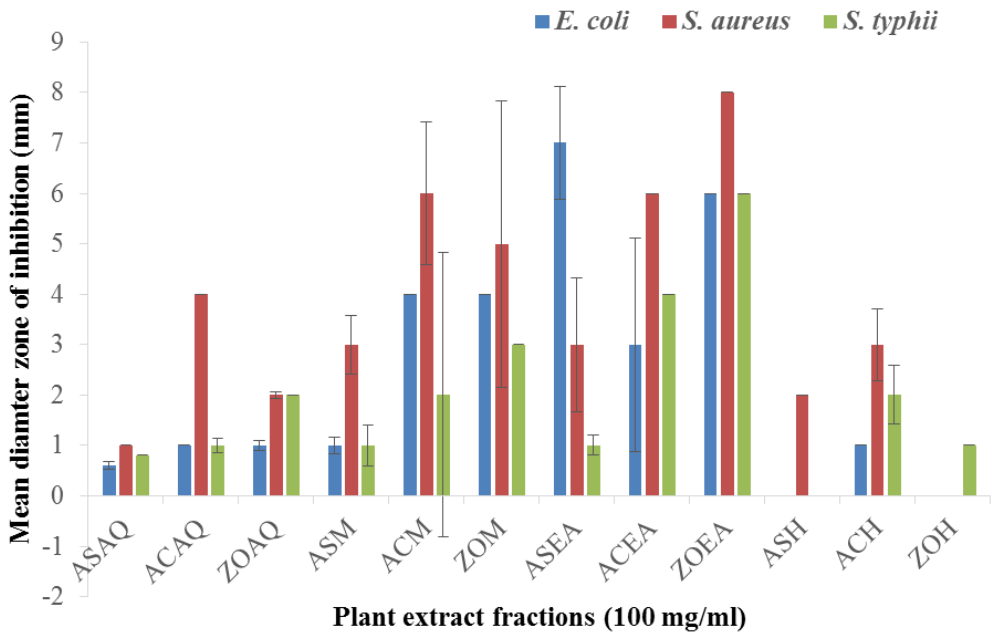

Figure 1. Antibacterial tusceptibility trend across 100 mg/ml plants extract.

Key: ASH – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

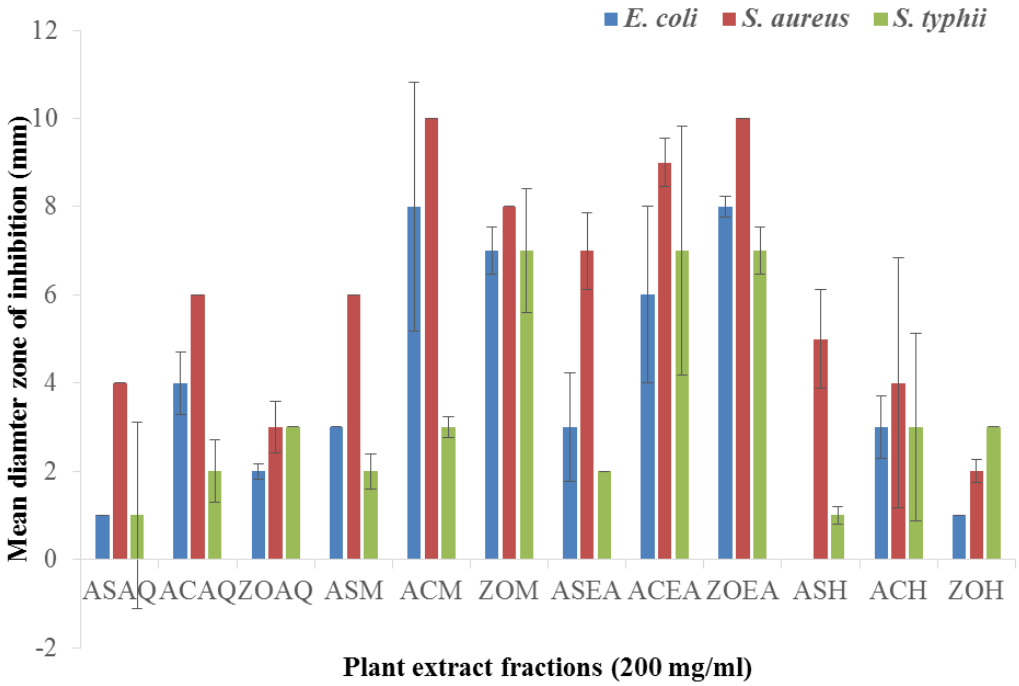

Figure 2. Antibacterial susceptibility trend across 200 mg/ml plants extract.

Key: ASH – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

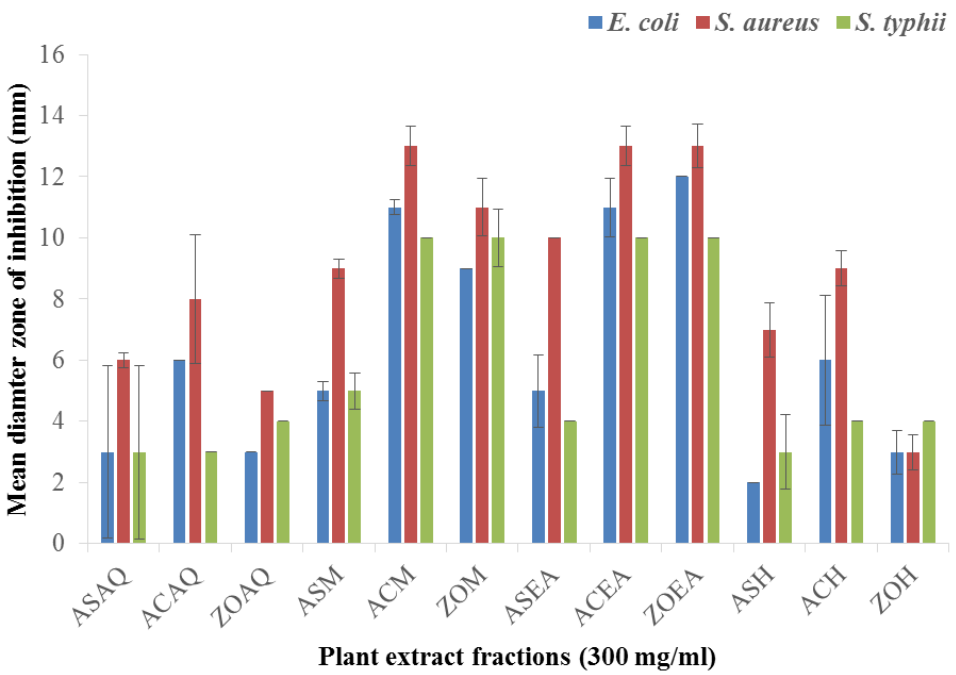

Figure 3. Antibacterial susceptibility trend across 300 mg/ml plants extract.

Key: ASH – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

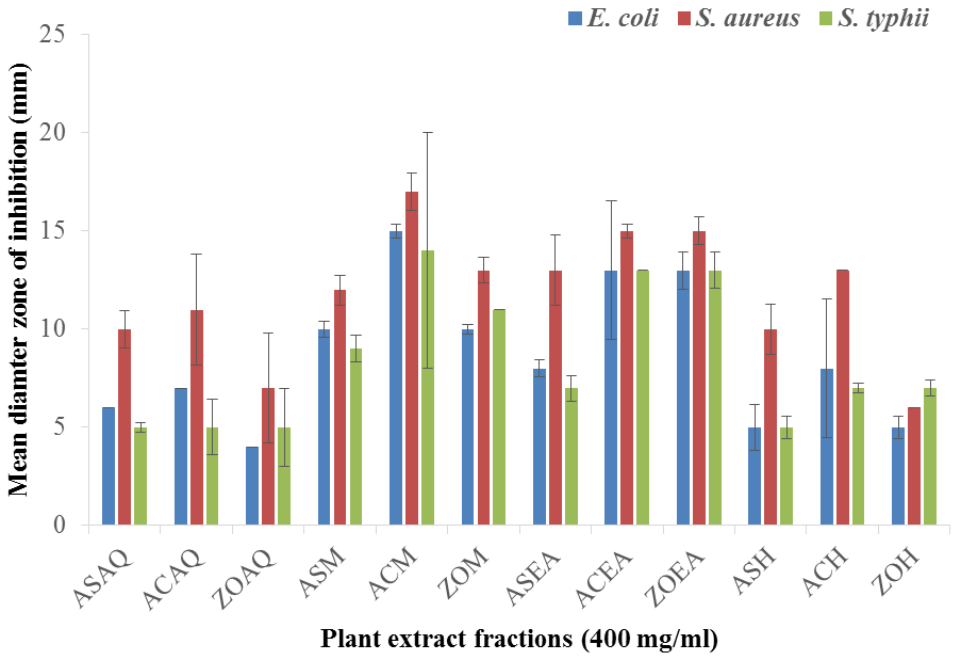

Figure 4. Antibacterial susceptibility trend across 400 mg/ml plants extract.

Key: ASH – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

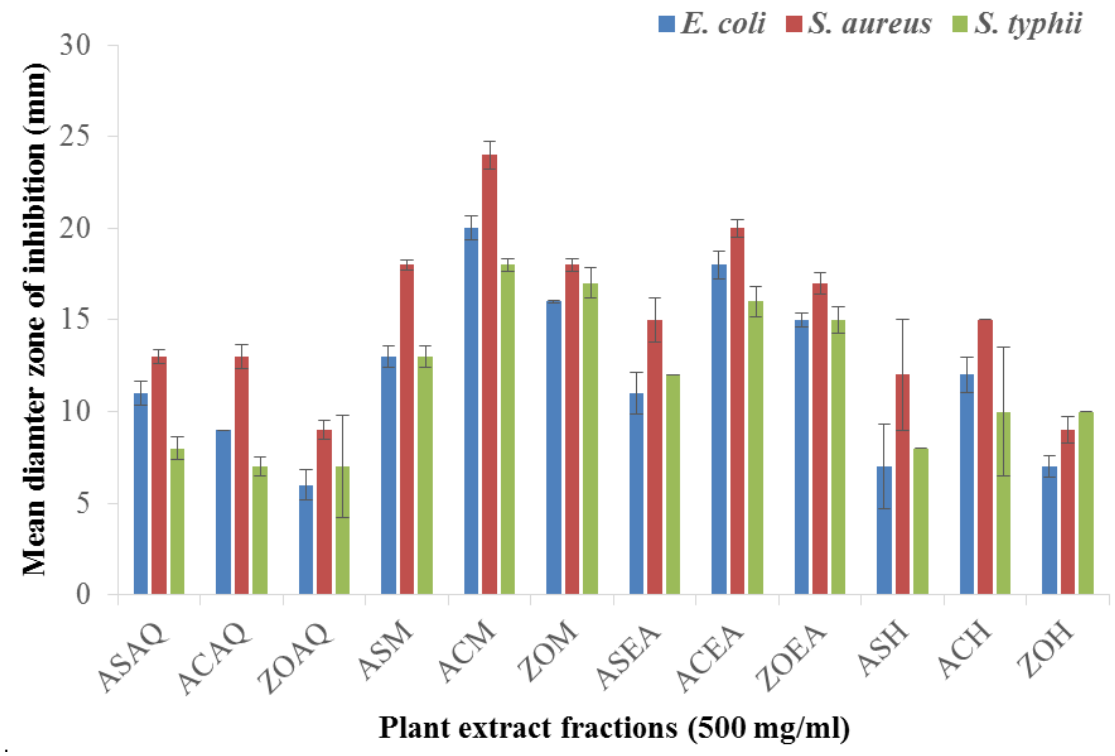

Figure 5. Antibacterial susceptibility trend across 500 mg/ml plants extract**.**

Key: ASH – *A. sativum* (Hexane), **ACH** – *A. cepa* (Hexane), **ZOH** – *Z. officinale* (Hexane), **ASEA** – *A. sativum* (Ethylacetate), **ACEA** – *A. cepa* (Ethylacetate), **ZOEA** – *Z. officinale* (Ethylacetate), **ASM** – *A. sativum* (Methanol), **ACM** – *A. cepa* (Methanol), **ZOM** – *Z. officinale* (Methanol), **ASAQ** – *A. sativum* (Aqueous), **ACAQ** – *A. cepa* (Aqueous), **ZOAQ** – *Z. officinale* (Aqueous).

Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentrations (MBC) of extracts of garlic, onion, and ginger on *E. coli*, *S. aureus* and *S. typhii*

The summary results for the Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentration (MBC) of the three plant extracts are presented in Table 3. The findings revealed that *S. aureus* was the most susceptible to garlic extracts, with the lowest MBC recorded at 200 mg/mL, while *E. coli* and *S. typhii* showed MBC values of 300 mg/mL for aqueous fractions. For hexane extracts of garlic, the MBC values for *S. aureus* and *S. typhii* were 500 mg/mL, whereas the highest concentration tested (500 mg/mL) was insufficient to inhibit the growth of *E. coli*.

Table 3. Minimum Inhibitory Concentration (MIC) and Minimum Bactericidal Concentrations (MBC) of extracts of garlic, onion, and ginger on *E. coli*, *S. aureus* and *S. typhii.*

Plants	Organisms	n-Hexane		Ethyl acetate		Methanol		Aqueous	
		MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
Garlic	*E. coli*	500	ND	400	500	300	400	200	300
	S. aureus	400	500	200	300	200	300	100	200
	S. typhii	400	500	300	400	200	300	200	300
Onion	*E. coli*	400	500	300	400	400	500	300	400
	S. aureus	300	200	200	400	300	400	200	300
	S. typhii	300	400	300	400	300	400	200	300
Ginger	*E. coli*	500	ND	500	ND	300	400	400	500
	S. aureus	400	500	300	400	200	300	200	300
	S. typhii	400	500	400	500	400	500	300	400

Key: ND - not determined within concentrations used.

Similarly, for onion extracts, *S. aureus* demonstrated the lowest MBC of 200 mg/mL, while *E. coli* and *S. typhii* had MBC values of 400 mg/mL for ethyl acetate extracts. In the case of *Zingiber officinale* (ginger) extracts, the MBC for *S. aureus* was 300 mg/mL, *E. coli* was 400 mg/mL, and *S. typhii* was 500 mg/mL for methanol fractions.

In summary, onion extracts showed the highest susceptibility against all the tested organisms, followed by garlic extracts. However, the MBC for *E. coli* could not be determined for n-hexane extracts. Ginger extracts demonstrated the least susceptibility, with no MBC determined for *E. coli* in both n-hexane and ethyl acetate extracts.

DISCUSSION

The determination of biochemical constituents revealed that the three plants - ginger, garlic, and onion - contain secondary metabolites, including alkaloids, flavonoids, tannins, saponins, terpenes, phenols, anthraquinones, and cardiac glycosides, in varying proportions. This chemical diversity could be attributed to genetic and environmental factors affecting the secondary metabolism of these species, the harvesting time of the biological materials at different developmental stages, interactions with microorganisms and insects, and different post-harvest techniques, such as extraction methods and the solvents used. These findings align with the observations of Morais and Castanha (2012) and Camilotti et al. (2015).

It was observed that the activity of the various plant extracts increased with higher extract concentrations. A similar trend was reported by Ural et al. (2001). The Gram-positive bacteria were found to be more sensitive than Gram-negative bacteria for both garlic and onion extracts. This observation aligns with the findings of Onyeagba et al. (2004) and could be explained by the structural differences in the bacterial outer membrane. The outer membrane of Gram-negative bacteria provides strong hydrophobicity and acts as a significant permeability barrier. This is consistent with an *in vitro* study by Burt (2004), which evaluated the antibacterial activity of essential oils against *Listeria monocytogenes, Salmonella Typhimurium, Escherichia coli* O157:H7, *Shigella dysenteriae, Bacillus cereus,* and *Staphylococcus aureus,* concluding that Gram-negative bacteria are less susceptible than Gram-positive bacteria.

The results of this study demonstrated that onion exhibited the highest antibacterial activity against the tested organisms, followed by garlic, while ginger showed the least activity among the extracts tested. These findings concur with those of Barht et al. (2013) and Vamshi et al. (2010), who reported antimicrobial activities of onion extracts against various test organisms. Mohamed et al. (2013) noted that the methanolic suspension of onion exhibited higher activity at 100 µg/mL against *S. aureus* (26 mm inhibition zone) compared to the aqueous extract (23 mm inhibition zone) at the same concentration. Similarly, both the methanol and ethyl acetate extracts of garlic showed inhibitory effects on the test organisms in a concentration-dependent manner.

These findings are consistent with the work of Islam et al. (2014), Skrinjar and Nemet (2009), and Natta et al. (2008), who reported various antibacterial activities of ginger and garlic against certain bacteria. Furthermore, Onyeagba et al. (2004) highlighted the synergistic effects of ethanol extracts of ginger and garlic against *Bacillus* spp. and *Staphylococcus aureus*. They also documented the antimicrobial activity of ethanol extracts of ginger, lime, and garlic against a broad spectrum of bacteria, including *Bacillus* spp., *Staphylococcus aureus, Escherichia coli,* and *Salmonella* spp.

CONCLUSION

In conclusion, this study confirms the antimicrobial potential of *Allium sativum* (garlic), *Allium cepa* (onion), and *Zingiber officinale* (ginger) against *Escherichia coli, Staphylococcus aureus,* and *Salmonella typhi*. The antimicrobial activities of these plant extracts are attributed to their secondary metabolites, which highlight their therapeutic potential for combating bacterial infections.

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