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Antibacterial, phytochemical and GC-MS analyses of argel (*Solanum argel*) leaves

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Abstract

Finding novel, efficient antimicrobial drugs is crucial in this age of pressing global health challenges. The medicinal qualities of the leaves of the argel plant (*Solanum argel, or S. argel*) have been recognized in traditional medicine for quite some time. The medicinal potential of these leaves may be due to the presence of bioactive substances such as alkaloids, flavonoids, and phenolic acids. S. argel leaf antibacterial, phytochemical, and gas chromatography–mass spectrometry (GC–MS) characteristics are the focus of this investigation. To conduct the study, bioactive compounds would be extracted from the leaves and tested against a panel of bacterial pathogens. Then, the compounds would be identified using GC-MS analysis. Mean inhibition zones of 15.30±1.0 mm, 14.67±0.42 mm, 15.0±0.01 mm, and 15.56±0.22 mm for the bacteria E. coli, Staph. aureus, and Sal. typhimurium, respectively, were seen in the antibacterial results at a concentration of 3 µg/disc. Secondary metabolites such as alkaloids, flavonoids, phenolic substances, and tannins were identified using phytochemical investigation. Antimicrobial, antioxidant, and anti-inflammatory are just a few of the many bioactivities associated with these phytochemicals. Argel plant leaves contain bioactive chemicals that show they could be a source of new pharmaceuticals. Argel leaves were analyzed using GC-MS and 37 different chemicals were found. The most abundant compounds were 4H-Pyran-4-one and 2,3-dihydro-3.5-hydroxy, followed by 3-Pentanol, 2,2,4,4-tetramethyl, and 2,2-Dimethyl-3-[3-methyl-5-(phenylthio)-, with areas of 11.80%, 10.6%, and 9.47%, respectively. The analysis was performed within a time range of 5.070 to 34.464 minutes. According to the research, Argel leaf has powerful antioxidant and antibacterial capabilities, making it an excellent substance for medical and food preservation applications.

Keywords: *Salmonella typhimurium*, Flavanones, Alkaloids, Flavonoids, Phenols

1. Introduction

Apocynaceae includes Solenostemma, a genus identified in 1825. Only one species, *S. argel*, lives in North Africa and the Arabian Peninsula [1]. Herbal therapy uses the leaves to treat kidney, liver, and allergy problems. It effectively treats neuralgia, sciatica, and pneumonia. Sometimes crushed, it treats open wounds. Incense is used to treat measles. When steeped, the leaves treat cramps, colic, colds, U.T.I.s, and stomachaches. The leaves also fight syphilis if consumed for 40–80 days. Leaf purgation may be due to stem latex. *Solenostemma* generated a large number of distinct active ingredients. *S. argel* hashistorically been used by Sudanese to treat stomach pain, childbirth pangs, and appetite loss [2].

Many scholars studied *S. argel* phytochemistry. Studying *S. argel* leaves stems, and flowers yielded numerous components and crystalline compounds. Previously, S. argel contained largely argelosid, choline, flavonoids, monoterpenes, pregnane glucoside, sitosterol, and saponin. In 2001, Hamed [3] identifiedstemmosides A and B as pregnane ester glycosides and stemming C as polyhydroxy pregnane of the Argel plant. Quercetin, rutin, flavanones, alkaloids, flavonoids, and kaempferol are all present in leaf extracts [3].

S. argel leaf was found to contain 64.8% carbohydrates, 15% protein, 1.6% crude oil, 4.4% moisture, 7.7% ash, and estimated mineral content: 0.54% potassium, 0.06% calcium, 0.03% magnesium, and sodium, 0.01% manganese, 0.002% ferrous and 0.001% lead (4). Separation Argel leaf protein revealed high albumin, non-nitrogenous protein, prolamine, and low globulins, and glutenin, moreover, phytic acid and tannin, two antinutritional components, were also present in large leaves [4].

Leave infusion is indicated for 40–80 days for gastrointestinal cramps, stomach aches, anti-colic, urinary tract infections, colds, and antisyphilis[5]. It is also an anti-inflammatory. Argel leaves are also used as measles incense and crushed for sciatica, neuralgia, wound support, and bronchitis [6]. Argel leaves are used in Yemen as tea and diabetes prevention herbal medicine [7] and for treating measles, diabetes, hypercholesterolemia, coughs, colds, and jaundice where the entire argel plant is smoked

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as incense [5].

Leading sources of natural chemicals with beneficial antibacterial qualities include marine species, terrestrial organisms, medicinal plants, bacteria, and fungi. However, a significant diversity of plants is still mostly unexplored and has the potential to produce more pharmacological compounds and antibacterial candidates when thoroughly investigated [8]. It is widely acknowledged that the presence of bioactive compounds in plants, particularly those from the Solanaceae family, has enormous potential for developing new and effective antimicrobial agents.

Previous studies have reported the antimicrobial and antifungal activities of the Argel. When tested, aqueous extracts of *S. argel* were found to effectively suppress the growth of *A. niger*, *Pennicilium italicum*, *E. coli*, and *S. typhi* [9, 10].

The goal of the study was to provide a comprehensive analysis of the antibacterial, phytochemical, and GC-MS properties of Argel (*Solanum argel*) plant leaves from Gezira State.

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2. Materials and methods

2. 1. Materials

Argel leaves from the Wad Madani local market was used in this investigation. Samples of Argel (*Solanum argel*) plant leaves were collected from various natural habitats, ensuring that the specimens were free from any contamination or artificial preservatives. The selected leaves were cleaned to eliminate any dirt or debris, and then dried under shade at ambient temperature. A motorized grinder pulverized the dried leaves into a fine powder after 14 days. This preparation method ensures a consistent and uniform sample, minimizing any variations that may be caused by differences in leaf size, age, or environmental factors.

2.2. Plant extract preparation

Aqueous extraction involved gently boiling 20 grams of air-dried powder in 150 milliliters of distilled water for 2 hours. After eight layers of muslin, the fluid was centrifuged at 5000 times gravity for 10 minutes. The liquid supernatant was carefully taken. The technique was repeated twice. Supernatant was collected at 2-hour intervals after 6 hours, consolidated, and concentrated to 25% of the initial amount.

2.3. The plant extract activity test

The antibacterial activity of the Argel plant extract was evaluated using the agar well diffusion method [11]. A total of six bacterial strains, including *Staphylococcus aureus* (*Staph. aureus*), *Escherichia coli* (*E. coli*,), *Pseudomon aeruginosa* (*P. aeruginosa*), *Bacillus subtilis* (*B. subtilis*), *Salmonella typhimurium* (*Sal. typhimurium*), and *Klebsiella pneumonia* (*K. pneumoniae*), were selected for this study based on their common occurrence and relevance in human health (King Khalid Hospital provided the microorganisms). To prepare the inoculums for the antibacterial assay, each bacterial strain was grown separately in nutrient broth overnight at 37°C. The final cell suspensions were adjusted to a concentration of 10^8 colony-forming units per milliliter (CFU/mL) using a spectrophotometer. After cooling and solidifying 15-20 ml of nutrient agar medium in sterile Petri dishes, the agar well diffusion experiment was performed. After adding a 20 µL bacterial suspension aliquot to the center of each Petri dish, 6 mm diameter wells were inserted. The Argel plant extract and the positive control (gentamicin) were separately dissolved in 20 µL of dimethyl sulfoxide (DMSO) and added to the respective wells. The plates were incubated at 37°C for 24 hours, after which the inhibition zones were measured to assess the antibacterial activity of the Argel plant extract.

2.4. M.I.C. of plant extract determined by microdilution

To prepare each 96-well plate, 50 µl of Mueller-Hinton broth was dispensed for the bacteria. 50 µl of the stock solution, which contained 200 mg/ml of the tested extracts, was added to the plate's first row. Using a micropipette, twofold serial dilutions will be performed. Based on the 100–0.1953 mg/ml concentration range, ten microliters of inocula were added to each well. The positive control inoculum was increased to 1.5X108 CFU/mL. The inoculum containing the medium served as the negative control, while the plant extract served as the positive control. For eighteen hours, the test plates were incubated at 37 °C. The wells were incubated for a further hour after 18 hours, and then 50 µl of a 0.01% solution of 2, 3, and 5-triphenyl tetrazolium chloride (T.T.C.) was added. Throughout the T.T.C. incubation, the well's solution did not turn red, suggesting that the biologically active bacteria were preventing growth by coloring the colorless tetrazolium salt red. At the minimum concentration of the sample (M.I.C.), there was complete growth suppression and no discernible color change [12, 13].

2.5. Phytochemical profiles

The phytochemical analysis of Argel plant leaves was carried out using standard qualitative and quantitative methods to identify and quantify the presence of certain bioactive compounds, such as alkaloids, flavonoids, phenolics, saponins, and tannins. This analysis lays the foundation for understanding the potential therapeutic applications of Argel plant leaves [14].

2.5.1. Phenols

Three drops of 5% FeCl3 were added to 10 ml of each extract in 1 ml distilled water. A bluish-black tint indicates phenols.

2.5.2. Alkaloids

The test tube contained 5 ml of extract, 2 ml MeOH, and 2 ml 1% HCl. Next, 500 µl of reagent was added to the mixture. Orange or orange reddish-brown precipitate was positive. This extract was tested with two drops of Mayer's reagent in 1 ml. Alkaloids precipitate white or creamy.

2.5.3. Flavonoids Test for alkalinity

Adding 2 ml NaOH 2% to 5 ml extract intensified the yellow. The tint disappeared with diluted HCl, indicating flavonoids.

2.5.4. Salkowski-tested terpenes

We added 2 ml chloroform to 5 ml extract. Then 3 ml H2SO4 was added. Reddish-brown indicates terpenoids.

2.5.5. Sterols

Two ml glacial acetic anhydride was added to five ml extract with two H2SO4. Violet-to-blue or green color shifts indicate steroids.

2.5.6. Keller-Kiliani cardiac glycoside test

One ml glacial acetic acid and three drops 5% FeCl3 were added to 2.5 ml extract. Test tube side received 0.5 ml conc H2SO4. A green or blue color implies cardiac glycosides.

2.5.7. Saponins

Ten ml pure water was added to 5 mg extract. Five minutes were spent shaking the solution. A stable foam shows saponins.

2.5.8. Tannins

Three drops of 5% FeCl3 solution were added to 2 ml of each extract diluted with distilled water in a test tube. The hue green, black, or blue denoted tannins.

2.6. GC–MS analysis

To further understand the potential therapeutic benefits of ginger rhizome, it was essential to conduct a comprehensive phytochemical screening and GC-MS analysis of the sample. This testing allowed us to identify and quantify the various bioactive compounds present in the ginger extract, which could contribute to its antimicrobial, anti-inflammatory, and antioxidant properties.

Central Laboratories, University of Gezira, was the location where the GC-MS technique was utilized to analyze the ethanol extract of the various plant components that were chosen. In the sections devoted to the results, the chemical ingredients identified by the GC-MS analysis were reported, along with their retention time, base peak, molecular weight, molecular formula, and compound names. NIST 14S was the library that was utilized to identify chemicals.

2.6.1. Conditions of analysis

One milliliter of injected sample was divided into ten equal parts. Preheat the oven to 60 degrees Celsius. Cook for 25 minutes at a rate of 80 degrees Celsius each minute. There were 53.5 minutes in the show. Analyzing GC-MS. leaf oil requires specific conditions: Notedly, FAME molecules were discovered by G MS. At 0.7 mL/min, helium was flowing. Heats of 250, 250, and 220 °C were applied to the ion source, transfer, and injector, respectively. The oven was brought up to 250 °C in increments of 40 °C after being heated to 50 °C for 1 minute. From 35 to 500 amu, full-scan mass spectra were acquired for all data. Spectra were compared to mass spectral databases to identify substances. We set system calibration and minimal detection limits using manufacturing circumstances. Other sources provide the equation [15].

2.7. Statistical analysis

The obtained data were subjected to simple descriptive analysis. The significant cases were determined through the least significant difference (L.S.D.) analysis, which was reflected by letters for each case (the different letters reflected different significant levels).

3. Results

3.1. The phytochemical screening

Table (1) shows the results of the phytochemical screening of argel leaves. The plant exhibited the presence of flavonoids and steroids.

The phytochemical analysis of Argel plant leaves revealed the presence of various secondary metabolites, including alkaloids, flavonoids, phenolic compounds, and tannins. These phytochemicals are known to have diverse bioactivities, such as antimicrobial, antioxidant, and anti-inflammatory properties [16; 17; 18]. The presence of these bioactive compounds in Argel plant leaves highlights their potential as a source of novel pharmacological agents. Furthermore, the study confirmed that the Argel plant leaves exhibited high phenolic and flavonoid contents, which have been linked to numerous health benefits, including the prevention of chronic diseases like cancer and cardiovascular disease. The identification and quantification of these phytochemicals in Argel plant leaves underscore its potential as a valuable natural resource for the development of new therapeutic agents.

3.2. GC-MS analysis of Argel leaves

Thirty-seven distinct compounds were identified by the GC-MS analysis of Argel (*S. argel*) leaves (Figure 1 and Table 2). These compounds were dispersed over a retention time of 5.070 to 34.464 minutes. The primary component identified in the sample was 4H-Pyran-4-one, 2,3-dihydro-3.5-hydroxy-, accounting for 11.8% of the total. Subsequently, methyl 3-Pentanol, 2,2,4,4-tetramethyl (10.61%), 2,2-Dimethyl-3-[3-methyl-5-(phenylthio)-,

Table 1. Phytochemical screening of Argel leaves.

Main class	Argel Leaves
Saponins	+
Flavonoids	+
Tannins	+
Glycosides	+
Alkaloids	+
Steroids	++
Terpenoids	-

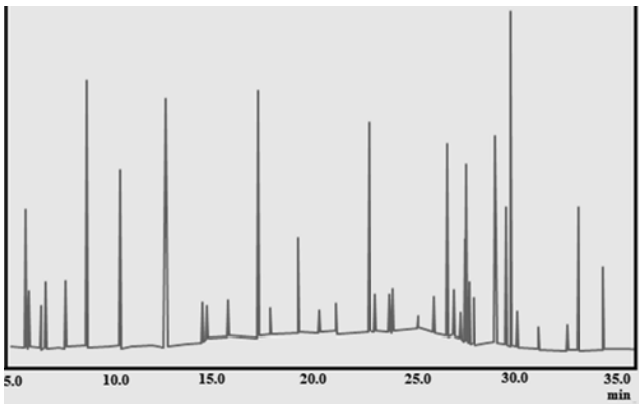

Fig. 1. GC-MS chromatogram of Argel (*S. argel*) leaves indicating various peaks of the identified chemical compounds.

Table 2. GC-MS of Argel (*S. argel*) leaves.

Peak	R. time	Area%	Compound name	Mol. form.
1	5.070	3.19	2- Furanmethanol	$C_5H_6O_2$
2	5.516	1.29	3-Hepten-2-one	$C_7H_{12}O$
3	5.815	0.95	Heptanal	$C_7H_{14}O$
4	6.036	1.52	6-Oxa-bicyclo[3.1.0]hexan-3-one	$C_5H_6O_2$
5	7.084	1.54	2,4-Dihydroxy-2,5-dimethyl-3(2H)-furan-3	$C_6H_8O_4$
6	8.205	10.61	3-Pentanol,2,2,4,4-tetramethyl-	$C_9H_{20}O$
7	9.855	4.12	N,N-bis(3-aminopropyl)ethylene diamine	$C_8H_{22}N_4$
8	12.177	11.80	4H-Pyran-4-one, 2,3-dihydro-3.5-hydroxy-	$C_6H_8O_4$
9	14.040	0.96	Benzofuran, 2,3-dihydro-	C_8H_8O
10	14.329	0.75	Acetic acid, 3-methyl-6-oxohex-	$C_9H_{14}O_3$
11	15.380	1.88	5-Hydroxymethylefurfural	$C_6H_6O_3$
12	16.838	5.76	2-Methyl-4-vinylphenol	$C_9H_{10}O_2$
13	17.548	0.66	Acetic acid, 2-propyltetrahydropyran-3-ester	$C_{10}H_{18}O_3$
14	18.986	2.53	Trans-Linalool oxide (furanoid)	$C_{10}H_{18}O_2$
15	20.089	0.59	3-Bromo-5,5-dimethyl-cyclohexane-2-enol	$C_8H_{13}BrO$
16	20.827	0.71	3-Acetoxydodecane	$C_{14}H_{28}O_2$
17	22.542	4.92	1,2.4- Cyclopentanetrione, 3-(-2-pentenyl)-	$C_{10}H_{12}O_3$
18	22.829	0.90	Stevioside	$C_{38}H_{60}O_{18}$
19	23.525	0.90	Spiro[androst-5-ene-17.1'-cyclobutan]-2'-one	$C_{22}H_{32}O_2$
20	23.744	1.02	12,15-Octadecadiynoic acid, methyl ester	$C_{19}H_{30}O_2$
21	25.010	0.36	Phnol, 2,6-dimethoxy-4-(2-propenyl)	$C_{11}H_{14}O_3$
22	25.809	0.85	2-Deoxy-D-galactose	$C_6H_{12}O_5$
23	26.470	4.41	Methyl-3-methyl butanoate	$C_8H_{16}O_5$
24	26.800	1.02	2-Cyclohexen-1-one, 4-hydroxy-3,5,5-trimet	$C_{13}H_{18}O_3$
25	27.158	0.37	3-Deoxy-d-mannoic lactone	$C_6H_{10}O_5$
26	27.327	2.33	Z-3-Methyl-2-hexenoic acid	$C_7H_{12}O_2$
27	27.469	4.07	1,3,5-triazine-2,4-diamino,6 chloro-n-ethyl	$C_5H_8ClN_5$
28	27.613	1.38	6-(4-Hydroxy-6-methoxy-2-methyl-tetrahydro	$C_{13}H_{22}O_6$
29	27.896	1.03	β,-D-Glucopyranose,4-O-β-D-galactose	$C_{12}H_{22}O_{11}$
30	28.954	8.55	n-Hexadecanoic acid, methyl ester	$C_{16}H_{32}O_2$
31	29.539	3.21	Phenol,2-(1,1-dimethyl ethyl)-	$C_{10}H_{14}O$
32	29.766	9.47	2,2-Dimethyl-3-[3-methyl-5-(phenylthio)-	$C_{16}H_{22}OS$
33	30.352	0.64	Ethyl iso-allocholate	$C_{26}H_{44}O_5$
34	31.170	0.24	Glycerol 1-palmitate	$C_{19}H_{38}O_4$
35	32.633	0.36	β,-D-Mannofuroside, farnesyl-	$C_{21}H_{36}O_6$
36	33.172	3.28	9,12-octadecedianoic acid,(z,z)-,methyl ester	$C_{19}H_{34}O_2$
37	34.464	1.83	Diazoprogesterone	$C_{21}H_{30}ON_4$
		100		

1,2.4- Cyclopentanetrione, 3-(-2-pentenyl)-, methyl-3-methyl butanoate (4.41%), 2-Furanmethanol (3.19%), and additional traces were present. These compounds were dominated by 4H-Pyran-4-one, 2,3-dihydro-3.5-hydroxy, followed by 3-Pentanol,2,2,4,4-tetramethyl and 2,2-Dimethyl-3-[3-methyl-5-(phenylthio)- with 11.80%, 10.6% and 9.47% areas, respectively. The study indicates that Argel leaf possesses significant antibacterial and antioxidant properties, making it a valuable agent for food preservation and medicinal purposes.

No terpenoids were identified; however, three N-containing compounds and five phenolic compounds were detected: 1,3,5-triazine-2,4-diaminobenzetine diamine, N, N-bis (3-aminopropyl) ethylene diamine, and 2,2-dimethyl-3-[3-methyl-5]. Among the phenolic compounds identified were the following: 3-pentanol, 2-dimethoxy-4-(2-propenyl); 2-methyl-4-vinylphenol; Phnol, 2,6-dimethoxy-4-(2-propenyl); 2-(1,1-dimethylethyl); 2,2-dimethyl-3-).

These findings suggest that Argel leaves may hold immense potential for use in various industries, including medicine and agriculture, due to their diverse range of compounds and properties. The continued study and research of these components can aid in the development of innovative solutions to pressing global issues, such as environmental degradation and disease management [19; 20; 21]. Some of the compounds found in Argel leaves, such as 4H-Pyran-4-one, 2,3-dihydro- 3.5-hydroxy- and 1,2.4-Cyclopentanetrione, may have potential uses in medicine. For instance, these compounds could be valuable

in the development of new pharmaceuticals, as they may possess unique biological properties that could aid in the treatment of various diseases or health conditions [22; 23; 24].

Other compounds identified in the GC-MS analysis, such as methyl 3- Pentanol, and 2,2 -Dimethyl-3-[3-methyl-5-(phenylthio)-, may have potential uses in agriculture. They could be used to improve crop yields, protect plants from pests and diseases, or enhance soil fertility[25; 26; 27]. For example, these compounds may possess properties that help to promote plant growth, increase resistance to environmental stress, or boost the plant's natural defenses against pests and diseases. By studying the potential applications of these compounds in agriculture, scientists can uncover new ways to optimize crop production, reduce the use of pesticides, and improve overall soil health. 4H-Pyran-4-one, 2,3-dihydro-3.5-hydroxy- is another example of a compound identified in the GC-MS analysis of Argel leaves that may have potential agricultural applications. This compound has been reported to possess antioxidant properties, which could contribute to its potential use in agriculture. Antioxidants are molecules that help protect cells from damage caused by reactive oxygen species (ROS), which are generated during normal metabolic processes in plants [27; 28]. Elevated ROS levels can lead to damage to cellular components, including lipids, proteins, and DNA, ultimately affecting plant growth and productivity. By supplementing plants with antioxidants such as 4H-Pyran.

3.4. Antimicrobial properties of argel leaves

The examined bacteria were subjected to in vitro antibacterial activity with argel extract. At the highest concentration of the extract (3 µg/disc), the mean inhibition zones measured 15.30±1.0 mm, 14.67±0.42 mm, 15.0±0.0 mm, and 15.56±0.22 mm, respectively. *K. pneumoniae* was the bacterium most significantly inhibited by plant extract, as shown in Table 3. Conversely, the mean inhibition zones measured by those measuring the extract at the lowest concentration (1.0 µg/disc) were as follows: 6.66±0.57 mm, 6.84±0.15 mm, 7.0±0.0 mm, 7.11±0.10 mm, and 8.73±0.32 mm.

The in vitro antibacterial assays demonstrated that Argel plant leaves exhibited significant antibacterial activity against several bacterial strains, with a specific emphasis on its efficacy against Gram-positive bacteria [7; 16; 29]. However, these antibacterial properties could be attributed to its rich phytochemical profile.

Upon testing the extracted bioactive compounds from Argel plant leaves against a panel of bacterial pathogens, the results indicated a significant level of activity against several strains. The in vitro antibacterial assays demonstrated that Argel plant leaves exhibited significant antibacterial activity against several bacterial strains, with a specific emphasis on its efficacy against Gram-positive bacteria. Notably, high antibacterial activity was exhibited against *Stap aureus* and *E. coli*, suggesting that Argel plant leaves may have potential applications in treating infections caused by these common bacterial pathogens. Additionally, the study found that the Argel plant leaves demonstrated moderate activity against other bacterial strains, such as *Pseudomonas aeruginosa* and *K. pneumoniae*. These findings support the traditional use of Argel plant leaves in treating various infections and underscore the need for further research to identify and optimize the specific bioactive compounds responsible for these antibacterial properties.

Table 4 presents the outcomes of the M.I.C.s, M.B.C.s, and ratio calculations utilizing the Argel ethanol extract in opposition to the chosen bacteria. The M.I.C. s values varied between 3.12 and 6.25 µg/ml for the microorganisms examined. The range for M.B.C. values is 25 to 50 µg/ml.

The M.I.C.s values for the microorganisms tested in Argel aqueous extract varied between 3.125 and 6.25 µg/ml (Table 5). The aqueous extract of Argel demonstrated bacteriostatic activity against both P. aeruginosa and S. aureus (MBC/MIC>4). Moreover, both *K. pneumoniae* and *E. coli* were susceptible to the bactericidal effects of the identical extract (MBC/MIC ratio≤4).

A comprehensive collection of indigenous Sudanese medicinal herbs has been recorded. The conditions encompass microbiological infections, wounds, cancer, gastrointestinal disorders, malaria, diabetes, rheumatic pain, respiratory system disorders, jaundice, and urinary system

Table 3. The inhibition zone of Argel hydroethanolic extract expressed as means of three replicates (mean±SE).

Microorganism	1 µg/disc	2 µg/disc	3 µg/disc
S. aureus	6.66±0.57 ^{b}	12.66±0.57 ^{a}	15.3±1.0 ^{a}
Sal. Typhi	6.84±0.15 ^{bc}	12.66±0.57 ^{a}	14.67±0.42 ^{b}
P. aeruginosa	7.0±0.0 ^{bc}	13.0±0.0 ^{a}	15.0±0.0 ^{b}
E. coli	7.11±0.10 ^{b}	13.0±0.0 ^{a}	15.34±0.0 ^{a}
K. pneumoniae	8.73±0.32 ^{a}	12.0 ±0.0 ^{b}	15.56±0.22 ^{a}

Different letters reflected different significant levels concerning the mean±SE.

Table 4. Determination of M.I.C.s, M.B.C., and ratios of the Argel ethanol extract against the selected microorganisms expressed in µg/ml.

Microorganism	MIC	MBC	Ratio*
S. aureus	6.25	50	8
Sal. typhi	6.25	25	4
P. aeruginosa	3.125	50	16
E. coli	6.25	25	4
K. pneumoniae	3.125	25	8

Table 5. Determination of M.I.C.s, M.B.C., and ratios of Argel aqueous extract against the selected microorganisms expressed in µg/ml.

Microorganism	MIC	MBC	Ratio*
S. aureus	25	50	2
Sal. typhi	3.125	25	1
P. aeruginosa	3.125	25	1
E. coli	6.25	25	4
K. pneumoniae	6.25	25	4

inflammations. Most of the pharmacological research supported the traditional uses. Moreover, a range of bioactive substances, including flavonoids, saponins, alkaloids, steroids, terpenes, tannins, fatty acids, and essential oils, have been identified as active constituents [30].

According to Khalid *et al*. [31] and El Ghazali *et al*. [32], Sudan's toxic plants and occasional scientific research studies on medicinal and aromatic plants have a valid role in healthcare as herbal pharmaceuticals, nutraceuticals, and dietary supplements. These products contribute to the nation's economy and trade through export, culinary use as spices and condiments, and consumption as fruits and vegetables.

The current study sought to evaluate the antibacterial properties of s argel (*S. argel*), clove (*S. aromaticum*), as well as their potential synergistic effects with antibiotic medications from the Wad-Medani area of Gezira State, Sudan. Fungus and hazardous bacteria were among the microbes tested. It was also determined how successfully the plant extract and antibiotic collaborated.

Extracts from several plants were discovered to have the ability to suppress the growth of the fungus *A. niger*, *A. flavus*, and *A. parasitics* in the laboratory [33; 34]. The growth of *A. flavus* and *A. parasiticus* was effectively inhibited by the extracts of Cypress (*Cupressus sempervirens*), Juniper (*Juniperus osteosperma*), and Rosemary (*Rosmarinus officinalis*); however, the extracts of Karkadi (*H. sabdariffa*) and Eucalyptus proved ineffective against these two fungi. Arozal *et al*. [35] found that extracts from about 20% of the 141 species of medicinal plants found in Indonesia could stop the growth of the fungi under test (*F. oxysporum* and *Saccharomyces cerevisiae*).

The extracts exhibit a substantial concentration-dependent effect when comparing the growth inhibition induced by crude extracts to that induced by equivalent dilutions. Dilutions of extracts are far less effective against fungi than crude extracts. These findings indicate that the plant extracts under study have varying levels of antifungal activity depending on the extract concentration. This conclusion is in line with the research done by Banso *et al*. [36], who found that the tested fungus's ability to grow was hindered by increasing concentrations of antimicrobial drugs.

The GC-MS analysis of Argel (*S. argel*) leaves has identified thirty-seven distinct compounds that may hold significant agricultural applications. These compounds can contribute to the development of new pest control methods, improve overall plant health, and enhance crop yields. Further studies should focus on understanding the specific roles these compounds can play in agriculture and optimizing their use for maximum benefits. As the need for sustainable and eco-friendly agricultural practices continues to grow, natural compounds like those found in Argel leaves have the potential to be invaluable to industry. These studies could include field trials to evaluate the effectiveness of these compounds under real-world conditions, as well as exploring the possibility of using these compounds not only as standalone treatments but also in combination with other agricultural practices. By doing so, we can better understand how these compounds can be integrated into existing agricultural systems to improve overall crop health and productivity.

4. Discussion

The detection of these bioactive compounds in the Argel plant extract underscores its potential as a natural source of compounds with therapeutic effects. As mentioned previously, alkaloids, flavonoids, saponins, tannins, and terpenoids are present in the Argel plant extract [22]. These compounds have been widely studied for their antioxidant, anti-inflammatory, and antimicrobial properties. The presence of phenolic acids and flavonoids, specifically, indicates that the Argel plant could be a valuable source of compounds with antioxidant properties [37-41].

These antioxidants are essential in neutralizing free radicals, which can cause cellular damage and contribute to various chronic diseases.

Additionally, the presence of flavonoids and phenolic acids in the Argel plant extract may also have anti-inflammatory properties, making them suitable for the treatment of a wide range of inflammatory conditions. For instance, studies have shown that flavonoids possess anti-inflammatory effects by inhibiting the production of pro inflammatory cytokines and enzymes, such as tumor necrosis factor-alpha (TNF-α), interleukin-6 (IL-6), prostaglandins, and cyclooxygenase 2 (COX-2), that contribute to inflammation. Therefore, the Argel plant may offer a natural solution for managing inflammation-related diseases like arthritis, asthma, and inflammatory bowel disease.

Moreover, the Argel plant extract has demonstrated significant antimicrobial activity against several pathogenic bacteria species. This property is attributed to the presence of bioactive compounds, including alkaloids, flavonoids, saponins, tannins, and terpenoids, which have been shown to possess antibacterial properties in numerous studies. For instance, research has demonstrated that the Argel plant's extract shows strong inhibitory activity against various Gram-positive bacteria, such as *Staph. aureus* as well as Gram-negative bacteria, such as *E. coli* and *P. aeruginosa*. The broad-spectrum antibacterial properties of the Argel plant make it a promising candidate for developing novel therapeutic agents to combat antibiotic- resistant bacterial infections [16; 42].

5. Conclusions

According to the results of the antibacterial test that

was conducted in this study, it was shown that *E. coli* is more susceptible to the argel plant extracts that were utilized than the other microbes that were investigated. The findings indicate that plant extracts of argel have great potential as antibacterial agents against microorganisms. Furthermore, these extracts have the potential to be utilized in the treatment of infectious illnesses that are caused by pathogens that are resistant to treatment. In order to precisely evaluate the specific antibacterial activity and hidden mechanisms, it is envisaged that future studies will separate the secondary metabolites from the extracts that are now being considered.

Treatment of inflammation-related diseases and as a natural antimicrobial alternative. The abundance of bioactive compounds within the leaves, such as flavonoids, alkaloids, and terpenoids, contribute to the diverse pharmacological properties of the plant. The serendipitous discovery of the Argel plant's remarkable properties highlights the importance of continued research and exploration of traditional medicinal plants to develop novel, safe, and effective therapeutic agents. As the global healthcare industry grapples with the increasing threat of antibiotic-resistant bacteria and the need for innovative treatments for inflammation-related diseases, the Solanum argel plant leaves might offer a valuable resource for the development of novel therapeutic approaches. It is crucial for scientists, pharmaceutical companies, and policymakers to work collaboratively towards fostering an environment that encourages the discovery, development, and wide spread adoption of these natural remedies.

Conflict of Interests
The author has no conflicts with any step of the article preparation.

Consent for publications
The author read and approved the final manuscript for publication.

Ethics approval and consent to participate
No human or animals were used in the present research.

Informed Consent
The authors declare that no patients were used in this study.

Availability of data and material
The data that support the findings of this study are available from the corresponding author upon reasonable request.

Authors' contributions
A.A. Abdelmuhsin, S.M. Ibrahim, M.A. Kehail, A. E. Sulieman – developed the concept, designed the experiment and wrote the manuscript. A.A. Abdelmuhsin . A. E. Sulieman, collected data and performed analyses; S. M. Ibrahim investigated the original draft and checked the final version. All authors confirm the sole responsibility for study conception, design, data collection, analysis of results and manuscript preparation.

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References

1. Teia FKF (2018) A review of *Solennostemma argel*: Phytochemical, pharmacological activities, and agricultural applications. J Ayu Herb Med 4, 99-101. DOI:10.31254/jahm.2018.4211
2. Elsanhoty RM, Ramada MF (2018) Changes in the physicochemical and microbiological properties of probiotic-fermented low-fat yoghurt enriched with barley β-glucan during cold storage. Mljekarstvo, 68(4). DOI: https://doi.org/10.15567/MLJEKARSTVO.2018.0405
3. Hamed A. (2001) New steroids from Solenostemma argel leaves. Fitoterapia 72(7):747-55. DOI:10.1016/S0367-326X(01)00308-2
4. El-Kheir KSE, Murwa AM (2010) Chemical composition, minerals, protein fractionation, and anti-nutrition factors in the leaf of the Hargel plant (*Solenostemma argel*). Eur J Sci Res 43: 430-434. at: https://www.researchgate.net/publication/281936574
5. EL-Kamali HH (2009) Medicinal plants in East and Central Africa: challenges and constraints. Ethnobotanical Leaflets (2): 12. at: https://opensiuc.lib.siu.edu/ebl/vol2009/iss2/12/
6. Tharib SM, El-Migirab S, Veitch GBA (1986) A Preliminary Investigation of the Potential Antimicrobial Activity of *Solenostemma argel*. Int J Crude Drug Res 24(2): 101–104. https://doi.org/10.3109/13880208609083313
7. Al-Deen, AT. & Al-Naqeb G. (2014). Hypoglycemic effect and *in vitro* antioxidant activity of methanolic extract from Argel (*Solenostemma argel*) plant. Int J Herb Med 2: 128-131. at: https://www.florajournal.com/archives/?year=2014&vol=2&issue=2&part=C
8. Sulieman AME, Abdallah EM, Alanazi NA, Ed-Dra A, Jamal A, Idriss H, Alshammari AS, Shommo SAM (2023). Spices as Sustainable Food Preservatives: A Comprehensive Review of Their Antimicrobial Potential. Pharmaceuticals 16: 1451. https://doi.org/10.3390/ph16101451.
9. Ahamed NSI, Kehail MAA & Abdelrahim YM. (2022). The chemical composition of argel (*Solenostemma argel*) and black seeds (*Nigella sativa*) and their antibacterial activities. IJFSTR, 2022, 03(02): 052–056. DOI:10.53294/ijfstr.2022.3.2.0057
10. Sulieman AE, Elzobair WM, Abdelrahim AM (2009) Antimicrobial activity of the extract of *Solenostemma argel* (harjal) plant. J Sci Technol 10: 120-134.
11. Soliman MSM, Khidr YA, Abdella A, Hassan GOO, Al-Saman MA, Elsanhoty RM. (2021). Pharmacological Activities and Characterization of Phenolic and Flavonoid Compounds in Methanolic extracts of *Euphorbia cuneata* Vahl Aerial Parts. Molecules 26(23): 3745. doi: 10.3390/molecules26237345.
12. Barry M, Cartei G, Sherlock S (1970) Quantitative measurement of iron stores with diethylenetriamine penta-acetic acid. Gut 11(11):891-8. doi: 10.1136/gut.11.11.891. PMID: 5492246; PMCID: PMC1553139.
13. Cruickshank R (1975) Medical Microbiology: A Guide to Diagnosis and Control of Infection. Livingston Ltd., Edinburgh and London, 16: 888.
14. El-Sherbini GT, Zayed RA, El-Sherbini ET (2009) Molluscicidal Activity of Some *Solanum* Species Extracts against the Snail Biomphalaria alexandrina. J Parasitol Res doi: 10.1155/2009/474360.
15. Al-Huqail AA, Elgaaly GA, Ibrahim MM (2018) Identification of bioactive phytochemicals from two Punica species using GC–MS and estimation of antioxidant activity of seed extracts. Saudi J Biol Sci 25(7): 1420–1428. doi: 10.1016/j.sjbs.2015.11.009

16. Ahamed NSI, Kehail MAA, Abdelrahim YM (2022) Phytochemical composition of Neem (Azadirachta indica A. Juss), and Argel (Solenostemma argel L.) and their biocidal activity against mosquitoes larvae. IJSTR 03(02): 057–062. https://doi.org/10.53294/ijfstr.2022.3.2.0058
17. Elsanhoty RM, Soliman MSM, Khidr, YA, Hassan GOO, Hassan AR, Aladhadh M, Abdella A (2022) Pharmacological Activities and Characterization of Phenolic and Flavonoid Compounds in Solenostemma argel Extract. Molecules 27(23): 8118. doi: 10.3390/molecules27238118.
18. Gutsch A (2023) A Study on the Use of the Phyto-Courier Technology in Tobacco Leaves Infected by *Agrobacterium tumefaciens*. Int J Mol Sci 24(18):14153. doi: 10.3390/ijms241814153.
19. Massadeh RK, El-Elimat T, Al-Gharaibeh M, Tawaha K, Alali FQ (2021) UPLC-HRESI-MS and GC-MS analysis of the leaves of *Nicotiana glauca*. Acta Pharm 30;72(1):97-108. doi: 10.2478/acph-2022-0001.
20. Prashanth GK, Krishnaiah GM (2014) Phytochemical Screening and GC-MS Analysis of the Leaves of *Pongamia Pinnata Linn*. IJIRSET 3(11): 17329-17334. DOI: 10.15680/IJIRSET.2014.0311034
21. Akanji OC (2020) Determination of bioactive constituents of Spondiasmombin leaves by GC-MS analysis. WJARR 6(3): 149-165. DOI:10.30574/wjarr.2020.6.3.0111.
22. Ozcan T (2024) The effect of plant mucilaginous gel polysaccharides on oxidative tolerance and fermentation of dietetic yoghurts. Mljekarstvo 74(1): 22-32. DOI: 10.15567/mljekarstvo.2024.0102.
23. Kaboré A (2024) Assessing the Efficiency of the Zagtouli Solar Plant: A Large-Scale Grid-Connected PV System in Burkina Faso. IJAS 18(4):67-84. DOI: http://dx.doi.org/10.21013/jas.v18.n4.p2
24. Kumari S, Gulia P, Sharma N, Dahiya S, Choudhary P, Chhillar AK (2023) Antimicrobial Activity of Bioactive Compounds Isolated from Plant Endophytes. Curr Bioact Compd 18(3): DOI**:** 10 .2174/1573407218666220524120648.
25. Vila JA, Argüello, GA, Malanca, FE (2019) Kinetics studies of 5-methyl-2-hexanol, 2,2-dimethyl-3-hexanol, and 2,4,4-trimethyl-1-pentanol with chlorine atoms: Photooxidation mechanism of 2,4,4-trimethyl-1-pentanol. Int J Chem Kinet 52(1): 29-34. DOI:10.1002/kin.21327
26. Dejoz A, González-Alfaro V, Llopis FJ, Miguel PJ, Vázquez M. (1999). Vapor−Liquid Equilibrium of Binary Mixtures of Tetrachloroethylene with 1-Pentanol, 3-Methyl-1-butanol, and 2-Methyl-1-butanol. J Phase Equilib 22(5): 531-538. DOI:10.1007/s12385-001-0070-6
27. Ragab A, Taher MA, EL-Rafey HH, El-Rokh AR (2024) Bioactive compounds from *Withania somnifera* dun and their toxicity against some piercing sucking pests. Appl Biol Chem 67(29):11. DOI:10.1186/s13765-024-00880-z
28. Li X, Chen J, Yin Y, Xiao S, zhang R, Yang Y, Li L, Xu H, Zhang X, Hu P (2024) Chemical structure elucidation and functional activities comparison of two polysaccharides purified from Citrus reticulata Blanco peels. Chem Biol Technol Agric 11-37. DOI:10.1186/s40538-024-00556-2
29. Khidr F, Abo-Hashem AAM, Mortada M (2018) Zinc Phosphide and Argel (Gomphocarpussinaicus Boiss) leaves as a rodenticide on the Norway rat, Rattus norvegicus Comparative Studies under Laboratory and Field Conditions. J Plant Protect Pathol 9(12):909-912. DOI:10.21608/jppp.2018.44110
30. Karar MG, Rezk A, Abdalla T, Ebrahim A, Ullrich S, Kuhnert N. (2017). Antimicrobial, antiparasitic, and antioxidant activities of medicinal plants from Sudan. J Complement Med Altern Health 2(5): 555597. DOI: 10.19080/JCMAH.2017.02.555597
31. Khalid H, Abdalla WE, Abdelgadir H, Opatz T, Efferth T. (2012). Gems from traditional north-African medicine: medicinal andAromatic plants from Sudan. Nat Prod Bioprospect 2(3): 92–103. https://doi.org/10.1007/s13659-012-0015-
32. El Ghazali, G, El-Egami AAB, Mohamed GM, Abdalla WE, Mohamed HA (2008) Poisonous plants of the Sudan. National Centre for Research, Ministry of Science and Technology, Khartoum, Sudan (Publisher). at: https://www.researchgate.net/publication/301892397_Poisonous_Plants_of_Sudan
33. Alderman GG, Marth EH (1976) Inhibition of growth and aflatoxin production of Aspergillus parasiticus by citrus oils. Z Lebensm Unters Forsch. 160(4): 353-8. doi: 10.1007/BF01106324. PMID: 973437.
34. Sulieman AME. Shaarawy SM, Alghamdi AA, Abdelgadir M and Veettil V. (2017). Evaluation of the antimicrobial and synergistic effect of selected medicinal plants with antibiotics in the Hail area. Conference paper presented at the 32 meeting of the Saudi Biological Society -Umm-AlQurra University, 18-20 April 2020.
35. Arozal W, Louisa M, Soetikno V (2020) Selected Indonesian Medicinal Plants for the Management of Metabolic Syndrome: Molecular Basis and Recent Studies. Front Cardiovasc Med 2020 May 6;7:82. doi: 10.3389/fcvm.2020.00082. PMID: 32435657; PMCID: PMC7218133.
36. Banso A, Adeyemo SO and Jerimiah P (1999) Antimicrobial Properties of *Vernonia amygdalina* Extract. J Appl Sci Magt 3: 9-11.
37. Islam A, Rahat I, Rejeeth C, Sharma D, Sharma A. (2024). Recent advcances on plant-based bioengineered nanoparticles using secondary metabolites and their potential in lung cancer management. J Future Foods 5(1): 1-20. https://doi.org/10.1016/j.jfutfo.2024.01.0015
38. Adepoju FO, Selezneva IS, Okpala CO (2024) Yoghurt fortification with Moringa oleifera: nutritional and production aspects. Mljekarstvo 74(1): 3-21. DOI:10.15567/mljekarstvo.2024.0101
39. Norani M, Crawford A, Aliahmadi A, Ayyari M (2023) Evaluation of *Tussilago farfara* L. Smoke by GC/MS: A Phytochemical Approach to a Traditional Medicine. Agrotech Ind Crops 3(1): 14-22. doi: 10.22126/atic.2023.8818.1083
40. Yousefi B, Karamian R (2024) Ameliorating Effect of Salicylic Acid on Physiological and Biochemical Characteristics of *Satureja spicigera* (C. Koch) Boiss. under NaCl Stress. Agrotech Ind Crops doi: 10.22126/atic.2024.9598.1112
41. Alhasani R (2024) Antioxidant, antidiabetic, neuroprotective, and phytochemical evaluation of Chenopodium ambrosioides ethanol extract. JMAHS. 36-48. DOI: 10.37881/jmahs.224.
42. Hamed SE, EL-Kamali HH (2016) Antibacterial Properties of Methanolic and Aqueous Extracts of Some Plants against Some