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Comparison of Growth, Antioxidant, and Antibacterial Activities in Hydroponic and Soil-grown *Moringa oleifera* in Armenia

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ABSTRACT

Moringa oleifera Lam. is a well-known medicinal plant and food source. It is rich in bioactive substances, has several pharmacological properties , and is an introduced species to Armenia. This study aimed to evaluate moringa for adaptability to Armenian climatic conditions while assessing its antioxidant and antibacterial activities in different cultivation systems. Moringa plants were grown in soil and hydroponic systems (on specific substrates: volcanic slag, gravel, volcanic slag mixed with gravel). We examined growth characteristics, yield, antioxidant activity, and antibacterial properties. The results showed that moringa can adapt to the Armenian climate. It is important to note that leaf dry mass increased by 1.6-1.7 fold in hydroponic-grown plants compared to soil-grown plants, regardless of the growth substrate. We observed a higher antioxidant activity in plants that grew on gravel only and gravel mixed with volcanic slag substrates. A comparative study of the antibacterial activity of moringa leaf water extract revealed that the plant extract (5000 µg mL^{-1}) in hydroponic conditions suppressed the growth of gram-positive (*Enterococcus hirae*) and gram-negative (*Escherichia coli*) bacteria in 24 hours. Soil-grown plants had similar extracts by concentration that inhibited the growth of gram-negative bacteria. Thus, moringa plants adapted to the Armenian climate. The plants performed better in the hydroponic system than in the soil system. This superiority in performance appeared in plant growth, yield , antioxidant activity, and antibacterial properties.

Abbreviations: Gravel (G), *Moringa oleifera* (MO), Useful biomass (UBM), Volcanic slag (VS)

Introduction

Since ancient times, medicinal plants have benefited human populations in traditional applications. Herbal drugs can effectively prevent and treat many diseases (Chen et al., 2022). Nowadays, people care more about their health because of rapid changes in socioeconomic environments and the necessity to change lifestyles from stressful to normal. In this context, natural products and plant-based remedies have shown fewer side effects and gained popularity. Due to the high demand for medicinal plants, many studies have revealed the efficiency and harmlessness of medicinal plants on human health (Hussein and Anssary, 2019). The results of these works have set a foundation for many herbal systems in pharmaceutical applications and plant cultivation.

Moringa oleifera Lam. (MO) is a fast-growing and drought-resistant plant with high nutritional value and healing properties. Moringa leaves, flowers, and seeds are edible (Lim, 2012). Other

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parts of this plant, such as its bark and mature pods, are used for biofuel production (Esmaeili and Esmaeilzadeh, 2019). Moringa is a rich source of bioactive substances. It contains many pharmacological properties that may derive from different biologically active compounds, such as ions of microelements, vitamins, alkaloids, carotenoids, polyphenols, fats, carbohydrates, and proteins. These ingredients are necessary for the normal functioning of human physiology and disease prevention. Moringa has anticancer, antiulcer, and antimicrobial properties (Amaglo et al., 2010; Surbhi et al., 2017). It is highly rich in many different immune-regulating bioactive substances for treating the immune system. Its function is effective against bacteria, fungi, viruses, and chronic inflammations, such as asthma, ulcer colitis, and metabolic diseases. Moringa may ameliorate physical and chemical irritation and autoimmune diseases (Xiao et al., 2020). e

The aerial parts of this plant, e.g., leaves, flowers, and seeds, have relatively high antioxidant and antimicrobial activities (Al Juhaimi et al., 2017), which are probably conditioned by flavonoids and phenolic compounds in moringa (Sulastri et al., 2018; Djemoui et al., 2019). Leaf extracts from mature and tender leaves have significant antioxidant activity against free radicals. They provide essential protection for biomolecules and prevent them from oxidation (Panya et al., 2018). Previous research indicated noticeable antimicrobial activity in ethanolic extracts of moringa leaves against gram-positive bacteria (*Bacillus cereus, Bacillus subtilis, Staphylococcus aureus, Sarcina lutea*) and gram-negative bacteria (*Escherichia coli*, acid-fast stain *Mycobacterium phlei*) (Priya et al., 2011). Recent studies revealed that moringa is an immune booster against SARS-Cov-2 (Hamza Shuja et al., 2020; Fajri et al., 2021). Hydroponic systems are considered alternative production systems to standardize medicinal plant cultivation methods and minimize variations among bioactive compound composition and concentration. In hydroponics, lower agricultural chemicals provide safer plant products (Managa et al., 2021). Also, hydroponic systems decrease plant water consumption and cause greater productivity (Aires, 2018). Thus, hydroponics has advantages when growing medicinal plant species (Managa et al., 2021).

This research aimed to compare several biochemical parameters of raw materials in moringa as a superfood, which is relatively new to Armenian society. Cultivations were in the soil and different substrates of outdoor hydroponics in Armenia. Moringa leaf extracts were estimable for antioxidant and antibacterial activities.

Material and Methods

Plant growth and sample collection

The experiment was carried out in an experimental field, Ararat Valley, Armenia, involving automatic irrigation hydroponic equipment (with a density of 6 plant m^{-2}) using the EBB and Flow hydroponic system (Wortman, 2015). A treatment group consisted of cultivation in soil conditions. Temperatures in Ararat Valley ranged from -26.1 to 32.6 °C in winter and 37.5 to 42.6 °C in summer. The average annual rainfall was 325 mm. Ararat Valley stands 800-1000 m above sea level (Margaryan et al., 2018). Moringa seeds were sown in pots during March and April in the greenhouse (23-28 °C). Seedlings were transferred outdoors to a hydroponic automatic system at the end of April and the start of May. The seedlings were planted in the hydroponic and soil vegetation vessels with a 1 m^{-2} surface. The hydroponic substrates were volcanic slag (VS) and gravel (G) with the 3-15 mm diameter particles and their mixture in a 1:1 ratio (VS/G). The soil culture (S) comprised the control group, involving agro-technical practices (Daryadar et al., 2019).

In hydroponic conditions, the plants were nourished 1-2 times during the day with a relevant nutrient solution provided by Davtyan (Mairapetyan, 1997). The soil-grown plants were irrigated every two days. Moringa may tolerate soil pH values ranging from 5.0 to 9.0 (Anwar et al., 2007). Davtyan's nutrient solution is suitable for moringa cultivation because its pH value is 5.5-7.0 (Tadevosyan et al., 2022). When the growing season began, 400-500 mg kg^{-1} of Davtyan's solution was used. Then, the nutrient supply was continued at 1200-1500 mg kg^{-1} nutrient solution.

Five harvests of the moringa leaves were under hydroponic conditions and four under soil conditions, with an interval of about one month. In hydroponic conditions, harvesting started in June. In soil conditions, harvesting began in July. Moringa plants have compound leaves attached to little leaflets and stems. The little leaflets comprise useful biomass (UBM). After one week of shade-drying at room temperature, the fresh biomass of leaves was separated into UBM and stems. The shoots were oven-dried for 72 h at 50 °C to reach a constant dry weight. Biometrical and morphological assessments considered harvested plant leaves in all treatment groups (MO-VS, MO-G, MO-VS/G, and MO-S). The measurements considered growth rate, development stage, harvest date, and shoot fresh and dry weights. Bio-pharma-chemical analyses were done throughout the whole experiment,

using six randomly selected plants from each studied group. UBM samples were taken for biochemical analysis.

Chemicals and reagents

Regarding phenolic and antioxidant analyses, the assessments involved 2,2-Diphenyl-1-picrylhydrazyl (DPPH), Folin–Ciocalteu reagent, DMSO (Dimethyl sulfoxide), tryptone, glucose, and gallic acid. These chemicals were of analytical grade, provided by Sigma–Aldrich. Peptone and Tris (aminomethane) were purchased from Carl Roth GmbH (Germany).

Determination of antioxidant activity

Antioxidant activity in ethanol extracts of moringa leaves was measurable with the reduction reaction of 2,2-diphenyl-1-picrylhydrasyl. Dry plant extracts of MO-S, MO-VS, MO-G, and MO-VS/G samples were obtained from each treatment group. The samples were added to 96% ethanol in 1 mg mL^{-1}.

The solution was diluted in 96% ethanol to make solutions at concentrations of 500, 250, 125, and 62.5 µg mL^{-1}.

To study each dilution (1000, 500, 250, 125, and 62.5 µg mL^{-1}), 500 µl of plant extract was obtained from an appropriate dilution and mixed with 250 µl 96% ethanol solution of DPPH (in 1 mg mL^{-1} concentration), with 1250 µL ethanol in a tube. Regarding the control group, the plant extract was replaced with similar amounts of 96% ethanol. The experiment had three repetitions. Tubes containing the solutions were incubated in the dark for 30 min at room temperature. The optical density of each solution was determined at 517 nm (spectrophotometer GENESYS 10S UV-Vis, USA). Substance antioxidant activities in each treatment group were estimated via the color reaction level (%). The IC50 value was determined to indicate the concentration of the extract that neutralizes 50% of free radicals in the solution (Moghrovyan et al., 2019; Sahakyan, 2021).

Measurement of total phenols

Phenolic compounds were described quantitatively according to Folin-Ciocalteu's method. Folin-Ciocalteu reagent is a mixture of phosphotungstate and phosphomolybdate, comprising a light green liquid. Phenols oxidized tungstate and molybdate under alkaline conditions up to a stage where a blue-colored oxide became apparent (WO2, MoO2). The more intense the blue color, the higher the quantity of the general phenols in the extract. Thus, 0.1 mL Folin-Ciocalteu's reagent was added to the 0.5 mL extract (1:1 ratio concentration) to enable the reaction progress. Various concentrations of gallic acid (62.5, 125, 250, 500, 1000 µg mL-1; R2=0.9908) were used as a standard to make a calibration curve. The absorption was measured at 765 nm (Sahakyan et al., 2019). Moringa leaf extracts were prepared based on 96% ethanol.

Estimation of antibacterial activity

Gram-negative and gram-positive bacteria enabled the study of antibacterial potential in aqueous moringa leaf extracts. BW 25113 line of wild-type *Escherichia coli* was obtained from the Keio collection (Tsuruoka City, Yamagata, Japan). The variant was selected as gram-negative bacteria. Regarding gram-positive bacteria, the ATCC 9790 line of wild-type *Enterococcus hirae* was provided by M. Solioz (Department of Clinical Pharmacology, University of Bern, Switzerland). To assess the antibacterial activity of MO leaf extracts, the bacterial strains were cultivated in peptone and tryptone growth media, respectively, at pH 7.5 and 37 °C. Anaerobic conditions were maintained throughout the experiment. To estimate bacterial growth, the optical density of bacterial suspension was measured at 600 nm using a spectrophotometer. To study bacterial susceptibility in *E. coli* and *E hirae*, 108 dilutions of bacterial suspensions were applied. Then, 100 µL of each sample was spread on 1.5 % nutrient agar plates (Aghajanyan et al., 2020). Bacteria were incubated for 24 h at 37 °C, after which bacterial colony growth was evaluated in each sample to determine antibacterial activities in moringa leaf extracts. The bacterial count was obtained from a relevant formula $T=10\times n\times 10m$, where n is the number of viable bacterial colonies, and m is the number of dilutions (Gabrielyan et al., 2019). Moringa leaf extracts (625-5000 mg mL^{-1}) were added to bacterial growth media. Representing positive and negative controls, bacteria and DMSO were used, respectively.

Statistical analysis

All data were analyzed using statistical programs, i.e., GraphPad Prism 8 and Microsoft Excel 2016. One-way analysis of variance (ANOVA) determined statistical significance and comparison of mean values. Sample selections of the studied groups were random, and the values were assessed for significant differences ($P\leq 0.05$).

Results

Plant growth media characteristics

The analysis of growth media showed that the soil

medium had the highest total porosity. Within hydroponic conditions, VS and VS/G substrates had the highest total porosity (Table 1). The lowest total porosity was observed in the G substrate. Air porosity was highest in the mixed substrate of VS/G. The lowest porosity occurred in the G substrate. The highest water porosity was observed in the soil. The mixed VS/G substrate showed the highest water porosity in the hydroponic environment. Maximum bulk and particle density were in the G substrate, but lowest in the VS substrate. Soil EC and pH were higher compared to the other growth media. Among the hydroponic substrates, the VS/G substrate had the lowest pH.

Table 1. Growth media characteristics.

Growing media	Total porosity (%)	Air porosity (%)	Water porosity (%)	ρ_b (g cm^{-3})	ρ_p (g cm^{-3})	EC (dS m^{-1})	pH
VS	50.96	43	7.96	0.56	0.99	1.2	7.52
G	38.61	37	1.61	1.58	2.51	1.0	7.33
VS/G	48.61	47	8.97	0.92	1.73	1.2	7.20
Soil	61.90	44.1	17.80	1.18	2.5	1.7	7.86

ρ_b – Bulk density, ρ_p – Particle density. Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S).

Plant growth and yield

Table 2 shows the fresh and dry weights of the samples. There were significant differences in leaf yield. The hydroponic cultivation caused the highest dry leaf yield (89.2-94.8 g plant^{-1}) during 5 months of growth, whereas the soil culture showed the lowest weight (55.2 g plant^{-1}). In both soil and hydroponics, UBM comprised 70-75% of leaf mass (Fig. 1). The highest UBM was observed in plants of the VS and VS/G substrates.

Table 2. Leaf productivity of moringa in different growth media.

Growing media	Leaves weight (g plant^{-1})	
	Fresh	**Dry**
VS	406.2±46.9^a	94.8±13.9^a
G	381.2±13.3^a	86.4±1.2^a
VS/G	383.0±52.8^a	89.2±3.5^a
S (control)	233.2±34.5^b	55.2±13.8^b

Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S). Values are mean values ± SE of three replicates. Mean values marked with the same letter in columns do not differ significantly based on Duncan's Multiple Range Test ($p \leq 0.05$).

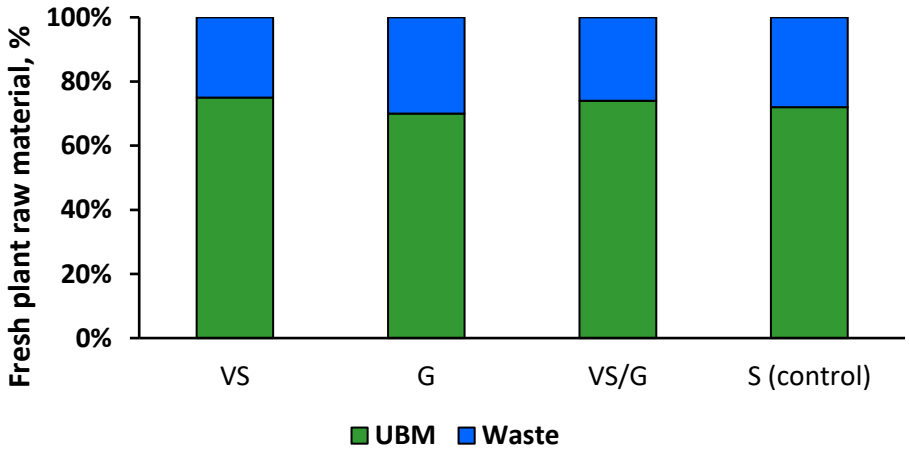

Fig. 1. Content of fresh UBM (useful biomass) and moringa leaf waste in different growth media. Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S).

Since the leaves were harvested once a month from June (hydroponic-grown plants) and July (soil-grown plants), moringa leaf biomass peaked in September and October in Ararat Valley conditions (Fig. 2). Regardless of the type of the hydroponic substrate, during these two months, more than 60% of leaf yield developed. In soil conditions, more than 70% of leaf yield accumulated during these two months.

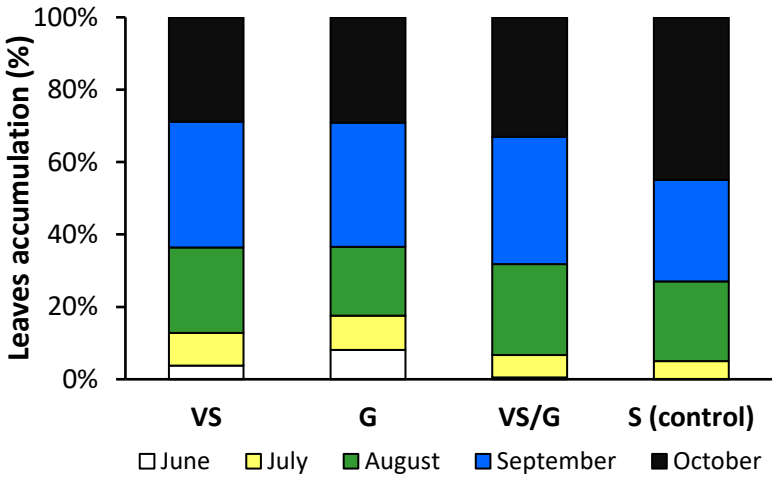

Fig. 2. Moringa leaf accumulation during the vegetative growth. Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S).

Antioxidant activity

The results showed that in soil-grown plants, IC50 values started from a low concentration (125 µg mL^{-1}) (Fig. 3). In the case of 250-500 µg mL^{-1}, the lowest antioxidant activity was observed in plants with the gravel substrate. By doubling the 250 µg concentration, the antioxidant activity of hydroponic samples increased. In different growth media, all moringa plants neutralized 82-88% of the free radicals in the solution when using the maximum active concentration.

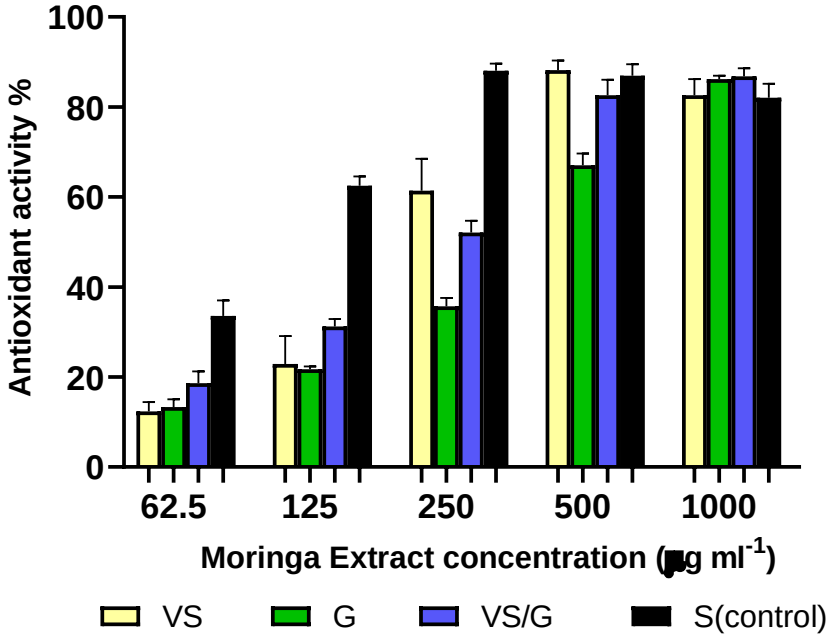

Fig. 3. The antioxidant activity of different moringa extract concentrations in different growth media. Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S). Data are mean values ± SE of three replicates.

Phenolic compounds

Phenolic compounds varied in moringa leaf extracts (96% ethanol), depending on their growth in soil or hydroponic conditions (Fig. 4). Plants grown in the VS/G substrate had higher amounts of phenolic compounds, thereby surpassing the amounts in plants grown in other hydroponic substrates and the soil medium. Phenolic content in plants of the VS/G substrate were 2.1-2.3 times more than the amount observed in plants of other hydroponic substrates, and 1.2 times more than the amount observed in plants of the soil medium.

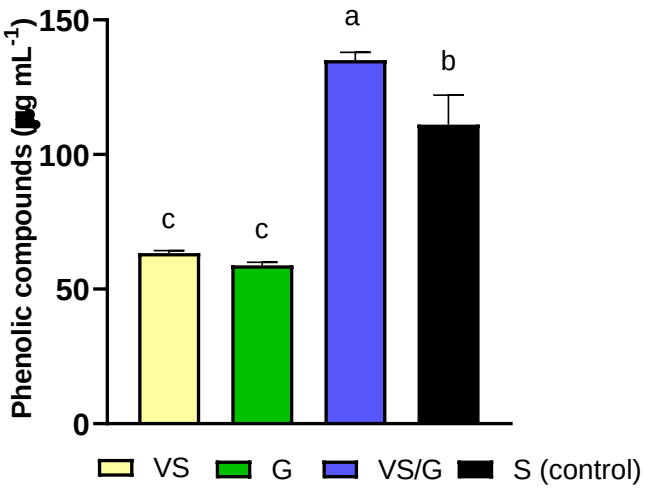

Fig. 4. Total phenolic content in moringa leaf samples. Volcanic slag (VS), gravel (G), their mixture in a 1:1 ratio (VS/G), and soil (S). Data are mean values ± SE in the three replicates. Mean values marked with the same letter in each column do not differ significantly based on Duncan's Multiple Range Test ($p \leq 0.05$).

Antibacterial activity against E. coli and H. hire

We compared the antibacterial activity of aqueous leaf extracts of plants grown in soil and hydroponic VS/G conditions. In hydroponic conditions, the VS/G substrate caused moringa plants to show the most intensive growth compared to the other substrates.

Moringa leaf extract (5000 µg mL^{-1}) had the strongest antibacterial activity against gram-negative bacteria. Hydroponic (VS/G) and soil moringa were superior to DMSO in enhancing antibacterial activity (Fig. 5).

During 24 hours, hydroponic moringa extract (5000 µg mL^{-1}) inhibited the growth of gram-positive and gram-negative bacteria, whereas soil-grown moringa extract (5000 µg mL^{-1}) inhibited the growth of gram-negative bacteria only. The aqueous leaf extracts of hydroponic-grown plants inhibited bacterial growth more effectively (Fig. 5 and 6). In 6 and 24 hours, hydroponic- and soil-grown moringa extracts (5000 µg mL^{-1}) inhibited bacterial growth more effectively than DMSO at the same concentration.

The antibacterial activity of moringa leaf extract affected colony formation in gram-positive and gram-negative bacteria where bacterial populations were in 108 dilutions. In the case of gram-negative *E. coli* BW25113, a clear inhibition of colony formation was observed under the influence of leaf extract solutions obtained from soil and hydroponic-grown moringa (Fig. 7). Regarding soil-grown plants, the growth of colonies was inhibited 7.7 times (bacterial population: 96×10^8) compared to bacterial colonies cultivated under a common culture medium (bacterial population: 740×10^8). Leaf extracts of hydroponic-grown plants inhibited bacterial growth 67.3 times (bacterial population: 11×10^8). Thus, the hydroponic treatment was more successful than the soil treatment (8.7 times) regarding bacterial inhibition. Moringa leaf extracts effectively inhibited gram-positive *E. hirae* ATCC9550. Soil-grown moringa plants had leaf extracts that inhibited bacterial growth 4.6 times (bacterial population: 323×10^8), whereas hydroponic-grown moringa plants had leaf extracts that inhibited bacterial growth 8.4 times (bacterial population: 175×10^8). In the control group, the bacterial population was 1472×10^8. Data showed that the aqueous leaf solution influenced gram-negative bacteria more than gram-positive bacteria.

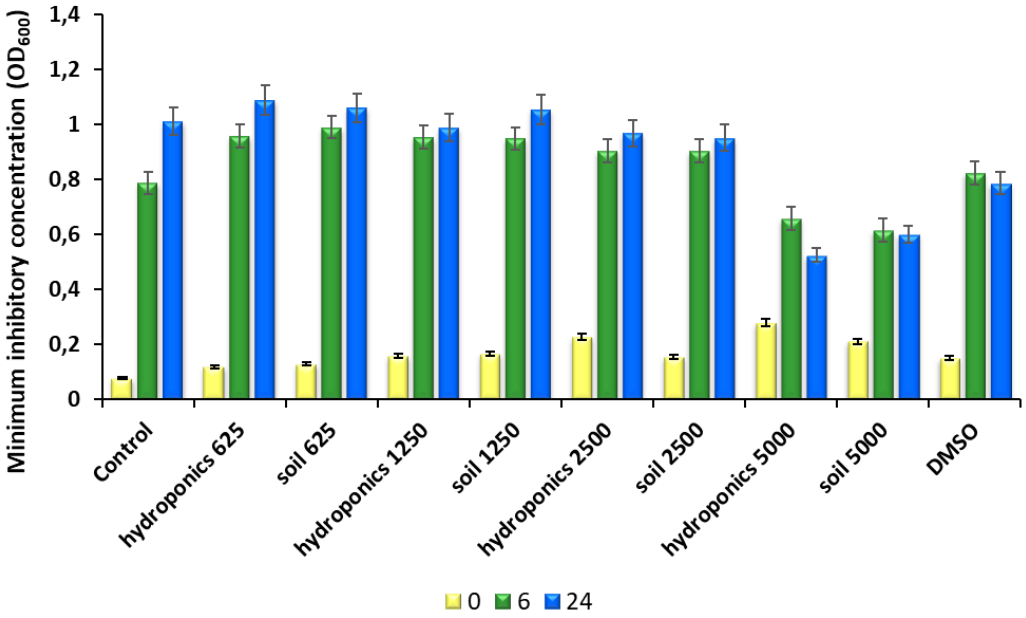

Fig. 5. Antibacterial activity of moringa leaf extract against gram-negative bacteria *E. coli* BW 25113 in different time periods (0, 6 and 24 h after incubation). Bacteria and DMSO were used as positive and negative control groups, respectively. Data are mean values ± SE of three replicates.

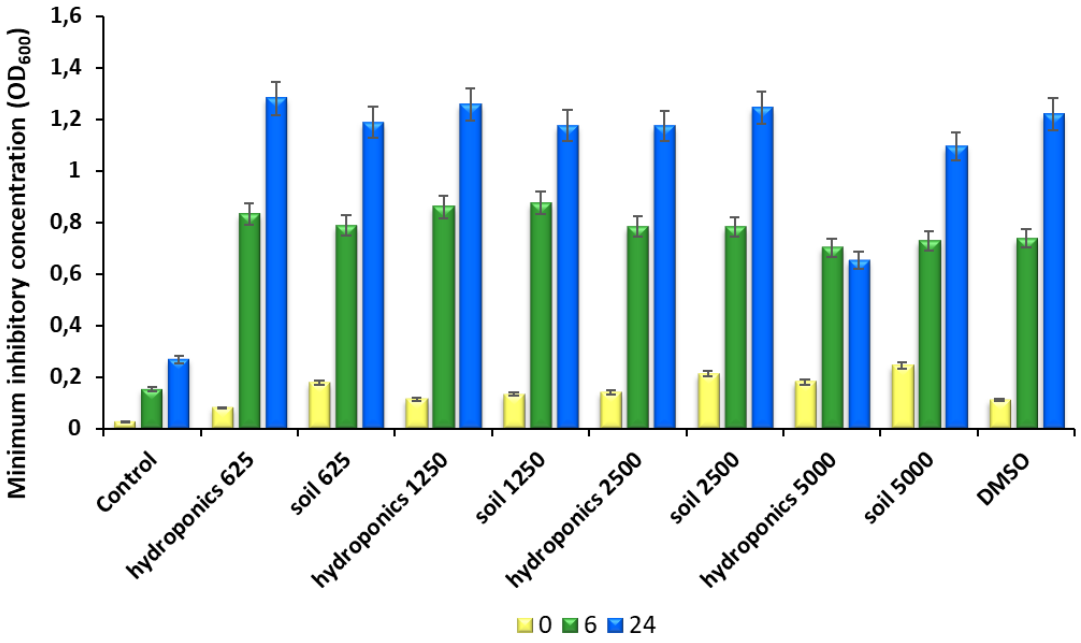

Fig. 6. Antibacterial activity of moringa leaf extract against gram-positive bacteria *E. hirae* ATCC 9790 in different time periods (0, 6 and 24 hours after incubation). DMSO was used as a positive control. Bacteria and DMSO were used as positive and negative control groups, respectively. Data are mean values ± SE of three replicates.

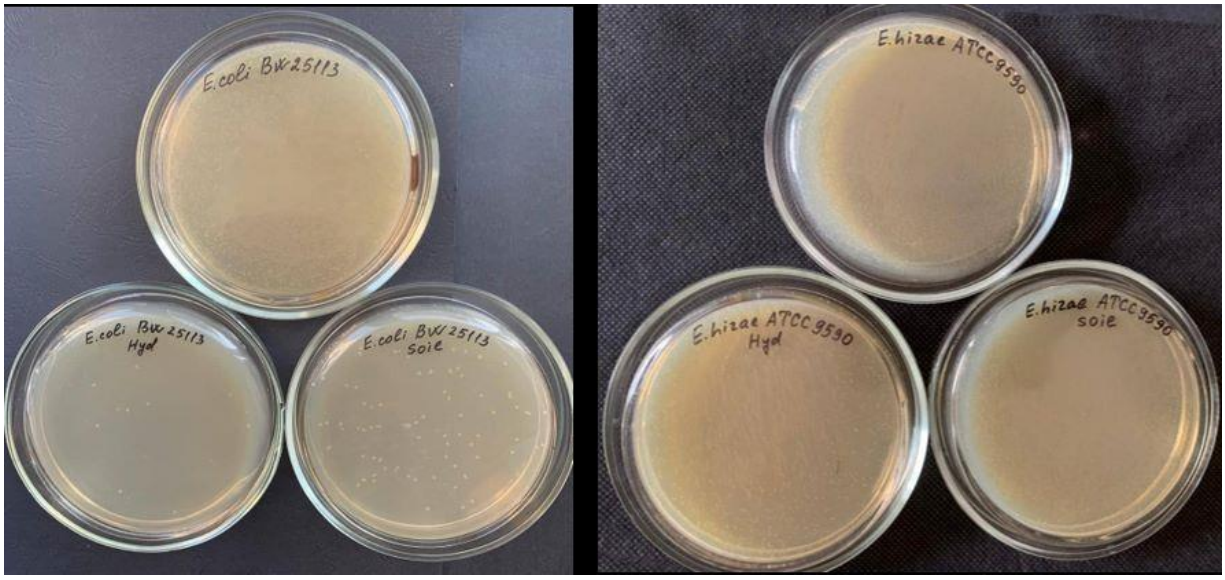

Fig. 7. Antibacterial activity of *Moringa oleifera* aqueous solution against colonies of Gram-negative *E. coli* BW25113 and Gram-positive *E. hirae* ATCC9550 strains. Cell colonies appear as stains in the control, hydroponic, and soil treatment groups in response to their respective aqueous leaf extracts.

Discussion

Moringa has value for its edible fruits, leaves, flowers, roots, and seed oil. It is used extensively in traditional medicine throughout its native and introduced ranges. UBM comprised 70-75% of leaf mass in the soil and hydroponic. In tropical forest conditions, UBM can reach 90% maximum (Mendieta-Araica et al., 2013). Motis and Reader (2018) reported that in southwest Florida, under subtropical conditions, dry moringa leaf matter was weighed at six harvests spanning 14 months. The values varied from 51 g tree^{-1} with no NPK to 108 g tree^{-1} with enough NPK fertilizer. Mendieta-Araica et al. (2013) indicated that moringa produced 21.2 tons ha^{-1} dry matter yield (126.9 g plant^{-1}) under dry tropical forest conditions in Nicaragua at a planting density of 167000 plants ha^{-1}. They showed that environmental factors (climate, geography, site, annual precipitation, growing seasons, etc.) and optimal management practices significantly affected the dry leaf yield. Zheng et al. (2016) reported that the moringa with 0.2 m×0.2 m planting density produced the highest dry leaf yield, up to 12.85 tons ha^{-1} (51.4 g plant^{-1}) in southwest China. To date, no documented information is available on the effects of the hydroponic Ebb and Flow growth system on moringa dry foliage yield. In the current experiment, plants in the VS substrate produced the highest (5.70 tons ha^{-1}) dry leaf yield. This lower yield was due to the low density of plants (6 plant m^{-2}) in our experiment compared to that of Zheng et al. (2016). Animashaun and Toye (2013) reported 6-18 harvests of moringa leaves (Animashaun and Toye, 2013), whereas Trigo et al. (2020) reported 3 to 5 harvests per season in Spain (Trigo et al., 2020). Mitariastini et al. (2022) reported that using the Bogor accession with a 7-week harvesting interval is advisable to apply for intensive moringa cultivation in Bogor or other wet lowlands. September and October were more favorable in the vegetative period for the plants to accumulate moringa leaf dry biomass in Ararat Valley conditions (Fig. 2). The VS/G growth media caused the highest plant growth, and the highest air and water porosity can be part of the reason for this result. However, the lowest moringa plant growth and yield occurred in response to the G substrate with the lowest air and water porosity. The G substrate had the highest bulk and particle density, which does not represent a suitable growth media. The VS and VS/G growth media had the lowest bulk and particle densities, which is appropriate for growth media.

Environmental parameters, such as annual precipitation, minimum and maximum temperatures, and soil type, influenced the antioxidant activity in plants. Soil type significantly affects antioxidant activity (Olaoye et al., 2021). Hydroponic conditions have reportedly influenced moringa antioxidant activity. Moringa leaf extracts were tested against the stable DPPH (2,2-diphenyl-1-picryl-hydrazyl-hydrate) free-radical technique for assessing antioxidant activity. Researchers evaluated the ability to scavenge DPPH radicals by staining the solution. Our results showed that in soil-grown plants,

IC50 started from a low concentration. The antioxidant activity of the hydroponic samples increased with higher moringa extract concentrations. The highest extract concentration in different growth media neutralized 82-88% of the free radicals in the solution. Santos et al. (2012) showed that the ethanolic extracts of leaf tissue, leaf rachis, and inflorescence rachis reduced DPPH faster than other extracts, such as seed extract. Although ethanolic and saline extracts had flavonoids, some amounts of steroids and triterpenoids were present only in ethanolic extracts. According to Shariff et al. (2020), the IC50 of aqueous ethanolic extract of moringa leaves (ethanol: water ratio was 80:20) was 25.28 mg mL^{-1}. This value was less than the aqueous methanolic extract with an IC50 of 15.92 mg mL^{-1} but showed lower teratogenicity than the methanolic one. The LC50 of the ethanolic extract on zebrafish embryo was 337.48 µg mL^{-1}, which is two times less than that of the aqueous methanolic extract (163.87 µg mL^{-1}). Teratogenicity in ethanolic extracts caused delayed embryonic development. Moringa leaves (4% ethanolic extract gel) accelerated wound healing due to their antioxidant activity and abundant bioactive polyphenols. The antioxidant activity means that moringa leaves can detoxify organisms from toxins, pollutants, and free radicals. Antioxidant activity was related to phenolic compound concentration, as evidenced by the VS/G and soil growth media. Susanto et al. (2019) reported that the antioxidant activity in moringa resulted from the amount of polyphenols. Du Toit et al. (2020) showed that mature dark green moringa leaves contained more phenolic compounds than immature leaves. A higher leaf phenolic content occurred in late summer and autumn.

In previous research, the aqueous, chloroform, and other leaf extracts, seeds, and stems of moringa were effectively used against *Bacillus subtilis, Escherichia coli, Klebsiella pneumoniae,* and *Shigella Staphylococcus aureus* (Priya et al., 2011). The extracts of moringa leaves may treat infections caused by various drug-resistant bacteria. At the same time, chloroform extract is more effective than aqueous extracts (Eremwanarue and Shittu, 2018). The ethanol extract from leaves inhibits the growth of *Staphylococcus epidermidis*, a type of gram-positive bacteria (Mursyid et al., 2019). Guillén-Román et al. (2018) reported that effective nitrogen fertilizers decreased plant antibacterial activity against Staphylococcus aureus and *Staphylococcus epidermidis* in acetone solutions of moringa extract.

One possible treatment for bacteria is natural products such as medicinal plants utilized by traditional healers to manage diseases caused by microbial pathogens. The synthesized *Moringa oleifera* leaf extract appeared in harmony with ZnO-nanoparticles for antibacterial activities against pathogenic bacteria *Bacillus subtilis* and *E. coli* at low concentrations. Researchers showed effective growth inhibitory activity against both microorganisms (Pal et al., 2018).

According to our results (Fig. 5 and 6), the leaf extract of hydroponic-grown moringa inhibited the growth of gram-positive and gram-negative bacteria for 24 hours, while leaf extracts of soil-grown moringa inhibited gram-negative bacteria only. This finding confirms that the aqueous leaf extract of plants in hydroponic conditions inhibited bacterial growth more effectively.

Extracts from hydroponic-grown plants outperformed extracts from soil-grown plants by 8.7 fold regarding the inhibitory effect on gram-negative bacteria *E. coli* BW25113 and only by 1.8 fold regarding the inhibitory effect on gram-positive bacteria *E. hirae* ATCC9550. The data showed that the aqueous solution of moringa leaves affected gram-negative bacteria more than gram-positive bacteria.

Conclusion

Moringa hydroponic culture systems, especially VS/G and VS growth media, caused higher yields than the soil treatment, making it more suitable for moringa growth. The physical properties of VS/G growth media provided better conditions than the other media. The G media was unsuitable for moringa production. At low concentrations, the soil-grown moringa extract showed antioxidant activity. High concentrations of leaf extract from hydroponic plants performed almost similar to extracts obtained from soil-grown plants. The highest phenolic activity was observed in plants grown in the VS/G substrate. The soil-grown moringa leaf extract (5000 µg mL^{-1}) showed antibacterial activity against gram-negative bacteria only. The same extract concentration from the hydroponic treatment suppressed the growth of both gram-positive and gram-negative bacteria. Hydroponic conditions enhanced the pharmaceutical and antibacterial efficiency of the moringa extract, making its medicinal properties more effective.

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Conflict of Interest

The authors indicate no conflict of interest for this work.

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