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Impact of Hydroponic Versus Soil Cultivation on Germination, Chlorophyll Content, and productivity of Arugula plant (*Eruca sativa* Mill)

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مقارنة تأثير الزراعة المائية بالزراعة في التربة على نسبة الإنبات، ومحتوى الكلوروفيل، والإنتاجية في نبات الجرجير (*Eruca sativa* Mill)

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Abstract:
Plants face many stresses from soil, such as water shortage, water quality and nutrient availability, which ultimately affect the growth and productivity of the plant. This study aims to verify the effectiveness of using hydroponics compared to soil cultivation, where the seeds of (*Eruca sativa* Mill.) were planted in both cultivation systems, using a model of hydroponics and a model of soil. The experiment was designed according to a completely randomized design (CRD), with (24) replicates for each model treatment. The germination rate, chlorophyll content, and productivity of (*Eruca sativa* Mill.) grown in all models were measured. The results showed that there were very significant differences (P<0.001) between the treatments. The germination rate and chlorophyll content for hydroponics and soil cultivation were (78.7%, 48SPAD) and (26%, 30SPAD), respectively. The results of this study also showed that the average of productivity for (*Eruca sativa* Mill.) grown in the hydroponic system was four times higher than it was for (*Eruca sativa* Mill.) grown in a soil system. These results are considered motivate to research and delve into this field.

Keywords: Hydroponic, Eruca Sativa, Germination Rate, Chlorophyll Content, Productivity.

الملخص
يتعرض النبات في التربة لإجهادات عديدة ناتجة عن شح ونوعية المياه وتيسر المغذيات، تؤثر في نهاية المطاف على نمو وإنتاجية النبات. تهدف هذه الدراسة إلى التحقق من مدى فاعلية استخدام الزراعة المائية مقارنة مع الزراعة في التربة، حيث تمت زراعة بذور نبات الجرجير (*Eruca sativa* Mill.)، في كل من النظامين الزراعيين، باستخدام نموذج للزراعة المائية ونموذج للزراعة في التربة. وصممت التجربة طبقا للنظام العشوائي الكامل (CRD) بعدد (24) مكررًا لكلا نظامي الزراعة، وتم قياس كل من نسبة الإنبات، ومحتوى الكلوروفيل، والإنتاجية لنبات الجرجير المزروع في كلا نماذج التجربة. أظهرت النتائج فروقا معنوية جداً(P<0.001) بين المعاملات، حيث كانت نسبة الإنبات ومحتوى الكلوروفيل لكل من الزراعة المائية والزراعة في التربة (78.7%، SPAD48)، و (26%، SPAD30) على التوالي.

كما بينت نتائج هذه الدراسة أن متوسط الإنتاجية لنبات الجرجير المزروع في النظام المائي كان أربعة أضعاف مقارنة بمتوسط إنتاجه في نظام التربة. وتُعد هذه النتائج محفزة للقيام بالكثير من الأبحاث والخوض في هذا المجال.

الكلمات المفتاحية: الزراعة المائية، الجرجير، نسبة الإنبات، محتوى الكلوروفيل، الإنتاجية.

Introduction

Traditional agriculture in many regions of the world, particularly in arid environments, faces increasing challenges related to water scarcity and poor soil quality, which negatively impact on plant growth and productivity. According to the Food and Agriculture Organization (FAO, 2017), over (70%) of global freshwater resources are used for agriculture. With the projected population growth to nearly nine billion by 2050, there is an urgent need to develop more efficient and sustainable agricultural systems that optimize water use and increase productivity.

Hydroponic farming, which delivers water and nutrients directly to plants through nutrient solutions, is a modern agricultural technique that provides a controlled environment. This system avoids many soil-related stresses, including drought stress in the root zone (Samarah, 2005; Gámez et al., 2019), osmotic or salt stress (Boyer, 1970; Greenway & Munns, 1980; Moaydi et al., 2009), and repellency-induced water stress (Hassan, 2013). Furthermore, hydroponics bypasses the effects of soil matric potential (Schmidt et al., 2009), which can create competition for water between soil particles and plant roots. Studies have shown that hydroponic systems can improve germination rates and increase productivity compared to conventional soil-based farming, making them particularly promising in regions with poor soil quality or limited water availability.

In Libya, where agricultural land is limited in fertility and characterized by sandy soil and an arid climate, hydroponics is seen as a viable strategy to enhance food security. This study aims to evaluate the effect of hydroponic farming compared to traditional soil-based farming on the germination rate, chlorophyll content, and productivity of an economically and nutritionally important arugula plant (*Eruca sativa* Mill.) in the country.

Literature Review

Previous studies have shown that hydroponic is one of the most efficient methods for enhancing plant growth and increasing crop productivity compared to traditional soil-based cultivation. Dunn (2013) reported that providing plants with nutrients directly in a balanced solution accelerates germination and promotes growth, moreover nutrients are readily available without the need for soil decomposition. Similarly, Sharma et al. (2019) demonstrated that hydroponic systems improve crop quality and nutritional value while increasing overall productivity, with the effects varying depending on the plant species and the growth medium used.

In addition, the choice of suitable hydroponic media, such as perlite and vermiculite, significantly influences plant growth and yield (Velazquez-Gonzalez et al., 2022), Asaduzzaman et al. (2013) found that the particle size of perlite affected carrot growth, while Samadi (2011) reported that fine perlite improved fruit weight, plant height, and leaf area. with a (30%) increase in the marketable yield of cucumber plants (Marsic & Jakse, 2010).

As reported by Meselmani (2022) using a well-balanced nutrient solution containing macro- and micronutrients, with proper pH and ionic balance, enhances germination rates and accelerates plant growth compared to conventional soil cultivation. Collectively, these studies highlight the significant role of hydroponics in improving key plant traits, including germination rate, growth performance, and yield, making it an effective cultivation method under various environmental conditions.

With respect to Germination rates, Yurina et al. (2019) reported positive effects by hydroponic cultivation, with hydroponically grown wheat seeds reached a germination rate of (98%).

Several studies have demonstrated that hydroponic cultivation enhances nutrient uptake and metabolic activity in plants. Rouphael et al. (2003) found that zucchini grown hydroponically absorbed higher levels of nitrogen, magnesium, sodium, iron, copper, zinc, and manganese, which was accompanied by increased accumulation of carbohydrates such as glucose, fructose, sucrose, and starch. Similarly, hydroponic soybean showed higher lipid content (17.37 to 21.94 g/100 g dry weight) and total dietary fiber (21.67 to 28.46 g/100 g dry weight), indicating improved nutritional quality (Palermo et al., 2011). Furthermore, Kide et al. (2015) documented an increase in protein and vitamin contents in barley and wheat cultivated under a hydroponic system.

In leafy vegetables, hydroponically grown lettuce exhibited significantly higher levels of chlorophyll, phenolics, flavonoids, antioxidants, minerals, and dissolved oxygen compared with soil cultivation (Abu-Shahba et al., 2021). accumulation of organic compounds has also been observed in hydroponic tomatoes, which contained higher concentrations of lycopene and β-carotene (Verdoliva et al., 2021), as well as in chrysanthemum, the chlorogenic acid and flavonoids increased notably relative compartig to soil-grown plants (Ai et al., 2021).

The productivity under hydroponics seems to be significantly increased per unit area. Barbosa et al. (2015) found Lettuce production in hydroponic systems was (11 times) higher than in soil-based cultivation. Similarly, hydroponic strawberry yield increased by (17%) compared to soil-grown plants (Treftz & Omaye, 2016). Hydroponic spinach yielded (2780 g) per unit area, compared to (188 g) under soil cultivation, with an average yield per plant of (6.9 g) versus (2.2 g) in soil (Verner et al., 2021). Moreover, hydroponic systems shorten the crop cycle by (7–10 days) (Al-Karaki & Al-Hashimi, 2012), leading to early market entry and economic feasibility.

Materials and methods

3.1 Experimental Models

Hydroponic system: The hydroponic setup was obtained from Hydrolipid Company (Al-Zawiya), it composed of closed-ended PVC tubes (8–9 cm in diameter) mounted horizontally on supports. Circular holes (6.5 cm in diameter) were spaced (6–8 cm) to apart plastic planting perforated pots (230 cm^3), filled with perlite. The system was connected to a pump in basin to irrigation and drainage were with automatic system, as shown in figure (1-B).

Soil cultivation system: The soil-based cultivation was homemade, with the same specifications as a hydroponic system, except, the pots filled with soil and irrigation was applied manually, as shown in figure (1-A).

Figure 1: A model of a soil-based farming system is on the left (A)and a model of a hydroponic farming system is on the right (B).

3.2 Nutrients Solution and irrigation water

Nutrient solution (Hydro Libya) A and B obtained from Hydro Libya Hydroponic Agriculture Company, with composition as shown in **Table (1)** and **Table (2)**. the water use was with total dissolved salt (100mg/l).

Table 1: Contents and concentration of the nutrient solution (hydrolibia), Class A of nutrients.

Element	ppm (Concentration Range mg/L)
Macro Elements	-
Nitrogen(N)	200
Phosphorus(P)	55- 60
Potassium(K)	280-310
Magnesium(Mg)	50
Sulfur(S)	60-80
Micro Elements	
Copper(Cu)	0.09 - 0.10
Manganese(Mn)	2
Molybdenum(Mo)	0.2
Zinc(Zn)	0.1

Table 2: Contents and concentration of the nutrient solution (hydrolibia), Class B of nutrients.

Element	Concentration Range ppm(mg/L)
Macro Elements	
Nitrogen(N)	200
Calcium(Ca)	175-180
Micro Elements	
Boron(B)	0.2- 0.3
Copper(Cu)	0.09 - 0.10
Iron(Fe)	6

3.3 Plant Material

Local arugula seeds (*Eruca sativa* Mill., Brassicaceae) were used.

3.4 Experimental procedure

Two cultivation systems hydroponic and soil-based were established in an open field located on a farm south of Zawiya under uniform environmental conditions of light and temperature. The experiment was arranged following a Completely Randomized Design (CRD). The hydroponic basin and PVC tubes were filled with irrigation water by pump, requiring a total volume of 60 L. Planting pots in the hydroponic unit were filled with perlite and placed into the holes to allow full saturation prior to sowing. For the soil system, 213 g of soil were weighed for each pot, mixed thoroughly with organic fertilizer, and placed in the soil cultivation holes.

Arugula (*Eruca sativa* Mill.) seeds were sown on 23 June 2023 at a density of nine seeds per pot in both systems (Hassan, 1991). Water circulation in the hydroponic system was initiated immediately after sowing, whereas soil pots were irrigated manually (3–4 times) per day, receiving a total of 4.2 L Day^{-1} per 24 pots. After approximately seven days, equal volumes of nutrient solutions A and B were added to the hydroponic reservoir until the electrical conductivity reached (350 ppm). In the third week, nutrient concentrations were increased to (650 ppm) using A and B solution. plants in Soil fertilized also with nutrient solutions A and B (1) mL L^{-1}each two weeks, through irrigation.

Water p^H and electrical conductivity were monitored regularly using a pH meter and an EC meter. Additional water was supplied to the hydroponic reservoir as needed; Plant growth was monitored continuously across all experimental units until maturity.

3.5 Measurements

1. **Germination**

$$\textbf{Germination (pot) (\%)}= \frac{Number\ of\ seedlings}{\text{total of seeds}} \times 100$$

2. **Chlorophyll content (SPAD):** was determined using a SPAD-502 Plus chlorophyll meter (Konica Minolta). A total of (24) randomized selected replicate were measured for each cultivation system. three readings were taken from each selected plant by placing the leaf between the sensor arms of the device and pressing the measurement button. The mean SPAD values were calculated to represent chlorophyll content.
3. **wet weight (g):** fresh plant biomass measured per pot using a digital balance.

3.7 Statistical Analysis

The data were statistically analyzed using SPSS (version 28). An independent sample T-test was performed to determine significant differences between the means of the two cultivation systems (hydroponic and soil) at a 5% significance level ($p \leq 0.05$).

4. Results

Based on the statistical analysis, the studied traits of *(Eruca sativa* Mill.) exhibited significant differences between the two cultivation systems. Germination percentage, Chlorophyll content, and productivity were particularly influenced by the type of system. Table (3) summarizes the P-values for these traits, indicating highly significant differences between the hydroponic and soil systems.

Table 3: The probability values(P-Value) for the effect of cultivation system(hydroponic and soil) on germination percentage, Chlorophyll content, and productivity of (*Eruca sativa* Mill.), based on SPSS statistical analysis.

Studied Trait	P-value
Germination percentage (%)	(P<.001)
Chlorophyll content(SPAD)	(P<.001)
Productivity (g)	(P<.001)

4.1 Effect of Cultivation System on Germination Percentage

The results indicated that the average germination percentage of arugula seeds *(Eruca sativa* Mill.) was significantly higher in the hydroponic system than in the soil system, with a mean difference of (51.9%) ($P < 0.001$). Figures (2) and (3) illustrate the differences in germination percentage between the two systems.

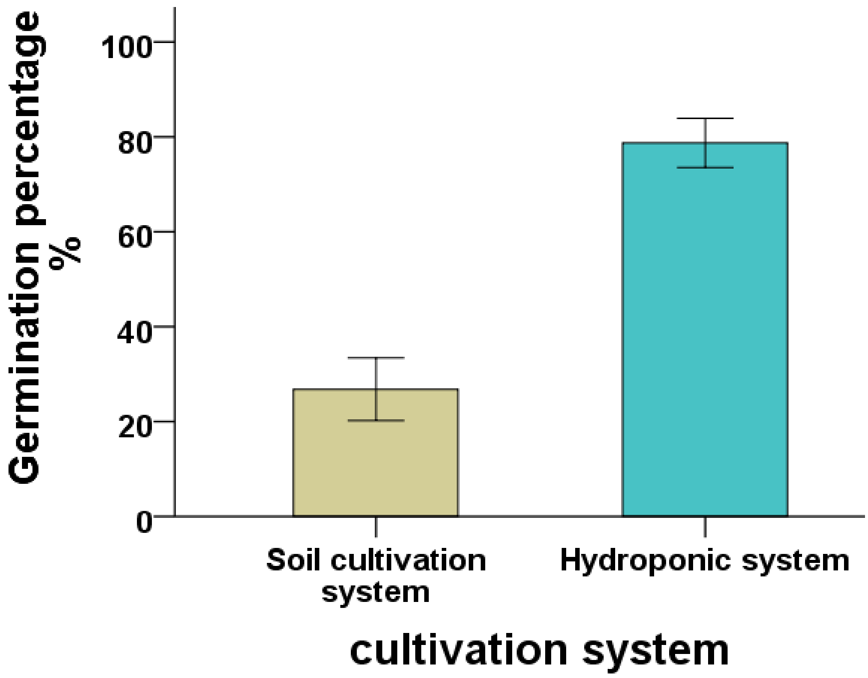

Figure 2: The effect of the cultivation system (hydroponic and soil) on the germination rate of arugula (*Eruca sativa* Mill.) seeds.

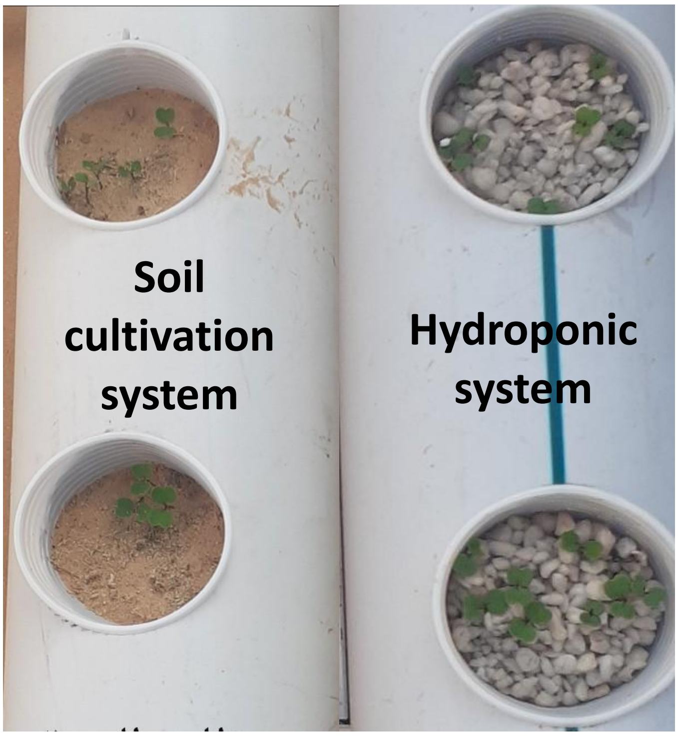

Figure 3: Differences in the number of germinated argula (*Eruca sativa* Mill.) seeds grown under hydroponic and soil cultivation systems.

4.2 Effect of Cultivation System on Chlorophyll Content in Arugula*(Eruca sativa* Mill.) Leaves.

Statistical analysis revealed that arugula(*Eruca sativa* Mill.) leaves in the hydroponic system exhibited the highest average chlorophyll content (SPAD 48.5), whereas those grown in the soil system showed the lowest average (SPAD 37.3). The difference between the means was highly significant ($P < 0.001$), as illustrated in Figure (4).

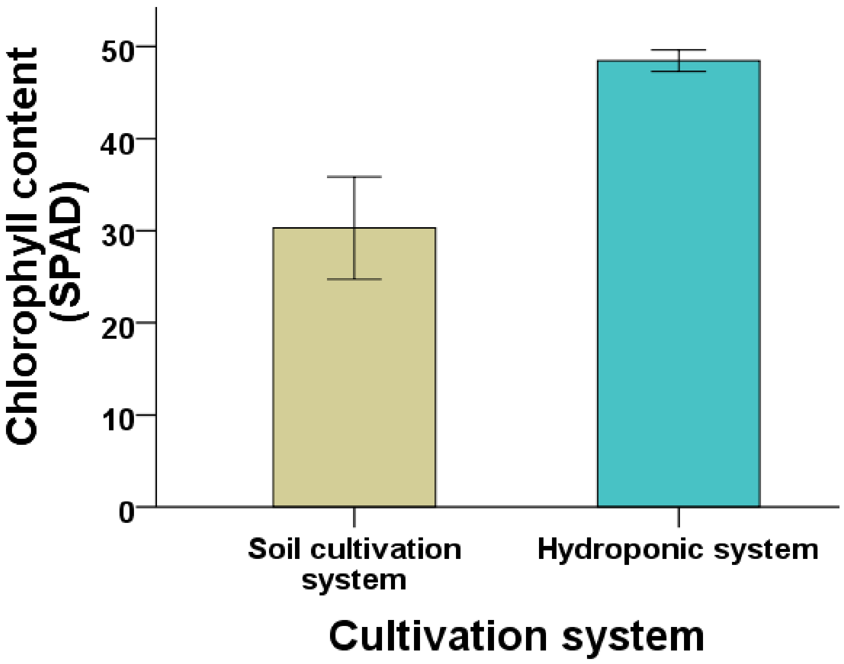

Figure 4: Effect of cultivation system (hydroponic and soil) on SPAD chlorophyll content in arugula (*Eruca sativa* Mill.) leaves.

4.3 Effect of Cultivation System on productivity and Maturity Period

The results obtained from statistical analysis of (24) pots each system, showed that the average productivity of arugula plants(Eruca *sativa* Mill.) grown under the hydroponic system was significantly higher than that of plants grown in the soil system, with an approximate difference of (51) grams ($P<0.001$). Additionally, plants cultivated in the hydroponic system exhibited a notable increase in overall plant size compared with those grown in the soil system. Figures (5) and (6) illustrate this difference.

Furthermore, the maturity period was shorter in the hydroponic system, with plants reaching maturity within (21) days, compared to (45) days in the soil system. These findings indicate that the hydroponic system accelerates plant growth and reduces the maturity period.

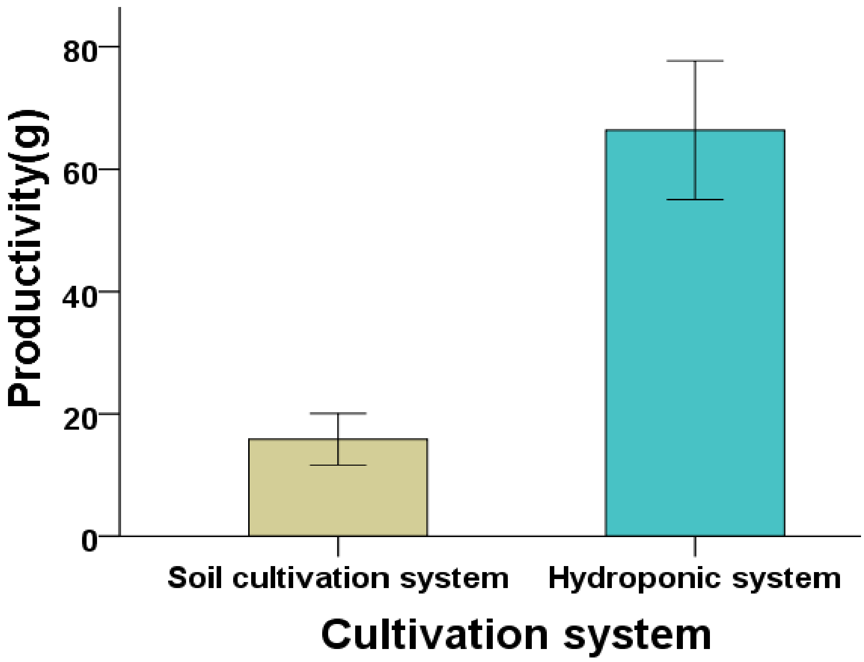

Figure 5: Average productivity of arugula (*Eruca sativa* Mill.) plants grown under hydroponic and soil cultivation systems.

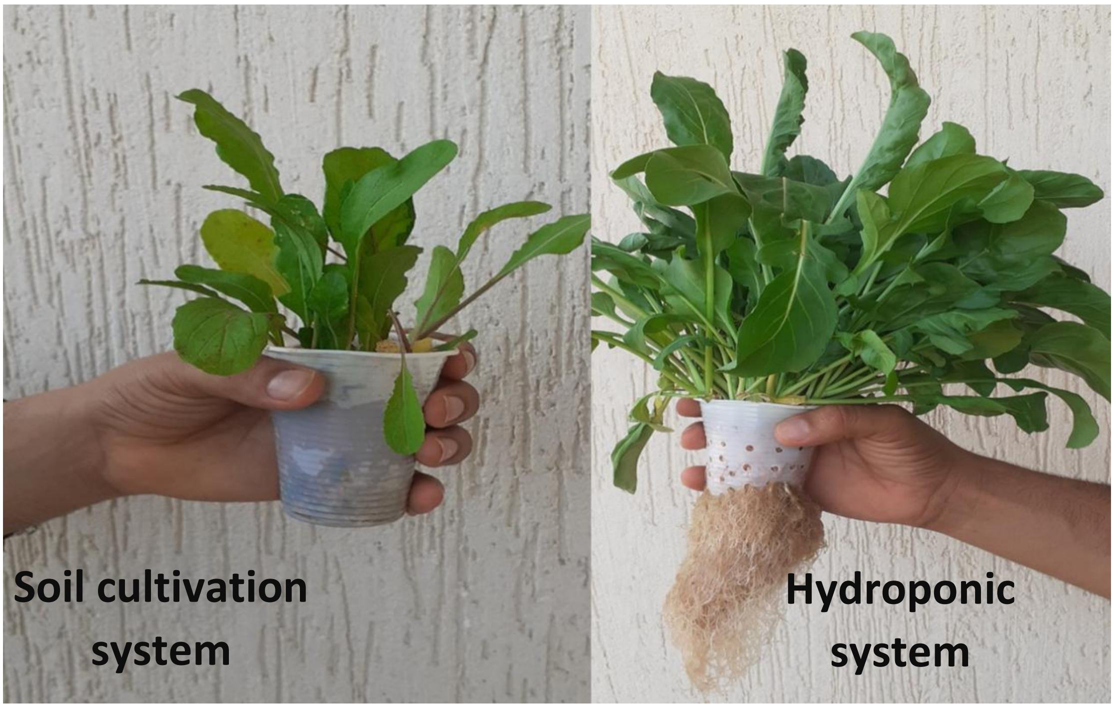

Figure 6: Difference in plant size of arugula (*Eruca sativa* Mill.) grown in pots under hydroponic and soil cultivation systems; plants were randomly selected.

Discussion

The results presented in Figures (2) and (3) indicated that the cultivation system had a highly significant effect ($P < 0.001$) on seed germination percentage, with the highest number of seeds germinated per pot observed under hydroponic cultivation. These findings are consistent with Yadav & Ekka (2024), who reported that the germination percentage of M. arvensis was 42% higher under hydroponic cultivation. Similarly, Meng et al. (2025) observed a germination rate of 87% under optimized moisture conditions. Furthermore, Yurina et al. (2019) reported a germination percentage of 98% for wheat grown under hydroponic cultivation. This result may be attributed to the optimal growth conditions provided by hydroponic cultivation, including consistent moisture availability and the absence of soil water tension (Schmidt et al., 2009; Pecnha et al., 2021). Likewise, Aliniaeifard et al. (2011) reported significant improvements in all growth parameters of Lippia plants grown in perlite relative to soil, attributing these effects to the favorable physical properties of perlite as a growth medium. In contrast, soil cultivation is affected by summer planting and high temperatures, resulting in soil water evaporation despite continuous irrigation, consistent with Kumar et al. (2025).

As illustrated in Figure (4), the cultivation system has a significant effect on the chlorophyll content. A relatively higher chlorophyll content was recorded in the leaves of arugula (*Eruca sativa* Mill.) grown under the hydroponic system compared to those cultivated in soil. This difference can be attributed to the continuous availability and enhanced uptake of water and nutrients in the hydroponic system. This result consistent with the findings of Sankhalkar et al. (2019), who reported an increase in chlorophyll content in hydroponically grown okra seedlings compared with soil-grown seedlings. Similarly, Abu-Shahba et al. (2021) found that lettuce cultivated under hydroponic conditions exhibited significantly higher chlorophyll content than those in soil-grown, attributing this to the effect of perlite as a growth medium. Ebrahimi et al. (2012) explained that Perlite provides a favorable growing environment by ensuring adequate aeration and porosity for root gas exchange, in addition to its high capacity for water and nutrient retention and efficient delivery to the plant, enhancing photosynthetic efficiency.

Based on the foregoing results, it is evident that hydroponic cultivation exerted a positive and statistically significant effect on the evaluated traits, resulting in increased productivity of arugula (*Eruca sativa* Mill.). This improvement is clearly illustrated in Figures (5) and (6). The observed increase in productivity is consistent with previous studies on various crops. For instance, Barbosa et al. (2015) reported that the yield of lettuce grown under hydroponic conditions was up to (11) times higher than that of soil-grown plants. Similarly, Shongwe et al. (2019) found that hydroponically grown zucchini produced an additional 10 tons per hectare compared with soil-based cultivation. In strawberry production, Treftz and Omaye (2016) documented a (17%) increase in yield under hydroponic cultivation relative to conventional soil systems. Furthermore, Elmulthum et al. (2023)

reported that fresh forage and dry matter yields per square meter in hydroponic systems were (2.83) and (2.30) times higher, respectively, than those obtained under field cultivation.

In addition to yield, hydroponic cultivation significantly enhanced plant development and reduced the time required to reach maturity. In the present study, the growth cycle of hydroponically grown arugula was shortened by (24) days compared with soil-grown plants. This finding aligns with Al-Karaki and Al-Hashimi (2012), who reported a reduction of (7–10) days in plant growth cycles under hydroponic systems. Likewise, Majid et al. (2021) observed that the growth period of hydroponically cultivated lettuce was approximately (15) days shorter than that of soil-grown plants.

Conclusion

This study demonstrates that hydroponic systems significantly enhance both seed germination percentage, chlorophyll content and the productivity of arugula (*Eruca sativa* Mill.). Moreover, hydroponic cultivation reduced the time to plant maturity by approximately 24 days compared to soil-based cultivation. Given these advantages, hydroponics represents a promising approach for crop production in marginal lands, including rocky or saline soils. Although the system entails higher costs and requires careful monitoring, its environmental benefits and potential to produce higher-quality, more sustainable crops make it a viable alternative to conventional soil-based agriculture.

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Conflict of Interest

The authors declare that there is no conflict of interest.

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