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Comparing the Characteristics of Lemongrass Plant in Different Harvesting Time under Soil and Soilless Cultivation Systems

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ABSTRACT

In the past decade, there has been a surge in interest regarding the cultivation of medicinal plants. Controlled environment farming methods, particularly soilless techniques, have emerged as effective alternatives to enhance production and water efficiency sustainably. This study aims to assess the morpho-physiological and biochemical characteristics and antioxidant capacity of lemongrass cultivated in soilless conditions in comparison to traditional soil-based cultivation, as well as comparisons of various harvesting times (two harvests). Results revealed notable distinctions in various parameters between the two cultivation methods and harvest times. Chlorophyll a, b, carotenoid, relative water content (RWC), plant height, leaf number, as well as fresh and dry weights exhibited higher values in soilless-grown plants, particularly during the second harvest. The biomass or dry matter generated in soilless cultivation exhibited a 25% increase during the initial harvest and a 27% augmentation in the second harvest in comparison to soil-based cultivation. Conversely, soil-grown plants displayed elevated levels of phenols, flavonoids, antioxidant activity, ion leakage and proline, especially during the second harvest compared to the first harvest, increased (25%, 26%, 12%, and 32%) respectively and the total chlorophyll in soilless cultivation compared to soil cultivation in the first and second harvest was observed to increase by 1.01 and 1.05 times, respectively. The highest content of essential oil (3.03%) was observed in soil cultivation and first harvest. This study contributes valuable insights into the optimization of lemongrass cultivation and time harvesting, emphasizing the advantages of soilless techniques in enhancing key morpho-physiological attributes and antioxidant potential.

Keywords: DPPH, Electrolyte leakage, Flavonoid, Poaceae, Phenol

INTRODUCTION

Currently, medicinal plants hold economic significance as they find applications in both traditional and industrial medicine, either in their raw or processed forms [1,2] The lack of water, the impossibility of precisely controlling plant nutrition in soil systems, and the need to stop indiscriminate plant harvesting from nature from resulting in plant extinction have all made it more and more necessary to cultivate medicinal plants utilizing environmentally friendly techniques like soilless systems [3-4, 5]. Up-to-date production techniques compared to traditional methods, in, development, and exploitation can have a significant impact on societal health, employment generation, and non-oil export growth. According to research, growing medicinal plants in controlled and soilless environments improves the quality and quantity of biomass produced on a commercial scale. Application of several soilless cultivation systems on different medicinal plants such as *Glycyrrhiza glabra* [6], Mentha spicata [4], *Narsicuss tazetta* [7], *Cannabis sativa* [8] showed an increase in quantitative and qualitative traits. However, a study comparing lettuce grown in soil and soilless conditions revealed that while the size of the aerial part, plant biomass, and leaf size of the soilless lettuce were not significantly different from the soil-grown lettuce, the soilless lettuce exhibited much longer roots, higher moisture content and lower ash content compared to conventional lettuce [9]. A study was carried out to examine the biomass and volatile compounds of rose-scented geranium under different cultivation systems and elicitors. The findings demonstrated that plants grown in soilless systems had significantly higher biomass, stomatal conductance, chlorophyll content, and leaf area than plants grown in soil [10]. Overall, soilless growing systems have advanced significantly in recent years as contemporary agricultural techniques can lower water usage, boost biomass, and improve the output of horticulture products.

Depending on the species and parts of medicinal plants, the harvesting techniques and time are different [11]. As a consequence, for both quality and quantity, they should be harvested at the appropriate season or time. The impact of cutting time on two varieties of mint, peppermint and Japanese mint, was examined by [12]. who showed that harvest time had a significant effect on plant biomass, essential oil percentage, and essential oil quality. Lemongrass (*Cymbopogon citratus* L.), renowned for its medicinal and aromatic properties, is a warm-season (tropical) and subtropical plant belonging to the Poaceae family of perennial grasses. This plant has an unstable oil that has a pleasant lemon aroma. Citral is the most important ingredient in lemongrass essential oil, and it is responsible for the plant's lemony aroma. According to scientific research, numerous medical benefits associated with Cymbopogon citratus oil include antioxidant, antibacterial, anti-inflammatory, anti-amoebic, anti-malarial, anti-filarial, anti-diarrheal, anti-fungal, anti-mycobacterial, anti-mutagenic, hypoglycemic and neuroprotective effects, anti-rheumatic, anti-cancer, anti-protozoan, and heart-protective effects [13-14,15]. Due lack of information regarding the effect of harvesting time and cultivation type on the morphological and biochemical properties of lemongrass, this research was conducted.

MATERIAL AND METHODS

Experimental Conditions

The research was carried out within the greenhouse facilities of the Shahid Bakeri Higher Education Center in Miandoab (Iran), under controlled conditions, with a 12-hour light cycle, diurnal temperatures set at 25°C and 18°C, and a relative humidity range of 65–75%. In this experiment, lemongrass cuttings prepared from the specialized collection of Zargiah medicinal plants in Shiraz province were used. Identical cuttings with a height of approximately 25 cm were planted. The conducted experiment followed a factorial design structured upon a complete randomized block design, with three replicates incorporated. The primary factor involved the cultivation system, categorized into two levels—soil and soilless culture—while the secondary factor encompassed harvest time, with two levels identified as the first and second harvests. Within each pot, two lemongrass seedlings of uniform size, approximately 20 cm in height, were cultivated. The initial harvest was conducted three months following the commencement of the experiment, with a subsequent second harvest occurring three months after the first. Following each harvest, the relevant parameters were measured during both stages of the experiment.

Photosynthetic Pigments

The method outlined [14] was used to determine the contents of carotenoids (carotene and xanthophylls), total chlorophyll, and photosynthetic pigments Chl a, b, and total chlorophyll. Using a spectrophotometer UV-1601 (Rayleigh, China), the pigment extract was measured at wavelengths of 663.2 and 646.8 nm for chlorophyll (Chl) assays and 470 nm for carotenoid (Car) assays against a blank of pure methanol.

$$Chla = (12.25A_{663.2} - 2.79A_{646.8})$$

$$Chlb = (21.21A_{646.8} - 5.1A_{663.2})$$

$$ChlT = Chla + chlb$$

$$Car = \left(\frac{(1000A_{470} - 1.8Chla - 85.02Chlb)}{198} \right)$$

where Ch-a is the chlorophyll a, Ch-b is the chlorophyll b, TCC is the total carotenoid content, β-carotene is the beta-carotene and A is the absorbance.

Anthocyanin

The method outlined [16] was used to determine the contents of carotenoids (carotene and xanthophylls), total chlorophyll, and photosynthetic pigments Chl a, b, and total chlorophyll. Using a spectrophotometer UV-1601 (Rayleigh, China), the pigment extract was measured at wavelengths of 663.2 and 646.8 nm for chlorophyll (Chl) assays and 470 nm for carotenoid (Car) assays against a blank of pure methanol.

where Ch-a is the chlorophyll a, Ch-b is the chlorophyll b, TCC is the total carotenoid content, β-carotene is the beta-carotene and A is the absorbance.

Total Flavonoid Content

Total flavonoid content was determined using aluminum chloride as a reagent (TFC). For each sample, 15 µl of an 80% (v/v) methanol extract was mixed with 1400 µl of distilled water, 500 µl of potassium acetate (1 M), and 10% w/v aluminum chloride. The tubes were stored at room temperature (25°C) and in the dark for thirty min. Finally, a spectrophotometer was used to measure the samples' absorbance at 415 nm. The TFC was expressed in mg of quercetin per g of dry weight (mg QUE g^{-1} DW) in this experiment, with quercetin serving as the standard [16].

Total Phenol Content

Folin-Ciocalteu reagent was used to quantitatively determine the total phenolic content (TPC) in plant samples [19]. For every sample, the reaction components were as follows: 960 µl of sodium carbonate (7% w/v), 180 µl of distilled water, 1200 µl of folin (10% v/v), and 5 µl of methanol extract (80% v/v). Consequently, the tubes were moved and left at room temperature (25°C) for 30 min in the dark. In the final stage, a spectrophotometer set to 760 nm was used to measure the samples' absorbance. Gallic acid was utilized as the standard in this experiment, and the TPC was expressed as mg of gallic acid per g of dry weight (mg GAE g^{-1} DW).

Total Radical Scavenging Activity by DPPH (RSA-DPPH)

According to 33, the total antioxidant capacity (AOC) or activity based on DPPH assay was assessed as AOC-DPPH. The assay's principle relied on the DPPH (α, α-diphenyl-β-picrylhydrazyl) solution's color changing from purple to yellow, which represents the antioxidants' ability to scavenge. To summarize, 900 µL of 25 µM DPPH in ethanol and 100 μL of methanolic lemongrass leaf extract were mixed and let to sit at room temperature in the dark for 30 minutes. By detecting the absorbance drop at 517 nm, the DPPH absorbance was calculated. The blank was made of ethanol. To calculate the inhibition percentage (I%), the following formula was used [18].

$$I(\%) = \left(\frac{A_{control} - A_{sample}}{A_{control}}\right) \times 100$$

$A_{control}$ is the absorbance of the control (containing DPPH, plus methanol), and A_{sample} is the absorbance of the test compound in the sample (DPPH, methanol plus sample).

Proline Content

In this method, 0.05 g of fresh weight was immersed in 2 cc of 70% ethanol at 100°C in a bain-marie. Then, 1 ml of reagent and 0.5 ml of ethanol extract were added, and the mixture was centrifuged at 2500 rpm for one minute. The absorbance of the dye was measured at 520 nm wavelength [20].

Leaf Relative Water Content (RWC)

To determine leaf RWC, samples were obtained from the final developed leaf in the experimental units and their wet weight was quantified. The samples were placed in distilled water and stored in a cold room at 4 °C for 24 hours. The saturated weight of the leaves was then measured, and they were placed in an oven at 70 °C for another 24 hours before being measured dry. The RWC was calculated using the following equation [21].

$$RWC = (Fw - Dw / Sw - Dw) \times 100$$

Fw is the leaf's wet weight, Dw is the dry weight after removal from the oven, and Sw is the saturated weight after removal from distilled water.

Electrolyte Leakage (EL)

To measure EL, leaf segments from treated plants were cut into 1- 2 cm sections and placed in test tubes containing 20 mL of deionized distilled water. Following vortexing the samples, the initial electrical conductivity (EC0) of each treatment was determined. The samples were then held at 4°C for 24 hours, and conductivity (EC1) was measured again. The samples were then autoclaved for 15 minutes, cooled to room temperature, and conductivity (EC2) was measured [20].

$$EL = ((EC_1 - EC_0) / (EC_2 - EC_0)) \times 100.$$

Essential Oil Content and Yield

To measure EL, leaf segments from treated plants were cut into 1- 2 cm sections and placed in test tubes containing 20 mL of deionized distilled water. Following vortexing the samples, the initial electrical conductivity

(EC0) of each treatment was determined. The samples were then held at 4°C for 24 hours, and conductivity (EC1) was measured again. The samples were then autoclaved for 15 minutes, cooled to room temperature, and conductivity (EC2) was measured [22].

$EL = ((EC_1-EC_0)/ (EC_2-EC_0)) \times 100$.

Statistical Analysis

Plant samples from each harvest time were air-dried in the shade at room temperature. Essential oils were extracted by water distillation of dried and powdered leaves (20g) for 3 hours, using Clevenger-type apparatus [23]. The essential oil yield (g $plant^{-1}$) was calculated as dry matter × oil content.

RESULTS

Morphological Traits

The simple and interaction effects of the type of cultivation system and harvesting time significantly affected parameters such as plant height, leaf length and width, number of leaves, crown diameter, and plant fresh and dry weight (Table 1). The optimal growth parameters were observed in lemongrass plants subjected to soilless culture during the second harvest. The maximum values for height (94cm), leaf number per plant (20.33), leaf width (30.84 mm), leaf length (76.04 cm), total fresh (127.05 g) and dry weight (27/53 g) were associated with the soilless culture and second harvesting. The lowest values for height (77.33 cm), leaf length (62.33 cm), leaf width (23.86 mm), and totally fresh and dry weight (65.33 and 16.76 g, respectively) were associated with soil-grown plants and first harvesting, also the lowest leaf number (5.66) was related to soil cultivation and second harvesting (Table 2).

Photosynthetic Pigments

The evaluation of photosynthetic pigments (Table 3) revealed significant variations in traits such as chlorophyll a, chlorophyll b, total chlorophyll concentration, β-Carotene, and carotenoid between various factors and their interactions ($P < 0.01$). The highest amounts of Chl a, Chlb, total Chl, and carotenoid (3.20, 0.98, 1.22 mg/g respectively) were associated with the soilless culture and second harvesting (Fig1). The highest amount of β-carotene was 0.25 mg/g in soil culture and first harvesting.

Table 1 Influence of cultivation system and harvest time on morphological traits of lemongrass

Mean square								
Source of variance	df	Plant height	Leaf length	Leaf width	Leaf Number	Crown diameter	Total wet weight	Total dry weight
Block	2	0.09 ^{ns}	5.108E-5^{ns}	1.225E-5 ^{ns}	0.001 ^{ns}	1.583E-6 ^{ns}	0.03 ^{ns}	0.05 ^{ns}
Cultivation system (A)	1	736.0 **	21.3 **	11.5 **	520.1 **	34.9 **	5470.3 **	150.2 **
Harvest time (B)	1	38.5 **	365.5 **	75.6 **	0.08 **	12.3 **	1040.7 **	46.0 **
A × B	1	3.3 **	0.2 **	0.1 **	6.6 **	2.3 **	280.0**	3.7 **
Erorr	6	0.01	0.003	1.285E-5	0.001	1.136E-5	0.05	0.1
C.V%		1.7E-06	0.9	0.1	0.4	0.1	0.8	8.3

Different superscript letters indicate significant differences according to Duncan's multiple range test ($p \leq 0.05$).

Table 2 Influence of cultivation system and harvest time on morphological traits of lemongrass.

Cultivation system	Harvest	Plant height (cm)	Leaf length (cm)	Leaf width (mm)	Leaf Number	Crown diameter (mm)	Total wet weight (g)	Total dry Weight (g)
Soil	First	77.3 b	62.3 d	23.8 d	7.3 c	19.0 d	65.3 d	16.7 d
	Second	80.0 b	73.6 b	28.6 b	5.6 d	20.2 c	74.6 c	19.0 c
Soilless	First	90.6 a	65.2 c	25.6 c	19.0 b	21.6 b	98.6 b	22.1 b
	Second	94.0 a	76.0 a	30.8 a	20.3 a	24.5 a	127.0 a	27.5 a

Different superscript letters indicate significant differences according to Duncan's multiple range test ($p \leq 0.05$).

Table 3 Influence of cultivation system and harvest time on photosynthetic pigments of lemongrass

Mean square						
Source of variance	df	Total chlorophyll	chlorophyll a	chlorophyll b	β-Carotene	carotenoid
Block	2	3.033E-5 ^{ns}	3.083E-6 ^{ns}	4.083E-6 ^{ns}	1.083E-6 ^{ns}	9.100E-7 ^{ns}
Cultivation system (A)	1	0.05 **	0.05**	0.001 **	0.002 **	0.01 **
Harvest time (B)	1	0.4 **	0.05 **	0.1 **	0.004 **	0.04 **
A × B	1	0.01 **	0.007 **	0.001 **	0.001 **	0.01 **
Erorr	6	0.00002	0.00001	6.417E-6	2.308E-5	3.303E-5
C.V%		2.4	3.1	2.1	0.4	5.6

Different superscript letters indicate significant differences according to Duncan's multiple range test ($p \leq 0.05$).

Table 4 Influence of cultivation system and harvest time on biochemical treats of lemongrass

Mean square										
Source of variance	df	Anthocyanin	Phenol	Flavonoid	Antioxidant	Prolin	RWC	EL	Essential oil content	Essential oil yield
Block	2	0.000 ^{ns}	0.01 ^{ns}	0.1 ^{ns}	0.3 ^{ns}	7.233E-5 ^{ns}	0.06 ^{ns}	0.011 ^{ns}	3.900E-5 ^{ns}	0.000 ^{ns}
Cultivation system (A)	1	10.7 **	118.0 **	183.4 **	2.6 **	0.03 **	40.4 **	99.303 **	5.547 **	0.107 **
Harvest time (B)	1	0.011 **	971.8 **	86.2 **	564.5 **	0.1 **	9/5 **	38.607 **	0.457 **	0.197 **
A × B	1	4.5 **	109.2 **	192.7 **	93.2 **	0.000 **	7.4 **	0.317 **	0.048 **	0.002 **
Erorr	6	0.001	0.1	0.09	0.1	4.4444E-7	0.03	0.01	0.000024	0.000
C.V%		2.6	4.0	3.7	8.3	2.2	7.9	2.82	0.6	0.5

Different superscript letters indicate significant differences according to Duncan's multiple range test ($p \leq 0.05$).

Antioxidant Activity, Phenol, and Flavonoid Content

As the results showed, different treatments had various effects. The highest antioxidant activity, phenol and flavonoid were observed in the soil culture and the second harvesting, (93.5%, 53.52 and 22.5 mg/g) respectively. which increased (26%, 16% and 25%) compared to the first harvest, respectively, and the lowest activity of phenol and flavonoid was observed in the soilless culture. The second harvest and antioxidant activity was obtained in the first harvest.

Total Anthocyanin Content

The findings underscore the significant impact of both the cultivation system and harvesting time on the anthocyanin content of lemongrass leaves (*P<0.01)*. Total anthocyanin content values among treatments were detected between 3.2 and 6.44 µmol g^{-1} FW (Fig1). The lowest total anthocyanin content was noted in soil-grown plants during the second harvesting, while the highest content was observed in soilless-grown plants during the second harvesting as well.

Proline, Relative Water Content (RWC), and Electrolyte Leakage (EL)

The results listed in Table 4 show a significant difference between different factors in terms of proline, RWC, and EL (P<0.01). The highest amount of proline was obtained in soil culture and first harvesting (0.81 mg/g FW), while the lowest amount was obtained in soil culture and first harvesting (0.36 mg/g FW). The highest amounts of RWC (89.25 %) and EL (95.76%) were related to soilless culture and first harvesting and soil culture and first harvesting, respectively.

Essential Oil Content and Yield

The results of ANOVA showed that the type of harvest and cultivation system had a significant effect on the essential oil content and yield of lemongrass (Table 4). The highest essential oil content was observed in the first harvest of the soil system (3.03%), which increased by 96% compared to the first harvest of the soilless system. The lowest amount (1.27%) was obtained in the second harvest of cultivation without soil, which showed a 97% decrease compared to soil cultivation in the same harvest (Fig3). The highest yield of essential oil was observed in cultivation of Soilless and second harvest (0.66), which has increased by 84.34% compared to the lowest value. Its lowest amount (0.23) was obtained from soil cultivation and first harvest.

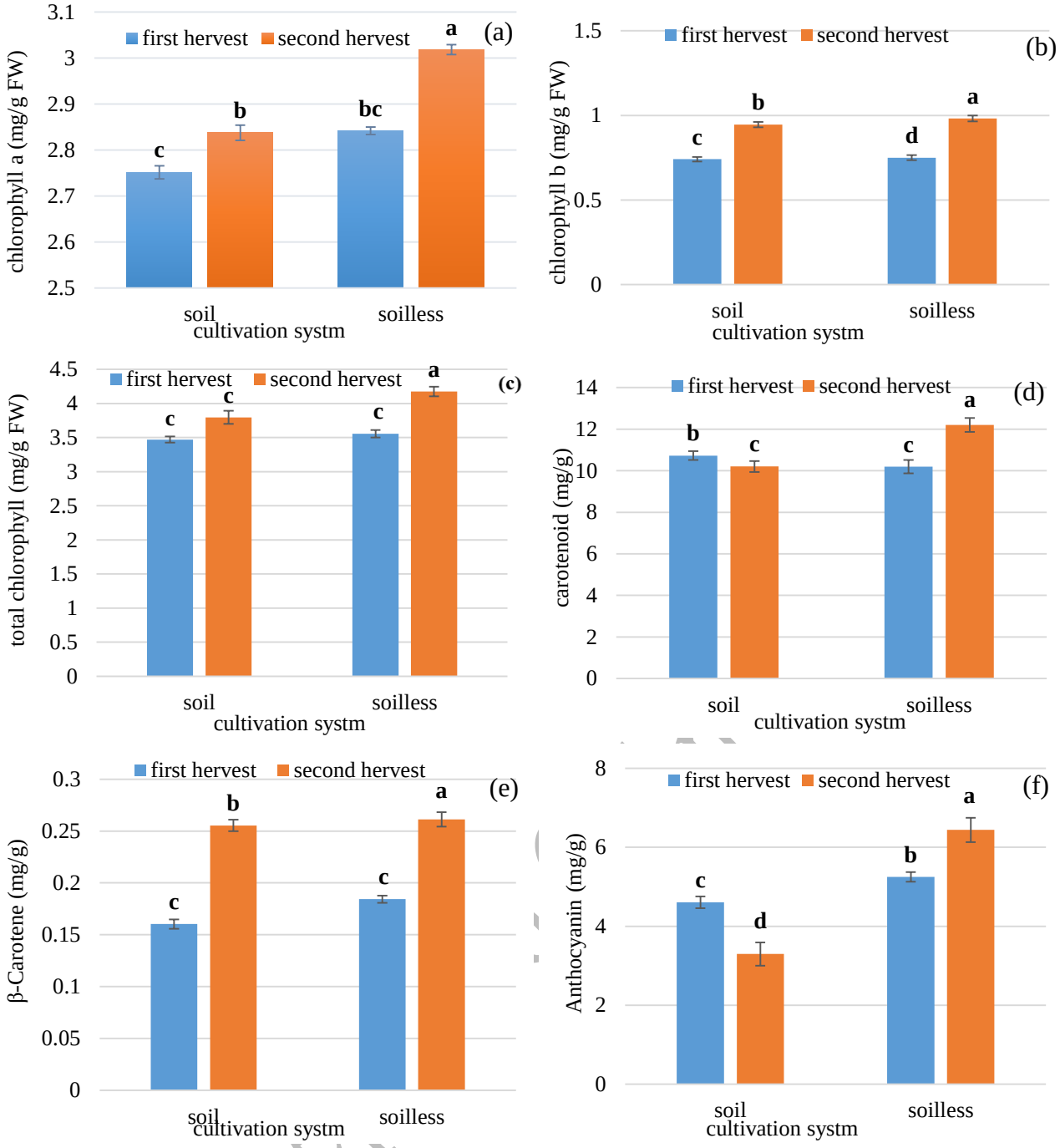
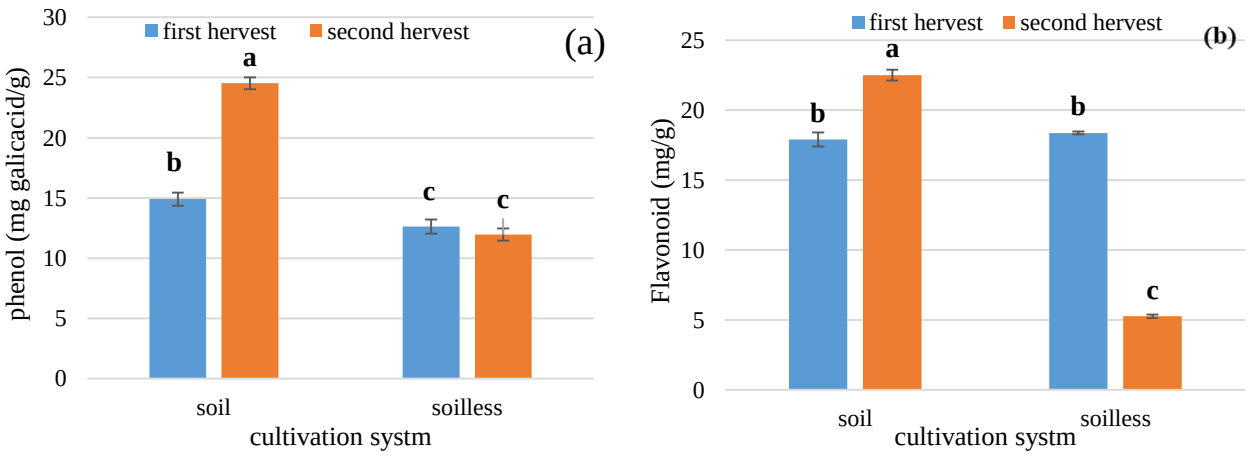


Fig. 1 Influence of cultivation system and harvesting time on chlorophyll a (a), chlorophyll b (b), total chlorophyll (c), carotenoid (d), β-Carotene (e) and nthocyanin content (f) of lemongrass.



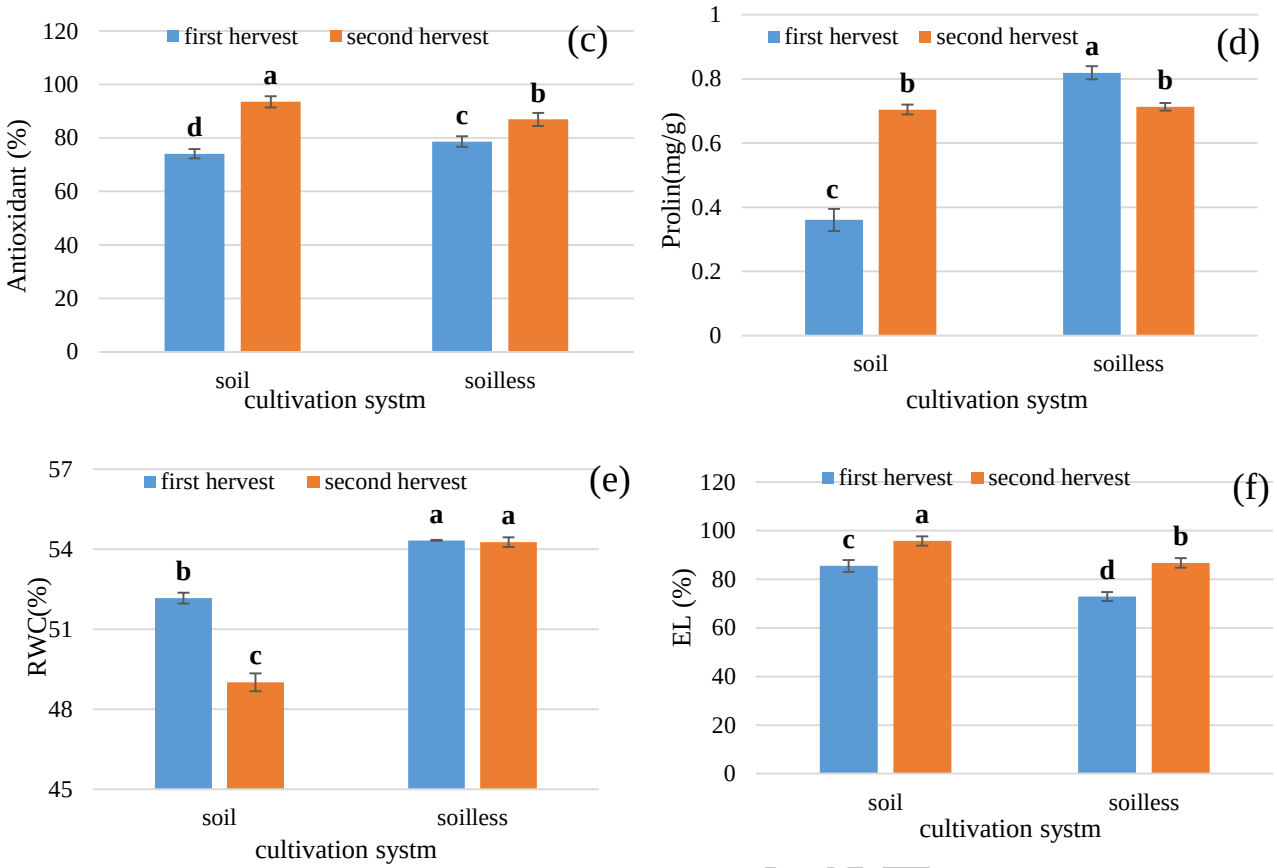


Fig. 2 Influence of cultivation system and harvesting time on phenol content (a), flavonoid content (b), antioxidant activity (c), prolin (d), RWC (e) and EL (f) of lemongrass.

Correlation Investigation

The results of the correlation study between the variables are shown in Fig. 4. Red and blue represent relationships that are both positive and negative. Moreover, the correlation coefficients correlate with the squares' size and color intensity. A positive correlation was observed between Chl a, Total chlorophyll and morphological characteristics. There was also a positive correlation between antioxidant activity, phenol, proline and electrolyte leakage. In addition, there was a negative correlation between flavonoids and morphological traits. Correlation research reveals that various traits have a direct and sometimes indirect relationship with one another. It is critical to consider these linkages while determining the optimum treatments and production procedures. The qualities associated with essential oils and yield components are more evident, necessitating greater attention from scientists and plant producers.

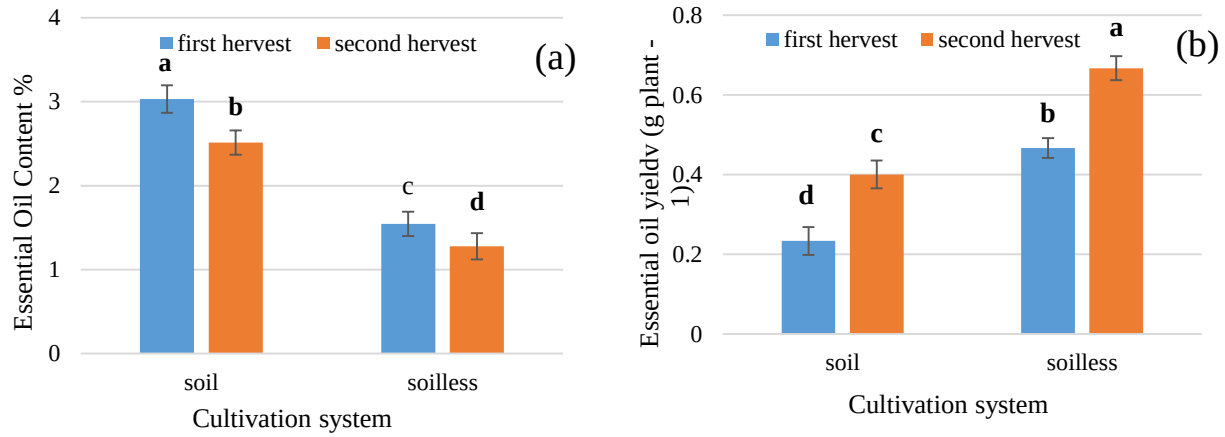


Fig. 3 Influence of cultivation system and harvesting time on essential oil content (a) and essential oil yield of lemongrass.

DISCUSSION

Various studies show a promising perspective on the use of soilless systems for the cultivation of medicinal plants [24]. The results of this research showed the better effect of the soilless system in increasing the morphological characteristics of the lemongrass plant. So traits such as plant height, leaf length and width, number of leaves, crown diameter, and fresh and dry weight of the plant increased compared to soil cultivation. The results obtained in this study are consistent with the results of the superiority of morphological traits in *Mentha spicata* [4], *Lavandula angustifolia and Thymus vulgaris* [25], Portulaca oleracea [26] plants in a soilless cultivation environment compared to soil cultivation. This is consistent with previous research that demonstrated plants can grow easily in soilless and yield maximal potential. This is because plants in soilless systems have ideal pH and electrical conductivity (EC) levels for greater nutrient and water uptake, as well as simple access to oxygen for roots [27]. In the present study, we utilized the Hoagland and Arnon (1950) standard solution, encompassing a comprehensive array of essential elements, including both macro and trace elements. This solution meticulously maintains a balance between anions and cations. Noteworthy advantages of this approach include precise control of the osmotic potential in the root environment (EC= 2.4 dS/m) and the maintenance of an optimal pH of 5.5, facilitating the absorption of all elements critical for plant growth. These factors collectively contribute to superior growth and yield in soilless cultivation compared to traditional soil-based methods. Additionally, the deliberate combination of coco-fiber and perlite in the soilless substrate has been chosen to provide maximum ventilation to the plant, surpassing the porosity levels of soil substrates. This strategic choice further fosters enhanced growth and developmental parameters in plants cultivated through soilless methods. According to growth as well as yield factors, it is suggested that soilless is an achievable alternative system in urban and peri-urban areas because higher output can be accomplished with less space [4-6, 28].

Also, the evaluation of morphological characteristics in both systems showed the superiority of the second harvest over the first harvest. It seems that in the first harvest, the plants had only one main stem, and as a result, they had fewer leaves and less photosynthesis, so they had less growth and development, on the other hand, in the first harvest, the plant spent some of its energy for establishment. In the second harvest, the lemongrass plant had already traveled part of the growth path and therefore the subsequent growth was faster and produced more plant material (Table 2). In peppermint and Japanese mint experiment, the second planting was significantly superior to the first in terms of plant height, dry biomass, leaf dry weight and essential oil yield [12]. The results showed that the amount of chlorophyll a and total chlorophyll in soilless-grown plants was higher than in soil-grown plants. Some researchers have also reported that the amount of chlorophyll a and total chlorophyll in soilless plants is higher than that of soil plants [4-29, 30]. Soilless systems may provide more favorable growing circumstances than soil cultivation because of the continuous flow of nutrient media through the plants, which results in plants with significantly higher chlorophyll levels [29-31, 32]. Observed a similar relationship between increased water availability in soilless cultivation and greater levels of chlorophyll a and b in lettuce. Since leaves are the foundation of photosynthesis, their quantity and area serve as indicators of a crop's strength. The area of a plant's leaves is directly related to the total amount of biomass or dry matter produced by photosynthesis. A greater amount of chlorophyll could mean that all the necessary nutrients and water were received. [4]. In the evaluation, the leaf chlorophyll content in both planting systems was higher in the first harvest than in the second harvest, which can be attributed to the better establishment of plants, better rooting, and the absorption of more elements.

The minimum of total anthocyanin content was observed in soil culture and second harvesting, as well as its maximum in Soilles culture and second harvesting. Anthocyanins are a subclass of flavonoids that are soluble in water [33]. Higher plants that contain anthocyanins benefit from their adsorption of pollinators, protection against oxidative stress, filtration against UV radiation, and avoidance of DNA damage [34].

There is a major correlation between antioxidant activity and phenolic compounds and flavonoids. Because phenolic compounds have hydroxyl groups (-OH) attached to aromatic rings in their structures, they can bind to macromolecules like proteins or enzymes and perform reductive and metal-ion-chelating functions [30-35]. The results of this research showed an increase in the amount of phenol, flavonoid, and antioxidant activity in plants grown in soil culture. The increase in the amount of phenol and flavonoids in soil cultivation conditions is probably due to the plant's defense response. Similar findings were obtained in a soilless system, which had

higher comparable phenolics, flavonoids, and antioxidant characteristics to those obtained in soil-grown systems [29-36]. Of course, contrary to our findings, the results about the ginseng plant showed that the amount of phenol, flavonoid, and antioxidant activity of plants grown in a soilless system is higher than that of plants grown in soil [37]. Proline content was higher in plants grown in soil than in plants grown in the soilless system. Plant osmosis is regulated by proline, which is typically produced by various plant species under various abiotic stresses [38-39]. In an experiment conducted on geranium plants, the results showed that total chlorophyll content, relative water content and proline content of leaves were higher in plants grown in soilless environments compared to plants grown in soil environments [10]. Compared to plants cultivated in a soilless environment, this suggests that plants grown in soil may be under some stress.

In this study, electrolyte leakage (EL) was higher in plants grown in soil culture. It seems that in soilless cultivation, the access of plants to sufficient water and nutrients has affected the integrity of the cell wall and increased the relative water content (RWC) of the leaves. The amount of essential oil in both planting systems was higher in the first harvest than in the second harvest. In some previous studies, in agreement with our results, the amount of essential oil in successive harvests followed a downward trend [12]. The evolution of production and accumulation of secondary metabolites in plants responds to environmental changes and plant growth stages [40]. Biomass production and essential oil yield in soilless cultivation can be many times more than soil substrate, because soilless cultivation allows the plant to grow more by providing optimal conditions, including optimal ventilation and available nutrients. And the lemongrass plant is from the grass family, it is a clawed plant, and it produces more claws and leaves in more frequent harvests, for this reason, the highest yield of essential oil was observed in cultivation without soil and the second harvest.

CONCLUSION

In conclusion, the findings of this study highlight the positive impact of soilless cultivation on the morphological characteristics of lemongrass. Notably, parameters such as plant height, leaf growth, crown diameter, as well as the fresh and dry weights of plants, chlorophyll content, and plant water status (RWC) exhibited significant

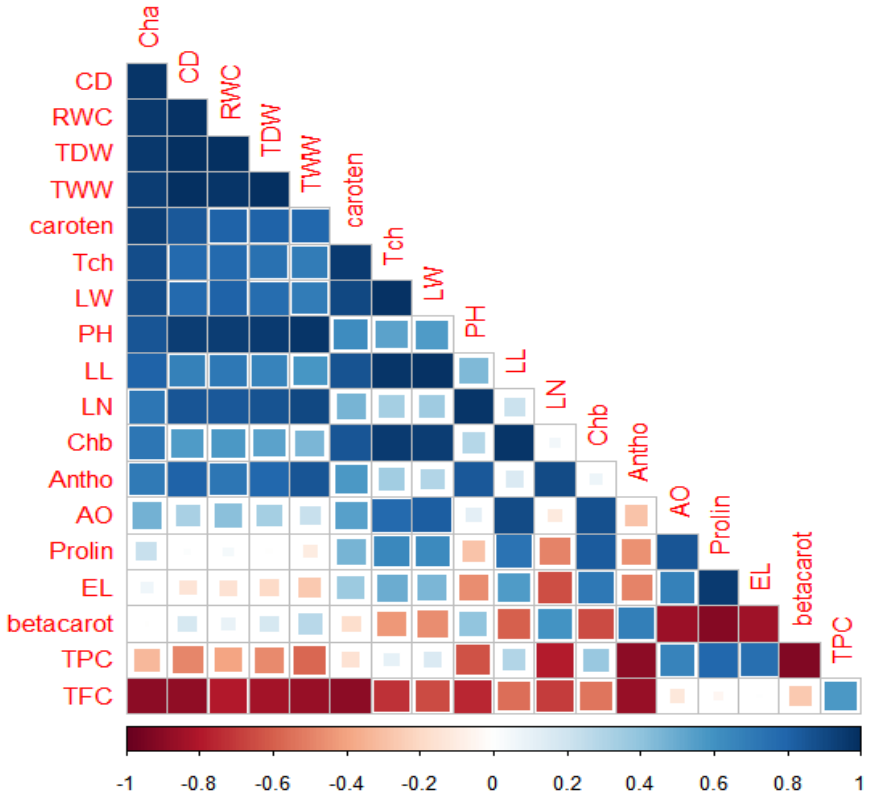


Fig. 4 Correlation between 18 main parameters on studied *Cymbopogon citratus*: CD, Crown diameter; RWC, Relative water content; TDW, Total dry weight; TWW, Total wet weight; Croten, Carotenoid; Tch, Total chlorophyll; LW, Leaf width; PH, Plant height; LL, Leaf length; LN, Leaf number; Chb, chlorophyll b; Antho, Anthocyanin; AO, Antioxidant activity; Prolin, Prolin; EL, Electrolyte leakage; betacarot, β-carotene; TPC, Phenol; TFC, Flavonoid.

increases in comparison to soil cultivation. It is noteworthy, however, that certain biochemical traits, including phenol, flavonoid, and antioxidant activity, demonstrated higher levels in plants cultivated in soil.

To further deepen our understanding of these dynamics and potentially optimize lemongrass cultivation, it is recommended that future experiments explore the underlying mechanisms influencing biochemical parameters in different cultivation systems. Additionally, investigating the impact of variations in soilless substrate composition and nutrient solutions could provide valuable insights into enhancing both the morphological and biochemical aspects of lemongrass growth. Further studies may also consider exploring the long-term effects of consecutive harvests to provide a more comprehensive perspective on the sustainability and productivity of lemongrass cultivation in soilless systems.

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