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RESEARCH PAPER

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EFFECTS OF SEED SOWING DENSITY PER TRAY CELL ON GROWTH, YIELD AND PHYSIOLOGICAL QUALITY OF SOILLESS PARSLEY CULTIVATION

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ABSTRACT

Parsley makes a significant contribution to a healthy diet. While parsley is generally grown by direct sowing of seeds, in recent years, seedling cultivation methods have been used to prepare seedlings for planting. Therefore, to find the most suitable seedling cultivation technique, *Petroselinum crispum* Mill. D'Giant Italian seedlings were grown soillessly to examine early yield and some quality characteristics. In this study, four different seed densities were tested in a randomized block design with three replications. For this purpose, 5, 8, 12, and 15 seeds per cell (50 mL cell volume) were sown. The results demonstrated that elevated seed sowing density per tray cell established higher plant populations within the seedling cluster, leading to significant increases in cumulative fresh yield, total leaf number, and total leaf area ($p < 0.05$). The highest total fresh yield was achieved with 15 plants per cluster (103.2 g plant cluster^{-1}), compared to 34.8 g plant cluster^{-1} in the 5 plants per cluster treatment. However, physiological and quality traits including leaf chlorophyll content (14.7 CCI) and stomatal conductance (351.3 mmol m^{-2} s^{-1}) peaked at 12 plants per cluster and exhibited a decline at 15 plants per cluster due to inter-plant competition. In conclusion, while 15 plants per cluster maximizes total biomass yield, sowing 12 to 15 plants per cluster provides an optimal balance between early yield and seedling physiological quality in soilless parsley production.

Keywords: early yield, *Petroselinum crispum* Mill., seedling quality, seed number per tray

INTRODUCTION

Parsley (*Petroselinum crispum* Mill.) is cultivated year-round in Mediterranean countries and commonly consumed fresh in salads and appetizers [UBSEP 2008, Al 2019, Yılmaz et al. 2024]. Parsley is a functional plant that exhibits antioxidant, anti-inflammatory, and anti-apoptotic properties due to its rich phytochemical profile, which includes flavonoids, carotenoids, and ascorbic acid. Through its essential oils, it can suppress various diseases and allergic reactions; furthermore, it may contribute to the repair of brain and intestinal damage caused by Methotrexate (MTX) through antioxidant mechanisms. Consequently, these attributes have made parsley a critical nutritional supplement for supporting a healthy lifestyle in modern diets [Sener et al. 2003, Mahmood et al. 2014, Maodaa et al. 2016, Ertaş et al. 2021, Franciscato et al. 2022, Yılmaz et al. 2024]. These properties have also ensured that parsley remains one of the highest-selling fresh herbs in Europe [Spence 2020, Califano et al. 2024].

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Today, the vegetable sector aims to achieve high yields through year-round cultivation. Therefore, starting production with high-quality seedlings grown from high-quality seeds enhances productivity [Ucan and Uğur 2021, Kaya 2022, Demir et al. 2025, Kartal and Şahin 2025]. The significance of starting production with seedlings has also influenced the seedling industry. In contemporary horticulture, seedling transplanting has become the standard commercial practice for a wide range of vegetable species, most notably tomato [Ucan and Uğur 2021, Kaya 2022, Demir et al. 2025, Kartal and Şahin 2025]. Consequently, the seedling sector in Türkiye has developed rapidly. Annual production has now reached 3 billion vegetable seedlings, with tomatoes alone accounting for 1.4 billion of this production [Demir et al. 2025].

Parsley is generally cultivated through direct sowing [Duyar and Kılıç 2016, Üstüner 2022]. Unlike direct seeding, seedling transplanting utilizes plants with well-developed root systems and higher initial dry matter accumulation, facilitating rapid crop establishment [Özer 2018, Ayaz et al. 2022, Şa et al. 2023, Çolak et al. 2025]. Furthermore, numerous problems are encountered in direct sowing, with weeds being the most critical factor affecting parsley production. Due to their robust root systems, weeds can absorb more water and nutrients from the soil compared to crop plants [Telli and Üremiş 2010, Üstüner 2022]. Güncan [2001] reported that weed species utilize twice as much nitrogen, phosphorus, and potassium as crop plants. Additionally, the tall, broad, and large leaves of weed species negatively impact crop plants by reducing light interception, leading to a decrease in photosynthetic products [Güncan 2001, Telli and Üremiş 2010, Üstüner 2022].

For parsley seedling cultivation, a significant member of the leafy greens family, planting multiple seeds in a tray cell is not a common strategy. However, recently in commercial production, some researchers have developed successful examples of planting different numbers of seeds per tray cell in parsley seedling cultivation to achieve denser vegetation formation and higher harvest volume per planting unit [Taşdelen et al. 2021, Okudur and Tüzel 2022, Yılmaz et al. 2024].

However, an excessive seed density per cell can induce severe intra-cell competition, leading to etiolation, reduced stem thickness, and lower leaf chlorophyll content. Despite the agronomic advantages of multi-seed sowing, empirical research systematically evaluating the optimal seed density per tray cell specifically for soilless parsley seedling production remains scarce. Therefore, this study aimed to investigate the effects of different seed sowing densities on seedling growth, quality traits, and early fresh yield of parsley in a soilless cultivation system.

MATERIALS AND METHODS

The study was conducted at the Department of Horticulture, Faculty of Agriculture, Ondokuz Mayıs University, between October 18, 2025, and February 23, 2026. The seedling period was carried out in a fully automated seedling production greenhouse (3.3 × 7 × 3.2 m) and a soilless cultivation greenhouse (120 m²). Humidity and temperature control in the greenhouses were performed automatically during cultivation. Seeds of *Petroselinum crispum* Mill. D'Giant Italian were used in the study. This parsley cultivar is suitable for cultivation in all regions. It has a high market value, is consumed fresh, and has a pleasant aroma.

Experimental setup

Seeds were obtained from a commercial seed producer (Arzuman, Konya, Turkey). For seedling cultivation, parsley seeds were sown in EPS (expanded polystyrene) trays with 216 cells (31 × 31 × 65 mm), a cell/root volume of 50 ml, and dimensions of 695 × 470 × 75 mm. The trays were filled with peat (Class I, KTS I, DRT, Antalya, Turkey), and the seeds were sown manually on October 18, 2025. The sown trays were then transferred to seedling production tables and watered using a sprinkler system connected to an automatic irrigation system. During the germination-emergence period, greenhouse temperatures were set at 25–27°C. After emergence, until the seedlings reached the four-leaf stage, daytime (22–23°C) and nighttime (18–20°C) temperatures were adjusted to vary. Four different seed sowing methods were tested in the study. Treatments were established in which 5, 8, 12 and 15 seeds were sown in one cell of the seedling trays, respectively. For this purpose, each of four different trays (216 cells) was randomly divided into four, and each treatment seed was sown.

The resulting parsley seedlings were transplanted on November 24, 2025, into 1.3-liter plastic pots filled with cocopeat (Arımanlar, Samsun, Turkey). All seedlings originating from a single tray cell were transplanted intact as a cluster into a single pot; thus, each pot contained 5, 8, 12, and 15 plants according to the respective seed sowing density treatments. The pots were placed in planting furrows that were opened at a 5% slope and 40 cm above the ground, with a spacing of 12 cm between plants within the row and 25 cm between rows. Following transplanting, the first harvest was performed on December 22, 2025, and the final harvest was conducted on February 23, 2026. The interval between successive harvests varied between 28 and 33 days. Subsequently, macro and micronutrients used in the fertilization process were carefully prepared as stock solutions in three tanks (A, B, and C), each with a capacity of 50 liters. The stock solutions were prepared using the recommended nutrient elements (N, P, K, Mg, Ca, Fe, Zn, Cu, Mn, B, and Mo) for soilless parsley production at doses of (105, 15.5, 117, 17, 80, 2.5, 0.05, 0.02, 0.5, 0.5, and 0.01 mg L^{-1}) respectively. The stock solution nutrient content was prepared according to Okudur and Tüzel [2022], with EC values of 1.3–1.5 dS m^{-1} and pH values of 5.5–6.0. Fertilization was monitored using a fully automated soilless farming system.

Throughout the research period, climate conditions in the greenhouse were continuously measured by using recording devices (Hobo, MX2301A and H21 Onset, Bourne, USA). According to these measurements, light intensity, relative humidity and temperature ranged from 106 to 321 µmol m^{-2} s^{-1}, 23.1% to 67.5%, and 12.8 to 21.1 °C, respectively. When relative humidity exceeded 70%, a ventilation system was used to regulate it.

Plant measurements

For measurements and observations, 4 plant clusters from each replicate (12 plants from each treatment) were repeatedly evaluated at each harvest time. Plant height (cm) was determined by measuring the distance from the soil surface to the top of the plant. Leaf color was determined in terms of CIE L*, Chroma*, and Hue*, and these color parameters were measured using a colorimeter (Minolta, model CR-400, Tokyo, Japan). Leaf number was determined by counting the leaves attached to the main stem of the plants. To determine leaf area (cm^2), selected leaves were pasted onto A4 paper, and photocopied leaves were measured with a digital planimeter (Placom Digital Planimeter, Sokkisha Planimeter Inc., Model KP-90). For treatments with 5, 8, 12, and 15 plants per harvest, yield value (g plant $cluster^{-1}$) was determined from the total fresh weight (g) at harvest time. During harvest, plants were cut along their stems with scissors 3–4 cm above soil level.

Leaf chlorophyll content (CCI) and stomatal conductance (mmol $m^{-2}s^{-1}$) were measured between 09:00 and 11:00 a.m. on leaves at different levels of the measurement plants (3 leaves per plant). Leaf chlorophyll content was measured using a CCM-200 chlorophyll meter (Opti-Sciences, USA). The assessment of stomatal conductance was performed employing an SC-1 leaf porometer (Decagon Devices, Pullman, USA).

Statistical analysis

In this study, established according to a randomized block design, an individual tray cell (and the plant cluster originating from it) was defined as the primary experimental unit. The experiment comprised four treatments (seedlings obtained from 5, 8, 12, and 15 plant per cluster) with three replications per treatment. For morphological and physiological measurements, four tray cells (plant clusters) were randomly sampled from each replication at each evaluation date. Statistical analyses were performed using SPSS software (v. 21.0) via one-way Analysis of Variance (ANOVA). Differences between treatment means were evaluated using Duncan's Multiple Range Test at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

Early yield of parsley

In our study, it was determined that yield values increased significantly in proportion to the different seed sowing numbers. Increasing seed density plants per pot significantly increased cumulative fresh

yield, leaf area, and leaf number. Seedlings grown with 15 plant cluster produced the maximum fresh yield during the second harvest (40.4 g plant cluster^{-1}), contributing to the highest total cumulative fresh yield of 103.2 g plant cluster^{-1} obtained from this treatment. While similar yield values were obtained with 5 and 8 seed sowings in general, a dramatic increase in yield was achieved with 15 seeds (Table 1). A study in which parsley seedlings were grown organically reported that harvest intervals similarly varied between 24 and 35 days [Yılmaz et al. 2024].

Table 1. The effects of growing parsley seedlings obtained from different numbers of seeds (5, 8, 12, and 15) in a soilless medium on fresh yield (g plant cluster^{-1})

Harvest time	Number of plants in pots			
	5	8	12	15
First	9.2 ±0.74c	16.9 ±0.59b	16.1 ±1.09 b	29.2 ±1.53a*
Second	12.7 ±1.04c	23.4 ±0.83b	22.2 ±1.56b	40.4 ±2.10a
Third	12.8 ±0.24d	18.1 ±1.91c	22.7 ±0.33b	33.5 ±0.84a
Mean harvest date	11.6 ±0.76C	19.5 ±1.14B	20.3 ±0.99B	34.4 ±1.49A**
Total yield	34.8 ±1.13C	58.4 ±1.44B	61.0 ±1.81B	103.2 ±2.06A***

Notes: *means within the same row and columns followed by different lowercase letters are significantly different at $p < 0.05$ according to Duncan's multiple range test; ** values in the same row followed by different letters are significantly different at $p < 0.05$; *** values in the same row followed by different letters are significantly different at $p < 0.05$

For a contextual baseline comparison with traditional soil production, Yılmaz et al. [2024] evaluated organic fertilization regimes in soil-based parsley cultivation, reporting single-harvest fresh yields of 0.87–1.49 kg m^{-2} (cumulative 5.24–8.95 kg m^{-2} across six harvests). By contrast, considering that approximately 33 seedling clusters were planted per square meter in our soilless system, optimizing plant density plant cluster achieved a total cumulative yield of 1.1–3.4 kg m^{-2} within just three harvest cycles. In a floating culture study on parsley, Okudur and Tüzel [2022] reported cumulative fresh yields between 408.8 and 786.9 g m^{-2}. When evaluated on a per-unit-area basis, our results demonstrate that optimizing seed sowing density per tray cell provides a highly effective strategy for achieving competitive unit-area productivity in soilless parsley cultivation. In another study, it was determined that the yield values of parsley grown by sowing at a rate of 1.5 g m^{-2} in a floating tray system varied between 909.3 and 1082.5 g m^{-2} [Duyar and Kılıç 2016]. When the number of seeds per square meter is calculated, it is seen that the yield values of our study are superior to those of direct seed sowing.

Growth and plant physiology

Plant height peaked at 12 plants per cluster (16.2 cm). However, at 15 plants per cluster, a slight reduction in plant height was observed (15.6 cm), which can be attributed to mutual shading and spatial restriction within the tray cell. Sowing density significantly influenced leaf production ($p < 0.05$). Increasing the seed number per cell led to a progressive and linear increase in the total number of leaves. The lowest leaf count was recorded in the 5 plants per cluster treatment (25.0 leaves plant cluster^{-1}), whereas the highest value was achieved in the 15 plants per cluster treatment (57.8 leaves plant cluster^{-1}). Total leaf area expanded continuously in response to higher sowing densities. Leaf area increased from 226.3 cm² in the 5 plants per cluster treatment to 537.2 cm² in the 12 plants per cluster treatment, reaching its maximum value at 669.1 cm² in the 15 plants per cluster treatment. L values decreased with increasing seed density, indicating darker green foliage in denser clusters. The lowest L values were recorded in the 15 (22.3) and 12 (23.0) plants per cluster treatments. Color saturation was highest in the lower density treatments 5 (33.1) and 8 (30.7) plants per cluster and declined to 22.8 at 15 plants per cluster. The highest Hue angle values were obtained from the 8 (214.4) and 12 (215.3) plants per cluster treatments, whereas a decrease was recorded in the 15-seed treatment (187.5). Chlorophyll content (CCI) exhibited a non-linear response to plants per pot density, peaking at 12 plants per cluster (14.7 CCI), followed closely by the 8-seed treatment (14.1 CCI). Increasing the density further to 15 plants per cluster resulted in a notable decline to 11.5

CCI, reflecting severe intra-cell competition for light and nutrient resources. Stomatal conductance was highest in the 12 plants per cluster treatment (351.3 mmol m^{-2} s^{-1}). At 15 plants per cluster, stomatal conductance dropped significantly to 267.4 mmol m^{-2} s^{-1}, indicating physiological stress induced by canopy crowding and reduced light interception (Table 2).

Table 2. The effects of growing parsley plant clusters obtained from different numbers of seeds (5, 8, 12, and 15) in a soilless medium on plant height (cm), leaf number, leaf area (cm^2), leaf color, leaf chlorophyll content (CCI) and stomatal conducance (mmol m^{-2} s^{-1})

Plants number	Plant height	Leaf number	Leaf area	Leaf color			Leaf chlorophyll	Stomatal conductance
				L	Chroma	Hue		
5		25.0	226.3	31.7	33.1	164.1	11.8	308.2
	15.2 ±0.25	±1.28d	±11.3d	±2.80a	±1.73a	±3.25c	±0.96b	±2.72c
8		38.0	438.5	26.1	30.7	214.4	14.1	332.3
	15.6 ±0.72	±0.42c	±11.8c	±1.54ab	±1.32a	±3.45a	±0.51a	±2.63b
12		44.8	537.2	23.0	27.9	215.3	14.7	351.3
	16.2 ±0.14	±0.32b	±1.65b	±1.03b	±2.09ab	±1.46a	±0.47a	±3.06 a
15		57.8	669.1	22.3	22.8	187.5	11.5	267.4
	15.6 ±0.54	±0.58a	±7.54a	±0.98 b	±1.09c	±4.33b	±0.38b	±4.34d

Notes: values, in columns, followed by different letter are significantly different at $p < 0.05$

The results indicated that while biomass yield and biometric parameters (leaf number and leaf area) significantly increased with higher seed density up to 15 plants per cluster, physiological quality traits such as chlorophyll content and stomatal conductance peaked at 12 plants per cluster before declining due to inter-plant competition. Sowing density per cell markedly influenced ($p < 0.05$) both plant height and stomatal conductance (Table 2). Both chlorophyll content and fresh yield were significantly affected by seed density per cell, reaching maximum values at 12 and 15 plants per cluster, respectively (Table 1–2). The morphologically measured values in the seedlings are generally similar to those reported for parsley seedlings by Taşdelen et al. [2021]. Although this decrease was not reflected in yield values, it can be considered an indication that seedling production may be sufficient with 15 plants per cluster.

Regarding foliage development, direct numerical comparisons with soil-based studies must be interpreted in light of fundamental differences in cultivation media, nutrient release dynamics, and planting density. Yılmaz et al. [2024] evaluated organic fertilization regimes in soil cultivation, where slow-release organic nutrient dynamics and unrestricted root zone volume favored individual shoot vigor, resulting in 7.87–10.08 leaves $plant^{-1}$. By contrast, our soilless multi-seedling system utilizes precise mineral fertigation and multi-sowing per cell, where high population density per tray cell drives rapid early canopy closure and maximizes foliage accumulation on a cell-cluster basis (25.0–57.8 leaves $cell^{-1}$). This comparison explicitly illustrates how multi-seedling cluster production in soilless media compensates for individual shoot foliage limits by optimizing spatial canopy efficiency per cell unit. In a study evaluating culinary herbs across different soilless substrates, Anderson et al. [2011] reported that individual parsley plants produced 4.67 to 7.33 leaves per plant over a 10-week growing period. In comparison, our multi-sowing cluster seedling system achieved significantly higher total foliage production per tray cell (25.0 to 57.8 leaves $cell^{-1}$), demonstrating the substantial agronomic advantage of multi-seedling cluster transplanting over single-plant establishment in soilless parsley production. In the study by Yılmaz et al. [2024] leaf area values were reported to range from 143.3 to 276.4 cm^2 plant $cluster^{-1}$. The slightly lower values in our study are thought to be due to the fact that measurements were not taken until the sixth and seventh harvest periods, when the plant is likely to yield more.

In the present study, leaf color parameters were recorded as L* (22.3–31.7), Chroma (C*, 22.8–31.7), and Hue angle (h°, 187.5–215.3). Rather than drawing a direct numerical comparison with soil-based organic cultivation such as the study by Yılmaz et al. [2024], which operated under fundamentally different growing media, organic fertilizer sources, and nutrient availability dynamics, these color values characterize the specific canopy pigmentation and foliage quality developed under controlled soilless fertigation. In

the study conducted by Okudur and Tüzel [2022], leaf color values were reported to be lower than those observed in the present study, which may be attributed to differences in nutrient solution management and light intensity during the cultivation period. Increasing seed density per cell significantly enhanced cumulative shoot density and accelerated early canopy closure, which in turn maximized photosynthetic active radiation (PAR) interception prior to harvest. In multi-sowing cluster seedling systems, higher seed numbers enhance early canopy closure and total light interception per tray cell, thereby accelerating cumulative fresh biomass accumulation prior to harvest [Ballaré and Pierik 2017, Taşdelen et al. 2021]. Similarly, studies on parsley [Duyar and Kılıç 2016], and other leafy greens cultivated in soilless systems such as rocket (*Eruca sativa* Mill.) as well as lettuce (*Lactuca sativa* L.) [Gonnella et al. 2003, Fallovo et al. 2009] demonstrated that increasing cell density promotes early canopy closure and enhances unit-area biomass accumulation before mutual shading induces intra-canopy light competition. However, in our study the higher biomass yield obtained at 15 plant cluster was accompanied by a clear physiological trade-off. As sowing density increased from 12 to 15 plant cluster, leaf chlorophyll content decreased markedly from 14.7 CCI to 11.5 CCI, and stomatal conductance fell from 351.3 to 267.4 mmol m^{-2} s^{-1}. This physiological decline illustrates severe intra-cell competition for light, air circulation, and root zone volume [Gonnella et al. 2003, Fallovo et al. 2009]. In overly dense clusters (15 plant cluster), mutual shading among overlapping leaves reduces photosynthetic active radiation (PAR) penetration to inner canopy layers, suppressing chlorophyll synthesis and inducing partial stomatal closure [Poorter et al. 2012, Ballaré and Pierik 2017].

CONCLUSION

It has been shown that starting parsley cultivation with seedlings is advantageous in terms of yield and quality. It has also been determined that soilless cultivation offers sustainable yield and quality advantages. Increasing the number of seeds sown in a single growing cell in seedling cultivation significantly increases yield. Consequently, while 15 plant cluster yields the highest total fresh biomass, it does not necessarily represent the most desirable condition in terms of seedling quality and photosynthetic efficiency. The 12 plant cluster treatment achieved an optimal balance, providing high fresh yield while maintaining peak chlorophyll concentration (14.7 CCI) and maximum stomatal conductance (351.3 mmol m^{-2} s^{-1}). Therefore, sowing 12 to 15 plants per cell with 12 seeds offering superior physiological vigor is recommended for commercial soilless parsley seedling production. Future research incorporating cost-benefit and economic feasibility analyses regarding optimal seed densities per tray cell will provide crucial insights for maximizing commercial profitability and resource efficiency.

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Not applicable.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

DECLARATION OF THE USE OF GENERATIVE AI IN THE PROCESS OF PREPARING THE PAPER

Notebook LM AI was employed as an assistive proofreading instrument for the article.

AUTHORS' CONTRIBUTIONS

E.M., A.Ç.T – investigation, data curation and visualization; H.Ö. – writing, reviewing, supervision, investigation, methodology, conceptualization, project administration.

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