



Investigating the Effect of Density and Cultivar on Onion Seedling Production in a Floating Culture System

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ABSTRACT

This research, conducted in 2023, identifies onion seedling production key challenges and explores two onion cultivars (Ramhormozi and Primavera) and four density levels {1, 2, 6, and 12 plants in a cell} in a factorial arrangement with three replications. The study focuses on current agricultural practices, the effectiveness of existing methods and the Agricultural factors influencing onion seedling farming such as two treatments cultivar and density. A analysis of variance using SPSS software version 21 revealed that the interaction between cultivar and density had a significant impact on Most of the traits examined. Each trait showed a different response to these two treatments. The highest and lowest leaf area index were observed in the Primavera cultivar at 6 plants (9.4 m²) and 1 plant (0.33 m²), respectively. So that the quantitative changes are 28 fold. The highest fresh aerial height weight was recorded in the Ramhormozi cultivar at 1 plant (7.6 g), while the lowest was in Primavera at 12 plants (1.7 g). The quantitative changes in fresh aerial weight are 4.47 fold. The Primavera cultivar at 1 plant (1.66 mg/g) and 12 plants (0.65 mg/g) had the highest and lowest total chlorophyll content, respectively. The quantitative changes in total chlorophyll are 2.5 fold. Also, The results of the correlation analysis among the studied traits in this experiment revealed significant correlations between the morpho-physiological and biochemical traits. The research demonstrated that hydroponic onion cultivation with Hoagland nutrient solution under two treatments of planting density and cultivar had a significant effect on the growth and functional characteristics of onion seedlings. In general, it can be concluded that marketable and healthy onion seedlings are produced at high densities and in different cultivars using the flotation system. This cultivation method can, as an efficient production system, compensate for the limitations of onion seedling production in uncultivable lands.

ARTICLE

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1. Introduction

Onion is one of the most important economic and medicinal vegetables in the world (Hassanzadeh Khankehdani *et al.*, 2019). This vegetable completes its life cycle in two growing seasons. In the first year, it forms a storage organ called a bulb, and in the second year, by planting the bulb and the emergence of flowering stems, it produces seeds (Wale *et al.*, 2025). By the end of 2022, Iran ranked ninth globally with the production of 1.9 million tons of onions. In the cold northern regions of Iran, onions are cultivated as a summer crop, and the harvest is obtained in late summer and early autumn. The shortage of onions is not noticeable until mid-winter, but from mid to late winter, the market faces limitations in supplying this vegetable. Therefore, to compensate for this shortage and meet societal needs, onions can be produced in the southern regions of Iran, such as Khuzestan, Bushehr, Kerman, and Sistan and Baluchestan provinces, during the autumn and winter seasons (Darabi and Hassanzadeh Khankehdani, 2022). To achieve early maturity, reduce the cultivation period, and increase production per unit area, producers have adopted the practice of planting onion seedlings at high densities in hydroponic systems. The management of production and optimal growth of onion seedlings at high planting densities in this system is influenced by two fundamental factors: cultivar and density, as selecting the appropriate density can lead to better utilization of environmental conditions, optimal expression of the potential of cultivated cultivars, and ultimately increased overall crop efficiency (Jones, 2016; Alamzadeh Ansari, 2010). Therefore, the development of modern seedling cultivation methods in hydroponic systems can play a key role in aligning per capita onion consumption with production levels in the country, as well as enhancing food security and the sustainability of agricultural production during crises (Silipour, 2019; Hassanzadeh Khankehdani *et al.*, 2019). On the other hand Today, this cultivation system has been increasingly developed due to its numerous advantages, such as optimal use of water and nutrient resources, reduced seed consumption, and minimized agricultural operations (Jones, 2016, Soufi *et al.*, 2024 a, Soufi *et al.*, 2024 b). Mouroutoglou *et al* (2021) conducted a study on the effect of soilless cultivation system on the growth, yield and nutrition of an onion cultivar. The aim of this experiment was to compare the effects of different hydroponic cultivation systems on some growth and morphological characteristics of onions and ultimately the water consumption efficiency. The results of their research showed that this cultivation system had a significant effect on (*Allium cepa L.*) So that by choosing the appropriate type of hydroponic cultivation system, onions with the highest fresh and dry weight and with the least water consumption can be produced. Sapkota *et al* (2019) a greenhouse research study was the effects of different nutrient solutions on the growth and weight of two lettuce cultivars buttercrunch and black seeded simpson grown in a floating hydroponic system. They reported that the cultivars responded positively to the nutrient solution in this cultivation system. They also found that high quality produce with maximum morphological and biochemical traits such as weight, root length, chlorophyll and etc. was obtained from the cultivars whose nutrient requirements were met. Rostamfaroudi and Zamani (2022) studied the effect of plant density and planting arrangement on the yield, bulb size, and storage capacity of two edible onion cultivars (Zargan and Morvarid). They found that the Morvarid cultivar at higher densities outperformed Zargan in terms of yield but produced smaller bulbs with lower marketability. Researcher found that new mehods of recipe of nutrient solution can increase morpho-physiological and yield traits in control environmental agriculture (Soufi *et al.*, 2023a; Soufi *et al.*, 2023b; Soufi *et al.*, 2023c). Recently, Roosta *et al* (2025) compared three nutrient solutions (Hoagland, Papadopoulos and Commercial) in hydroponic systems in Arak. They identified Hoagland as the best nutrient solution for greenhouse vegetable cultivation. Their results showed that the use of Hoagland nutrient solution improved the growth of a wide range of plants. Using a floating cultivation system, onion seedlings can be produced in a short period of time. Despite numerous studies on hydroponic vegetable cultivation, the

simultaneous effect of two treatments of cultivar and planting density on onion seedling growth in floating cultivation system has not been fully investigated. Therefore, considering the key role of these two important agronomic factors in onion seedling production and the lack of studies in this field, this study investigates the interaction of these two factors in floating hydroponic system in order to introduce the best and most efficient cultivar and density for economic onion seedling production.

2. Materials and Methods

This research was conducted during the 2023 growing season at the Faculty of Agriculture, Shahid Chamran University of Ahvaz, located at 31° 20' N latitude and 48° 41' E longitude, approximately 20 meters above sea level and an average light intensity 1163 ppfd. To investigate the effect of planting density and cultivar on onion production at the seedling stage in a floating culture system, a factorial experiment was conducted in a randomized complete block design with four seedling densities, two cultivar and three replications. The densities included: 1 plant in a cell, 2 plants in a cell, 6 plants in a cell and 12 plants in a cell. The cultivars tested were an early-maturing Iranian onion (Ramhormozi) and an imported one (Primavera). The seeds were germinated in a cocopeat-perlite (50:50) medium in 105-cell plastic trays and transferred to a floating culture system containing Hoagland nutrient solution with pH 6.4 immediately after sprouting. Seedlings were produced after 60 days under direct sun light in a soilless culture system.

2-1- Measurement of morphological and physiological traits of onion seedlings

2-1-1- Measuring the aerial height and root length

After transferring the seedlings to the laboratory, aerial height and root length were measured using a ruler with an accuracy of 0.1 cm.

2-1-2- Measuring leaf area

In order to measure leaf area, crop leaves were harvested from all cultivars at different densities during the seedling production growth period and the leaf area of each cultivar at four densities was measured using a surface area meter (Delta-T Divides LTD, UK).

2-1-3- Measuring weight traits

The fresh weight aerial, roots and biomass were separately weighed using a digital scale with an accuracy of 0.01 g. The fresh plant samples were then placed in an oven at 70°C for 24 hours to dry. Finally, the dry weight of the samples was measured using a sensitive four-decimal- place scale (0.0001 g).

2-2- Measurement of photosynthetic pigments

The concentrations of chlorophyll a, chlorophyll b, total chlorophyll and carotenoids in leaf tissue were measured using a UV-VIS-1201 spectrophotometer according to the method of Arnon (1967). The samples were read at wavelengths of 480 nm (A480), 645 nm (A645) and 663 nm (A663). The device was calibrated with the relevant solvent (80% acetone) before use. For this experiment, 0.1 g of fresh leaf tissue (W) was separated and 5 mL of 80% acetone was poured onto the leaf tissue. The samples were homogenized and finally brought to a volume of 10 mL. The falcon tubes containing the leaf samples and acetone solvent were then centrifuged at 4500 rpm for 15 minutes. Using the following equations, the amounts of chlorophyll a, chlorophyll b, total chlorophyll and carotenoids were calculated:

Chlorophyll a (mg/g tissue) = $((12.7A_{663} - 2.69A_{645}) \times V) / ((1000 \times W))$

Chlorophyll b (mg/g tissue) = $((22.9A_{645} - 4.68A_{663}) \times V) / ((1000 \times W))$

Total Chlorophyll (mg/g tissue) = $((20.2A_{645} + 8.02A_{663}) \times V) / ((1000 \times W))$

Carotenoids (mg/g tissue) = $((A_{480} + (0.114 A_{663}) - (0.638 A_{645})) \times V) / (1000 \times W)$

Where:

- ✓ A_{480} , A_{645} , A_{663} = Absorbance at wavelengths 480 nm, 645 nm, and 663 nm, respectively.
- ✓ V = Final volume of the extract (mL)
- ✓ W = Fresh weight of the leaf tissue (g)



Figure 1- Ramehramzi cultivar, 1 plant



Figure 2- Ramehramzi cultivar, 2 plants

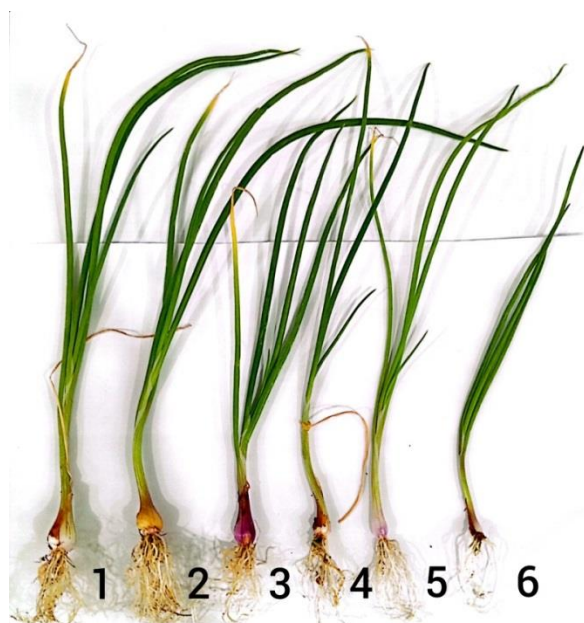


Figure 3- Ramehramzi cultivar, 6 plants



Figure 4- Ramehramzi cultivar, 12 plants



Figure 5- Primavera cultivar, 1 plant



Figure 6- Primavera cultivar, 2 plants

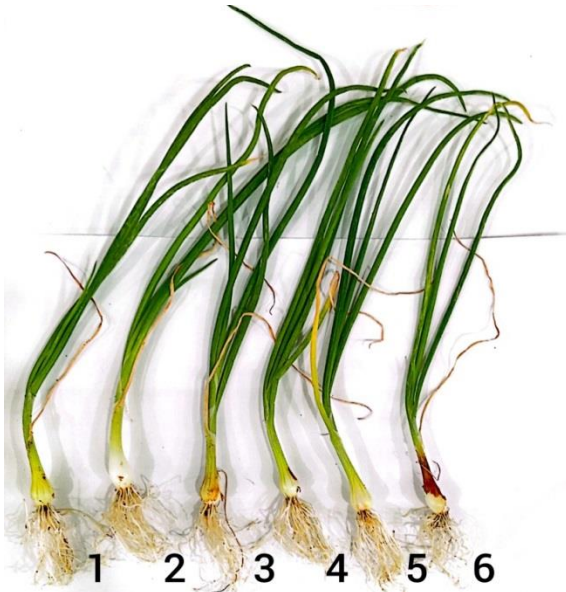


Figure 7- Primavera cultivar, 6 plants



Figure 8- Primavera cultivar, 12 plants

2.3. Data analysis

At the end, the data were analyzed using SPSS software version 21 and means were compared using Duncan's multiple range test.

3. Results and discussion

3.1. Aerial height and root length

The analysis of variance showed that the simple effect of cultivar and the cultivar \times density interaction on aerial height and root length were not significant. However, the simple effect of density on these traits was significant at the 1% level (Table 1). Mean comparison of the simple effect of density on aerial height revealed that the highest aerial height was observed at a density of 1 plant (32.6 cm), which was not significantly different from 2 plants. The lowest aerial height (24.8 cm) was recorded at 12 plants, showing no significant difference from 6 plants (Fig 1). The quantitative changes in the aerial height are 1.3 fold. Regarding root length, the mean comparison of the simple effect of density indicated that the longest roots

(9.2 cm) were observed at 1 plant, with no significant difference from 2 plants. The shortest roots (6.4 cm) were found at 12 plants, which did not differ significantly from 6 plants (Fig 2). The quantitative changes in the root length are 1.4 fold. Similar results were reported by Meless *et al* (2024) and Alemu *et al* (2022) in their studies on the effects of different planting densities on onion growth. Their findings demonstrated that lower planting densities provided more growth space for plants, leading to increased plant height. However, at higher densities, intraspecific competition for growth factors such as light and nutrients resulted in reduced aerial height and root length in onions. This discrepancy may be attributed to the specific genotype of the cultivars, as well as reduced shading and competition among plants at lower densities. Under ideal conditions, seedlings tend to allocate more energy to increasing diameter rather than length.

3.2. Leaf area index

The analysis of variance revealed that both the simple effects of cultivar and planting density, as well as their interaction, had significant ($p < 0.01$) effects on leaf area index (Table 1). Mean comparison of the cultivar \times density interaction for LAI showed that the Primavera cultivar at 6 plants (9.4 m^2) exhibited the highest LAI value. In contrast, the Ramhormozi cultivar at 1 plant (0.33 m^2) had the lowest LAI, which was not significantly different from Primavera at 1 and 2 plants or Ramhormozi at 2 plants (Table 2). The quantitative changes in leaf area index are 28 fold. These findings are consistent with the research of Rautela *et al* (2025), who found in their study on Spinach production in hydroponic cultivation systems that the soilless cultivation system had a significant effect on leaf area index. Jadhav *et al* (2025), who reported that leaf area was significantly influenced by both main and interactive effects of cultivar and planting density. The higher plant density likely enhanced photosynthetic efficiency through greater light interception and CO_2 assimilation by the increased number of leaves, ultimately leading to greater leaf area development. Furthermore, their study demonstrated that Lettuce and Basil cultivars with different genetic backgrounds exhibited distinct responses to varying planting densities.

3.3. Fresh and dry weight aerial, roots, and biomass

Analysis of variance revealed that: the simple effect of cultivar was non-significant for fresh weight aerial, root and biomass. Cultivar showed significant effects ($p < 0.01$) on dry weight all measured parts. Both planting density and the cultivar \times density interaction significantly affected ($p < 0.01$) all fresh and dry weight parameters (Table 1). Aerial weight. The cultivar \times density interaction for fresh aerial weight shown Ramhormozi at 1 plant had maximum fresh aerial weight (7.6 g). Primavera at 12 plants showed minimum fresh aerial weight (1.7 g), statistically similar to Ramhormozi at 1 plant (Table 2). The quantitative changes in fresh aerial weight are 4.47 fold. For dry aerial weight Ramhormozi at 1 plant recorded highest dry weight (2.3 g). Primavera at 12 plants had the lowest dry weight (0.14 g), not differing significantly from Ramhormozi at the same density (Table 2).

Table 1 Variance analysis of cultivar (C) and density (D) effects on morpho-physiological characteristics

Source of variance	DF	AH	RL	LAI	FWA	DWA	FWR	DWR	FWB	DWB
Replication	2	25.1	20.2	5.3	3.7	0.03	0.11	0.001	5.1	0.04
C	1	41ns	2.2ns	33.3**	1.5ns	0.04**	0.01ns	0.002**	1.1ns	0.06**
D	3	214.5**	14.3**	61**	21.1**	6.2**	7.9**	1.5**	33.1**	5.9**
D × C	3	17.6ns	1.5ns	21.8**	3.7**	0.03**	0.01**	0.001**	4.1**	0.04**
Error	14	14.8	0.81	0.87	0.36	0.003	0.01	0	0.51	0.004
CV (%)		12.8	11.3	27.5	17.5	6.6	11.6	1.9	18.1	7.3

Continues of Table 1

Source of variance	DF	Cha	Chb	Total Ch	Carotenoid
Replication	2	3.8	0.01	2.7	3.2
C	1	0.002**	0.1 ^{ns}	0.26**	7.01 ^{ns}
D	3	0.09**	0.1**	0.58**	0**
D × C	3	0.17**	0.16**	0.23**	6.3**
Error	14	0	0.21	0	4.6
CV (%)		0.43	29	0.32	6.4

** , * , ns: significant effect at 1% , 5% and no significant effect, respectively. AH- Arial height, RL- Root length, LAI- Leaf area index, FWA- Fresh weight aerial, DWA- Dry weight aerial, FWR- Fresh weight Root, DWR- Dry weight Root, FWB- Fresh weight biomas, DWB- Dry weight biomas, FWA M²- Fresh weight aerial in square meter, DWA M²- Dry weight aerial in square meter, FWR M²- Fresh weight Root in square meter, DWR M²- Dry weight Root in square meter, FWB M²- Fresh weight biomas in square meter, DWB M²- Dry weight biomas in square meter, Cha- chlorophyll a, Chb- chlorophyll b, Total Ch- total chlorophyll.

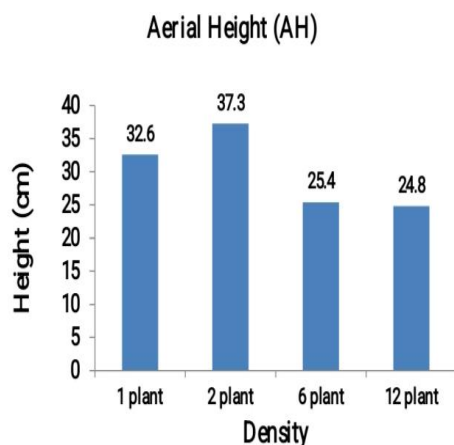


Fig 1. The effect of density on aerial height

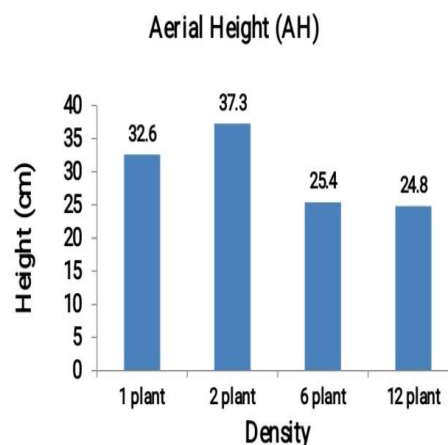


Fig 1. The effect of density on aerial height

Table 2- Results of comparison of the average effects of cultivar (C) and density (D) on some growth traits of onion seedlings in floating culture medium

Treatment	LAI (m ²)	FWA (g)	DWA (g)	FWR (g)	DWR (g)	FWS (g)	DWS (g)
C							
R	2.2b	3.6a	0.89a	1.05b	0.62b	4.1a	0.94a
P	4.5a	3.1b	0.80b	1.1a	0.64a	3.7b	0.84b
D							
1 plant	0.33b	2.3c	2.3a	2.3a	1.3a	2.3c	2.3a
2 plant	0.98b	6a	0.53b	1.1b	0.09b	7.2a	0.63b
6 plant	5.5a	3.5b	0.34c	0.54c	0.05c	4b	0.39c
12 plant	6.6a	1.8c	0.16d	0.26d	0.03d	2c	0.19d
C × D							
R × 1 plant	0.33d	7.4a	2.3a	2.3a	1.3a	8.6a	2.3a
R × 2 plant	1.1d	2.3de	0.68b	1.17b	0.12b	2.3de	0.81b
R × 6 plant	4.6c	3cd	0.35c	0.44cd	0.052cd	3.3cd	0.40c
R × 12 plant	5.6c	1.9e	0.18d	0.23d	0.03de	2.1e	0.21d
P × 1 plant	0.33d	2.3de	2.3a	2.3a	1.3a	2.3de	2.3a
P × 2 plant	0.77d	4.6b	0.38c	1.13b	0.06c	5.8b	0.45c
P × 6 plant	9.4a	4bc	0.33c	0.64c	0.051cd	4.6bc	0.38c
P × 12 plant	7.6b	1.7e	0.14d	0.29d	0.02e	2e	0.16d

The same letters indicate there is no significant difference at $p \leq 0.05$. R- Ramhormozi, P- Primavera, AH- Aerial Height, RL- Root Length, LEI- Leaf area index, FWA- Fresh weight aerial, DWA- Dry weight aerial, FWR- Fresh weight Root, DWR- Dry weight Root, FWB- Fresh weight biomass, DWB- Dry weight biomass.

The quantitative changes in dry aerial weight are 16.4 fold. Fresh root weight results indicated Ramhormozi at 1 plant achieved maximum fresh root weight (2.3 g) Minimum fresh root weight (0.23 g) occurred in Ramhormozi at 12 plants (Table 2). The quantitative changes in fresh root weight are 10 fold. Dry root weight analysis shown: Ramhormozi at 1 plant had peak dry root weight (1.3 g) Primavera at 12 plants showed minimum dry root weight (0.02 g) (Table 2). The quantitative changes in dry root weight are 65 fold. For fresh biomass Ramhormozi at 1 plant yielded maximum fresh biomass (8.6 g) Primavera at 12 plants produced minimum fresh biomass (2 g) (Table 2). The quantitative changes in fresh biomass are 4.3 fold. Ramhormozi at 1 plant showed highest dry biomass (2.3 g) Primavera at 12 plants had the lowest dry biomass (0.16 g) (Table 2). The quantitative changes in dry biomass are 14.3 fold.

3.4. Fresh and dry weight aerial, roots, and biomass per Square Meter

The results of the analysis of variance showed that the simple effect of cultivar on the fresh weight aerial and biomass per square meter was not significant, but it was significant at the 1% level for the fresh weight roots per square meter and the dry weight aerial and biomass per square meter. However, it was significant at the 5% level for the dry weight of roots per square meter. The simple effect of density was significant at the 1% level for all traits. The interaction between cultivar and density was significant at the 1% level for the fresh weight of aerial parts and biomass per square meter and at the 5% level for the fresh weight of roots per square meter. However, it was not significant for the dry weight aerial, roots and biomass per square meter (Table 1). The mean comparison results showed that the Ramhormozi cultivar at 12 plants/m² (19,268 g) had the highest fresh weight aerial per square meter, while the Primavera cultivar at 1 plant/m² (1,888 g) had the lowest, which did not differ significantly from the Ramhormozi cultivar at 1 plant/m² (Table 3). The quantitative changes in fresh weight aerial per square meter are 10.2 fold. The highest dry weight aerial per square meter was observed in the Ramhormozi cultivar (1,607.6 g) at 12 plants/m² (1,888 g). The lowest was in the Primavera cultivar (1,370.1 g) at 1 plant/m² (862.2 g) (Table 3). The quantitative changes in dry weight aerial per square meter cultivar are 1.17 fold and density are 2.1 fold. The mean comparison results showed that the highest fresh root weight per square meter was observed in the Ramhormozi cultivar at 12 plants/m² (3,106.6 g), which did not differ significantly from the Primavera cultivar at 12 plants/m². The Primavera cultivar at 1 plant/m² (1,888 g) had the lowest fresh root weight, which did not differ significantly from the Ramhormozi cultivar at 1 plant/m² (Table 3). The quantitative changes in fresh root per square meter are 1.6 fold. The highest dry root weight per square meter was observed in the Ramhormozi cultivar (663.3 g) at 12 plants/m² (1,888 g). The lowest was in the Primavera cultivar (626.8 g) at 1 plant/m² (151.3 g) (Table 3). The quantitative changes in dry root weight per square meter cultivar are 1.05 fold and density is 12.47 fold. The results showed that the Ramhormozi cultivar at 12 plants/m² (22,374.6 g) had the highest fresh biomass weight per square meter, while the Primavera cultivar at 1 plant/m² (1,888 g) had the lowest (Table 2). The quantitative changes in fresh biomass weight per square meter are 11.8 fold. The highest dry biomass weight per square meter was observed in the Ramhormozi cultivar (1,799 g) at 12 plants/m² (1,848.7 g) and the lowest was in the Primavera cultivar (1,524.9 g) at 1 plant/m² (1,008 g) (Table 3). The quantitative changes in dry biomass weight per square meter cultivar are 1.17 fold and density are 1.83 fold. Ryan *et al* (2024), in a study on the effect of three plant densities (10 × 10, 10 × 15 and 20 × 15 cm) and four nitrogen levels (0, 50, 100 and 150 kg of nitrogen per hectare) on onion growth and yield in Afghanistan, reported that the highest onion weight and yield were observed at the highest planting density (10 × 10 cm). However, the weight per plant increased at lower densities, which aligns with our findings. This, in addition to the genetic diversity of onion cultivars and the higher number of plants at higher densities, may also be influenced by environmental conditions and the type of nutrient solution. Ghasemi *et al* (2024) also obtained similar results in their evaluation of two yellow and white onion cultivars.

Table 3 Results of comparison of the average effects of cultivar (C) and density (D) on some growth traits of onion seedlings in floating culture medium

Treatment	FWAM ² (g)	DWAM ² (g)	FWRM ² (g)	DWRM ² (g)	FWBM ² (g)	DWBM ² (g)
C						
R	11734a	1607.6a	2047.6b	663.3a	13309.6a	1799a
P	11303b	1370.1b	2418.6a	626.8b	13249.6b	1524.9b
D						
1 plant	1888c	1888a	2582.6a	1888a	20079.3a	1848.7a
2 plant	9673.3b	1648.6b	2614a	292b	19630a	1897.6a
6 plant	17016a	1556.6c	1848b	248.9c	11521.3b	1113.5b
12 plant	17496.6a	862.2d	1888b	151.3d	1888c	1008c
C × D						
R × 1 plant	1888e	523.2e	1888c	268.8bc	1986d	676de
R × 2 plant	11880c	1106.1c	1882.6b	200d	16885.3bc	1301.7c
R × 6 plant	14764bc	1686.6a	2298.6b	249.8cd	20702.6ab	1936.4ab
R × 12 plant	19268a	1754.6a	3106.6a	1888a	22374.6a	2069.8a
P × 1 plant	1888e	523.2e	1888c	102.2e	1888e	635e
P × 2 plant	7466.6d	623.1d	1813.3b	160.6de	13762.2c	725.4d
P × 6 plant	15268ab	1610.6ab	2510.3ab	248cd	19456ab	1858.7ab
P × 12 plant	16589.3ab	1358.6bc	2886.6a	315.2b	1901ab	1627.5bc

The same letters indicate there is no significant difference at $p \leq 0.05$. R- Ramhormozi, P- Primavera, FWA M²- Fresh weight aerial in square meter, DWA M²- Dry weight aerial in square meter, FWR M²- Fresh weight Root in square meter, DWR M²- Dry weight Root in square meter, FWB M²- Fresh weight biomass in square meter, DWB M²- Dry weight biomass in square meter.

3.5. Photosynthetic pigments

The results of the analysis of variance showed that the simple effect of cultivar on chlorophyll b and carotenoids was not significant, but it was significant at the 1% level for chlorophyll a and total chlorophyll. The simple effect of density and the interaction between cultivar and density were significant at the 1% level for chlorophyll a, chlorophyll b, total chlorophyll, and carotenoids (Table 1). The mean comparison results showed that the Primavera cultivar at 1 plant (0.94 mg/g) had the highest chlorophyll a content, while at 12 plants (0.34 mg/g), it had the lowest (Table 4). The quantitative changes in chlorophyll a are 2.76 fold. The highest chlorophyll b content was observed in the Primavera cultivar at 1 plant (0.71 mg/g) and the lowest was at 12 plants (0.13 mg/g) (Table 4). The quantitative changes in chlorophyll b are 5.4 fold. The highest total chlorophyll content was observed in the Primavera cultivar at 1 plant (1.66 mg/g) and the lowest was in the Primavera cultivar at 12 plants (0.65 mg/g) (Table 4). The quantitative changes in total chlorophyll are 2.5 fold. The interaction between cultivar and density on carotenoids showed that the Primavera cultivar at 1 plant (0.04 mg/g) had the highest carotenoid content, which did not differ significantly from the Primavera cultivar at 2 plants. The Primavera cultivar at 12 plants (0.02 mg/g) had the lowest carotenoid content (Table 4). The quantitative changes in carotenoid are 2 fold. Our investigations showed that photosynthetic pigments were influenced by Floating culture system and both agronomic factors, cultivar and density. The Primavera cultivar at lower densities had the highest chlorophyll and carotenoid content. This may be due to the specific genetics of this vegetable in our region, the lower number of plants, less shading, greater light penetration and higher photosynthetic activity. The findings of Cekin *et al* (2025) on Assessing different hydroponic subsystems for Batavia lettuce growth under two planting density (20 × 25 cm) and (24 × 25 cm) treatments showed that the cropping system and plant density had a direct effect on lettuce growth. In general, plants grown at lower densities had higher chlorophyll content than those grown at higher densities, leading to higher quality lettuce production. Also, Kumar *et al* (2015) reported the highest chlorophyll content at lower densities. They found that at lower densities, due to less competition among plants for nutrient absorption and sunlight, as well as more available space, chemical composition improved.

Table 4- Results of comparison of the average effects of cultivar (C) and density (D) on some Biochemical traits of onion seedlings in floating culture medium

Treatment	Cha (mg/g)	Chb (mg/g)	Total Ch (mg/g)	Carotenoid (mg/g)
C × D				
R × 1 plant	0.40g	0.16c	0.9f	0.02d
R × 2 plant	0.79c	0.43b	1.1d	0.02d
R × 6 plant	0.73e	0.51ab	1.3b	0.03c
R × 12 plant	0.40g	0.46b	1.2c	0.03c
P × 1 plant	0.94a	0.71a	1.66a	0.04a
P × 2 plant	0.82b	0.56ab	1.66a	0.034b
P × 6 plant	0.58f	0.35bc	0.94e	0.03c
P × 12 plant	0.34h	0.13c	0.65g	0.02d

The same letters indicate there is no significant difference at $p \leq 0.05$ R- Ramhormozi, P- Primavera, Cha- chlorophyll a, Chb- chlorophyll b, Total Ch- total chlorophyll.

Table 5 Correlation coefficients among some traits

	1	2	3	4	5	6	7	8	9	10
1	1									
2	0.68**	1								
3	0.30	-0.37	1							
4	0.83**	0.54**	-0.16	1						
5	-0.16	0.46*	-0.56**	-0.14	1					
6	0.01	0.62*	-0.61*	0.08	0.95**	1				
7	-0.29	0.36	-0.50*	-0.29	0.98**	0.91**	1			
8	0.82**	0.51**	-0.13	0.99**	-0.21	0.02	-0.36	1		
9	-0.13	0.48*	-0.57**	-0.10	0.99**	0.96**	0.98**	0.17	1	
10	0.34	-0.28	0.82**	0.12	-0.79**	-0.82**	-0.79**	0.15	-0.79**	1
11	-0.007	0.12	0.19	-0.34	0.44*	0.26	0.47*	-0.40*	0.44*	0.12
12	0.36	0.04	0.85**	0.17	-0.33	-0.35	-0.32	0.03	-0.34	0.75
13	-0.031	0.33	-0.43	-0.34	0.97**	0.87**	0.99**	-0.41*	0.96**	-0.72**
14	0.35	-0.028	0.82**	0.14	-0.81**	-0.82**	-0.80**	0.17	-0.80**	0.99**
15	0.06	0.04	0.35	-0.30	0.22	0.03	0.25	-0.35	0.21	0.35
16	-0.23	-0.22	0.26	-0.27	-0.12	-0.30	-0.08	-0.30	-0.12	0.31
17	-0.27	-0.25	0.31	-0.26	-0.19	-0.33	-0.15	-0.26	-0.20	0.32
18	0.07	-0.31	0.17	0.06	-0.73**	-0.63**	-0.71**	0.14	-0.73**	0.32
19	-0.35	0.11	-0.18	-0.46*	-0.69**	-0.53**	0.73**	-0.51**	0.67**	-0.37

Table 5 Continuation- Correlation coefficients among some traits

	11	12	13	14	15	16	17	18	19
11	1								
12	0.42*	1							
13	0.56**	-0.25	1						
14	0.09	0.76**	-0.74**	1					
15	0.97**	0.55**	0.34	0.32	1				
16	0.35	0.23	-0.02	0.29	0.43*	1			
17	0.22	0.26	-0.10	0.31	0.30	0.85**	1		
18	-0.61**	0.09	-0.72**	0.39	-0.47**	0.22	0.22	1	
19	0.71**	-0.01	0.76**	-0.40*	0.57**	0.08	0.006	-0.75**	1

**Correlation is significant at the 0.01 level, *Correlation is significant at the 0.05. N = 12, 1- Height, 2- Root length, 3- Leaf area index, 4- Fresh weight aerial, 5- Dry weight aerial, 6- Fresh weight Root, 7- Dry weight Root, 8- Fresh weight biomass, 9- Dry weight biomass, 10- Fresh weight aerial in square meter, 11- Dry weight aerial in square meter, 12- Fresh weight Root in square meter, 13- Dry weight Root in square meter, 14- Fresh weight biomass in square meter, 15- Dry weight biomass in square meter, 16- chlorophyll a, 17- chlorophyll b, 18- total chlorophyll and 19- carotenoids.

3.6. Correlation coefficients among some traits

The results of the correlation analysis among the studied traits in this experiment revealed significant positive and negative correlations between the traits. The aerial height showed a positive correlation at the 1% significance level with traits such as root length (0.68), fresh weight aerial (0.83) and fresh biomass weight (0.82) (Table 5). Root length exhibited a positive correlation at the 1% significance level with the fresh weight aerial (0.54) and fresh biomass weight (0.51) and at the 5% significance level with the dry weight aerial (0.46), fresh root weight (0.62) and dry biomass weight (0.48) (Table 5). The leaf area index showed correlations at the 1% significance level with the dry weight aerial (-0.56), dry biomass weight (-0.57), dry weight aerial per square meter (0.82), fresh root weight per square meter (0.85), and fresh biomass weight per square meter (0.82) and at the 5% significance level with fresh root weight (-0.61), dry root weight (-0.50) and dry biomass weight (-0.57) (Table 5). The fresh weight aerial part was correlated at the 1% significance level with aerial height (0.68), root length (0.54) and fresh biomass weight (0.99) and at the 5% significance level with carotenoids (-0.46) (Table 5). The dry weight aerial showed correlations at the 1% significance level with leaf area index (-0.56), fresh root weight (0.95), dry root weight (0.98), dry biomass weight (0.99), fresh weight aerial per square meter (-0.79), dry root weight per square meter (0.97), fresh biomass weight per square meter (-0.81), total chlorophyll (-0.81) and carotenoids (-0.69) and at the 5% significance level with root length (0.46) and dry weight of the aerial part per square meter (0.44) (Table 5). The fresh root weight exhibited correlations at the 1% significance level with dry root weight (0.99), dry biomass weight (-0.82), dry root weight per square meter (0.87), fresh biomass weight per square meter (-0.82), total chlorophyll (-0.63) and carotenoids (0.53) and at the 5% significance level with root length (0.62) and leaf area index (-0.61) (Table 5). The dry root weight per square meter showed correlations at the 1% significance level with dry weight aerial (0.98), fresh root weight (0.91), dry biomass weight (0.98), fresh weight aerial per square meter (-0.79), dry root weight per square meter (0.99), fresh biomass weight per square meter (-0.80), total chlorophyll (-0.71) and carotenoids (0.73) and at the 5% significance level with leaf area index (-0.50) and dry weight aerial per square meter (0.47) (Table 5). The fresh biomass weight exhibited correlations at the 1% significance level with aerial part height (0.82), root length (0.51), fresh weight aerial (0.99) and carotenoids (-0.41) and at the 5% significance level with dry weight aerial per square meter (-0.40) and dry root weight per square meter (-0.41) (Table 5). The dry biomass weight showed correlations at the 1% significance level with leaf area index (-0.57), fresh root weight (0.96), dry root weight (0.98), fresh weight aerial per square meter (-0.79), dry root weight per square meter (0.96), fresh biomass weight per square meter (-0.80), total chlorophyll (-0.73) and carotenoids (0.67) and at the 5% significance level with root length (0.48) and dry weight aerial per square meter (0.44) (Table 5). The fresh weight aerial per square meter exhibited correlations at the 1% significance level with leaf area index (0.82), dry root weight (-0.79), dry biomass weight (-0.79), dry root weight per square meter (-0.72) and fresh biomass weight per square meter (0.99) and at the 5% significance level with dry weight aerial (-0.79) and fresh root weight (-0.82) (Table 5). The dry weight aerial per square meter showed correlations at the 5% significance level with dry weight aerial (0.44), dry root weight (0.47), fresh biomass weight (-0.40) and dry biomass weight (0.44) (Table 5). The fresh root weight per square meter exhibited correlations at the 1% significance level with leaf area index (0.85) and at the 5% significance level with dry weight aerial per square meter (0.42) (Table 5). The dry root weight per square meter showed correlations at the 1% significance level with dry weight aerial (0.97), fresh root weight (0.87), dry root weight (0.99), dry biomass weight (0.96), fresh weight of the aerial part per square meter (-0.72) and dry weight of the aerial part per square meter (0.56) and at the 5% significance level with fresh biomass weight (-0.41) (Table 5). The fresh biomass weight per

square meter exhibited correlations at the 1% significance level with leaf area index (0.82), dry weight aerial (-0.81), fresh root weight (-0.82), dry root weight (-0.80), dry biomass weight (-0.80), fresh weight aerial per square meter (0.99), fresh root weight per square meter (0.76) and dry root weight per square meter (-0.74) (Table 5). The dry biomass weight per square meter showed correlations at the 1% significance level with dry weight aerial per square meter (0.97) and fresh root weight per square meter (0.55) (Table 5). Chlorophyll a exhibited correlations at the 5% significance level with dry biomass weight per square meter (0.43) (Table 5). Chlorophyll b showed correlations at the 1% significance level with chlorophyll a (0.85) (Table 5). Total chlorophyll exhibited correlations at the 1% significance level with dry weight aerial (-0.73), fresh root weight (-0.63), dry root weight (-0.71), dry biomass weight (-0.73), dry weight of the aerial part per square meter (-0.61), dry root weight per square meter (-0.72) and dry biomass weight per square meter (-0.47) (Table 5). Carotenoids showed correlations at the 1% significance level with fresh weight aerial (-0.46), dry weight of the aerial part (-0.69), fresh root weight (0.53), dry root weight (0.73), fresh biomass weight (-0.51), dry biomass weight (0.67), dry weight of the aerial part per square meter (0.71), dry root weight per square meter (0.76), fresh biomass weight per square meter (0.57) and total chlorophyll (-0.75) (Table 5). Santos *et al* (2021) reported significant correlations between the Tokyo Kuro green onion cultivar grown in soilless culture and certain morphological traits. Brewster (2008) demonstrated through correlation analysis that high planting density reduces root growth while increasing plant height, though this height increase comes at the expense of reduced stem diameter. Resh (2022) found significant correlations between planting density and various morphological characteristics. At higher densities, competition for nutrients led to reduced bulb diameter in onions, consequently decreasing both fresh and dry plant weight. Jiang *et al* (2017) and soufi *et al* (2023 b) noted that increased leaf area enhances photosynthetic activity and carbohydrate production, significantly impacting plant weight. This relationship becomes particularly pronounced in soilless cultivation systems with artificial lighting. However, at high planting densities, excessive shading between plants may reduce photosynthetic efficiency. Kasim (2014) revealed significant correlations between chlorophyll a, b, and total chlorophyll content in tomato leaves during vegetative growth. Renna (2017) observed that at densities exceeding 30 plants/m², chlorophyll a content decreased by up to 20% due to reduced light availability, which inhibits chlorophyll and carotenoid synthesis. Supplemental growth factors can help maximize photosynthetic pigment production under these conditions.

Conclusion

This study investigated vegetative growth, root development and initial bulb formation in a low-cost hydroponic system. Conducted as a pioneering winter trial in India under open-roof conditions with natural sunlight, the system yielded promising results. Considerable variation existed across cultivars for most measured parameters. Increasing planting density increased leaf area index, increased shoot fresh weight, increased fresh biomass, increased dry biomass and improved root fresh weight per square meter. Ramhormozi produced heavier seedlings than Primavera, Plant height remained unaffected by higher densities, seedling quality was maintained across density treatments. Optimal light and temperature conditions during Khuzestan's autumn and winter likely contributed to these outcomes. Plant genetics significantly determined seedling size. Maximum photosynthetic pigments occurred in Primavera the floating hydroponic system demonstrated superior performance for: overall vegetative growth, root development, early bulb initiation, faster bulb development, improved plant establishment, enhanced pungency with reduced sweetness compared to soil - based systems. This cost-effective floating hydroponic technique offers: suitable for rooftop gardens, patios and balconies. Also, ideal for vertical farming, enables earlier harvests,

improves market yields, commands better market prices, simple management, low maintenance costs, reduced production expenses and facilitates early harvesting - is a critical factor for onion growers. Future Directions: further testing across different locations and conditions could help: optimize the system, increase overall onion production, better meet market demands. this innovative approach shows significant promise for helping future farmers enhance productivity while maintaining quality standards.

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