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RESEARCH ARTICLE

Assessing lettuce genotypes for yield and quality under aeroponic systems: Toward sustainable nutri-dense urban food production

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Abstract

A evaluation of 5 lettuce (*Lactuca sativa* L.) varieties (Summer Star, Grand Rapid, Tango, Bingo and Black Rose) was carried out at ICAR-Central Institute for Subtropical Horticulture's experimental block in Rehmankhera, Lucknow (Uttar Pradesh) India during 2021 to 2022 to assess the phenotypic variability among them in respect of growth and quality parameters under uniform agronomic conditions in aeroponic system. Significant differences were recorded in morphological traits including plant weight, plant height, leaf length and width, total leaf weight, stem diameter, root characteristics, number of leaves per plant, leaf area index and yield. Bingo showed the highest plant (345.50 g) and leaf weight (293.25 g), imputed its compact leaf structure while Tango represented highest plant height (29.25 cm), leaf length (23.01 cm), root length (41.23 cm), leaf area index (1.03), number of leaves (25.83) and total chlorophyll content (0.68 mg/g FW), refereeing strong vegetative vigour. Summer Star observed the highest yield (213.15 q/ha), along with superior leaf width, stem diameter and root weight, suggesting better overall biomass accumulation. Quality traits also have significant variation among the varieties. Black Rose recorded the highest vitamin C (15.80 mg/100 g) and total carotenoids (7.97 mg/100 g), may be due to its red pigmentation. While chlorophyll a content was not significantly observed, chlorophyll b and total chlorophyll value varied significantly among varieties, with Tango and Black Rose performing best. Dry matter content showed no significant variation among the varieties, while it is an important post-harvest trait. The findings highlight the substantial phenotypic variability among lettuce varieties, offering valuable insight for breeding programs focused on improving yield, market appeal and nutritional quality under aeroponic system. This study reinforces the importance of strategic varietal selection for enhancing lettuce productivity and functional quality also aeroponic system where provided the uniform soil media and environment condition retreated the value of germplasm collection and evolution for further breeding program.

Keywords: aeroponic system; lettuce; quality; variability; varieties; yield

Introduction

Lettuce (*Lactuca sativa* L.) belong to family Asteraceae and assume originated from Mediterranean region (1). It is widely recognised as leafy vegetable globally (2). It is most extensively cultivated and produced salad leaf vegetables among others salad vegetables. It is being popular in winter season in subtropical areas of metropolitan cities in India and growers gets high market value of their produce. Green leafy vegetables are used as raw in salad diets as well as for culinary applications worldwide with exceptional nutritional benefits (3).

It contains 94–95 % water and low in calories, making it a hydrating and light food choice (4). It is also a rich source of vitamins such as Vitamin A, C, B, K and minerals such as Ca, iron, magnesium, potassium and sodium and bioactive compounds like polyphenols, carotenoids and chlorophyll, which contribute to various health benefits (5). It is rich in antioxidant compound helped in reducing risk of chronic diseases, including cancer and cardiovascular conditions (6). Lettuce also considered as rich source of secondary metabolites, including phenolic compounds, flavanols, phenolic acids, carotenoids, ascorbic acid and folate, all of which contribute to promoting health (7). Previous researchers reported that lettuce leaves are widely used in various dishes, including soups, juices, salads, wraps, sandwiches and processed foods (8). Acknowledging the significant nutritional benefits of fruits and vegetables, as per recommendation of World Health Organization (WHO) a minimum daily intake of 400 g to help prevent chronic diseases (9).

With the continued growth of the world population, agriculture farming is facing huge pressures from urbanisation and pre urbanisation, industrialisation and climate change. These factors collectively sabotage the sustainability of traditional soil-based farming systems (10). Notable challenges include the progressive decline in soil fertility, reducing microbial activity due to intensive and continuous farming. moreover, these activities also responsible for increased frequency of drought events and greater variability in weather conditions (11). Additionally, upraised ambient temperatures, contamination of surface water bodies, inefficient irrigation practices make more vulnerable agricultural practices (12). In western and developed countries soilless cultivation is becoming popular. Aeroponics, aquaponics and hydroponics are innovative soilless cultivation techniques that improve productivity while ensuring efficient use of resources. These soilless techniques incorporate advanced technology of input and output management with least harm to the environment (13). In addition, it also reduces human interaction by adopting sensing, monitoring, automation and regulation of system use in this method (14).

Aeroponics, is a potential advance technology, which is proven may be alternative to traditional farming in cities and its periphery by cultivation of high value crops in an enclosed nutrient -rich mist chamber. It seems to appear more useful for cultivating high value vegetable crops like lettuce, cucumber, melon, tomato, herbs, potato and floral crops (15).

Numerous studies have demonstrated that aeroponics significantly enhances plant growth rates by optimising root aeration where the plant roots are suspended in air and misted with a nutrient-rich water solution, plants utilize 100 % of the oxygen available in the atmosphere (16). These growing systems offer numerous advantages over traditional cultivation methods, including the absence of soil-borne pathogens, pest control more manageable, fertilisers in more efficiently, reduced labor costs, minimized risk from natural conditions, increased yield, improved quality. It also offers the opportunity to cultivate certain plants out of season while preventing nutrient leaching into the environment (17). These systems can offer a sustainable solution to overcome agricultural farming challenges such as water scarcity, soil depletion and environmental degradation. These methods significantly increase water use efficiency up to maximum level and minimise the need for inorganic fertilisers and may provide a great window for efficient space-saving urban farming for high value crops. As well as timely optimised nutrient delivery and chemical free fresh products for urban population. Furthermore, this system can optimise food security by enabling year-round with reducing the carbon footprint associated with transportation. Although it also requires technological advancements continue to improve system efficiency and makes farmers affordable (18).

The primary objectives of the present study were to evaluate and compare the performance of different lettuce (*L. sativa*) varieties cultivated under aeroponic conditions. This involved estimate and observe the key growth traits like yield and yield attributing traits, dry matter content, ascorbic acid, total carotenoid content and chlorophyll. The aim was to identify varietal differences in adaptability and productivity within the aeroponic system, thereby providing insights into optimising crop selection for soilless cultivation frameworks.

Materials and Methods

Description of experimental site and environmental conditions

To identify lettuce varieties that produce higher-quality yields in aeroponic systems under subtropical climates, the experiment was conducted at ICAR-Central Institute for Subtropical Horticulture (CISH) in experimental block, Rehmankhera, Lucknow (Uttar Pradesh) India during 2021 to 2022. The experimental site is situated between 26°45' to 27°10' N latitude and 80°30' to 80°5' E longitude, at an elevation of 123 m above sea level (Fig.1). The experimental site falls within a subtropical climate zone, characterised by hot and dry summers and cool distinct winter. The southwest monsoon typically occurs from July to September (3 month) with average rainfall 927 mm in 2021–2022. During May and June, the average maximum temperature ranges between 40 °C and 45 °C, while under polyhouse conditions, temperatures from November 2021 to February 2022 vary, with maximum temperature between 23 °C to 29 °C and minimum temperature ranging from 7 °C to 13 °C (Central Ground Water Board, 2022). Additionally, relative humidity during the cropping season fluctuates, with maximum 82 % to 92 % and minimum levels ranging from 45 % to 68 % (Fig. 2).

Lettuce growing system using aeroponic technology

The aeroponic unit was set up inside a polyhouse equipped with an automated atmospheric control system (Fig. 3). The roof was fully covered with a 200-micron UV- stabilised polyethylene sheet, all those the side walls were constructed using either a 200-micron UV- stabilised polyethylene sheet or insect-proof netting. To maintain optimal experimental conditions, the interior was fitted with silver shade nets, fans, a cooling pad and misting system. The units were designed in an A-frame structure, with dimensions of 1.4 m in width, 1.4 m in hight and 6 m in length.

Selection of variety, nutrient solution, growing media and sowing

In 1st week of October, lettuce varieties; Summer Star, Grand Rapid, Tango, Bingo and Black Rose were sown in portrays using a prepared mixture. The mixture consisting of peat, vermiculite and perlite in a ratio of 3:1:1 (volume basis) and the mixture were sterilised using a 0.02 % hydrogen peroxide solution. The seeds were collected from ICAR-Central Institute of temperate horticulture, Srinagar, India. Once the plants developed 4–5 leaves (in 30 days), they were transferred to an aeroponic system within a polyhouse in 1st week of November (Fig. 3). The planting density was maintained at 25 plants per square meter, with each plant spaced 20 × 20 cm apart. After transplanting the crop into the aeroponic system, the plants undergo treatment with a 3x CISH nutrient solution CISH A and CISH B designed for leafy vegetables. One litter of nutrient solutions were added to each water tank under aeroponic system. In this automated aeroponic system, each nutrient rich misting session starts for 1 min in every 30 min interval. The temperature of nutrient solution was maintained between 15–18 °C, with an electrical conductivity range between 1.0–1.2 (mS/cm) and pH range of 5.5 to 6.5 throughout the growing season.

Yield and yield attributing traits

At harvest, ten fully grown plants were randomly selected from each treatment and replication for recording observations on yield and yield-attributing traits following standard procedures. Plant

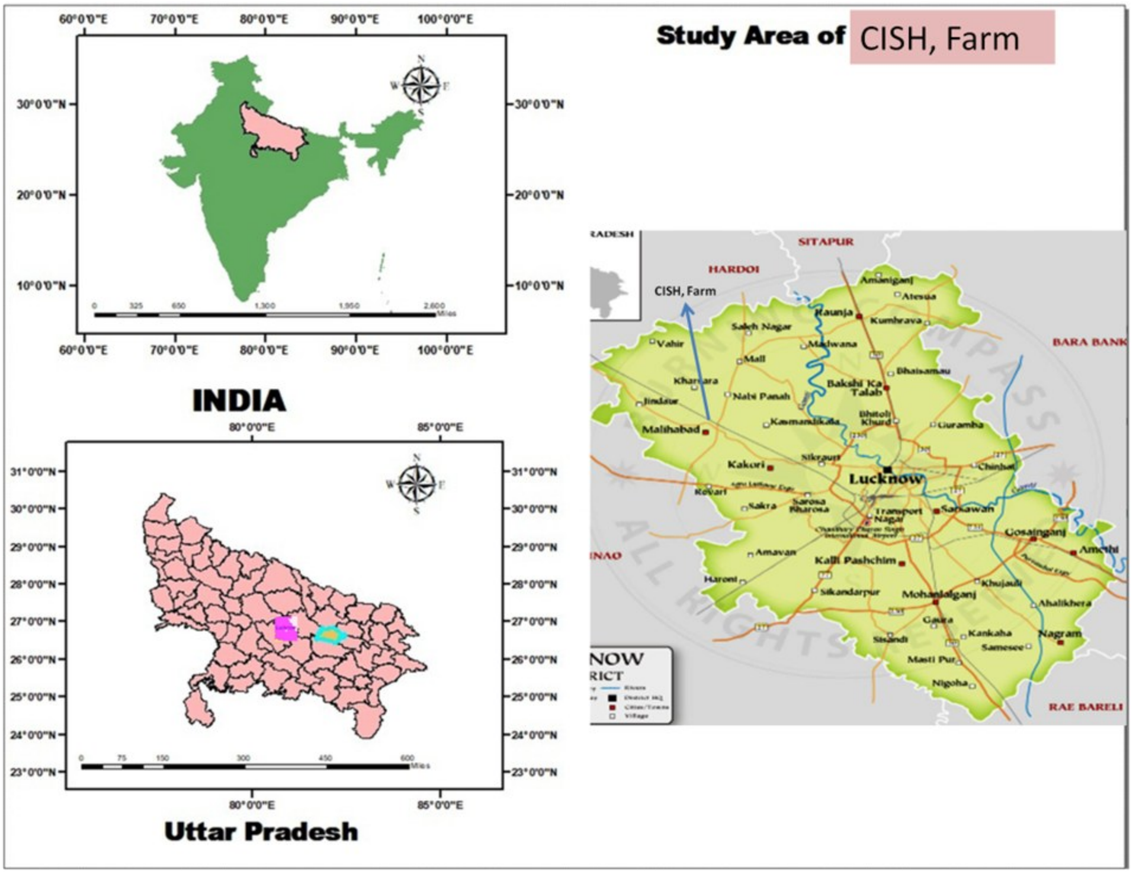

Fig. 1. Experiment site and map.

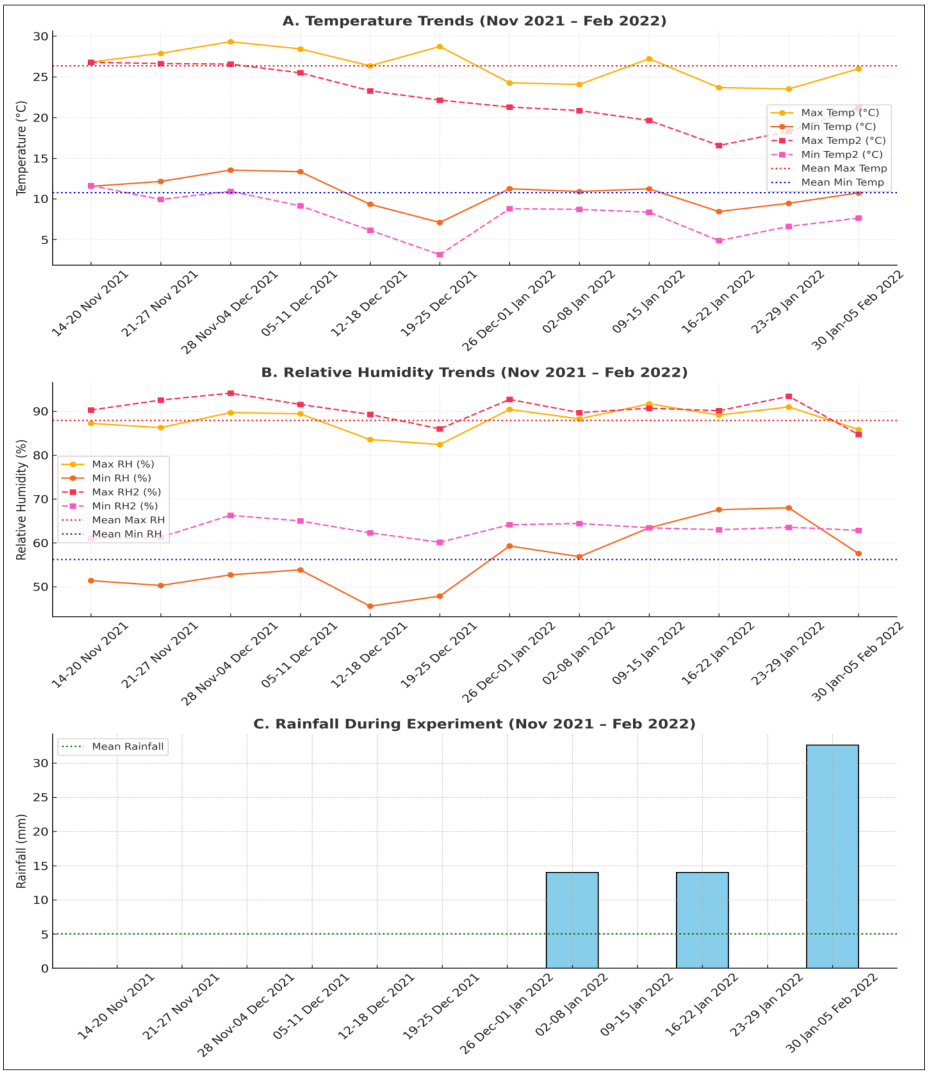

Fig. 2. Mean weekly weather data from November 2021 to February 2022 of experiment site.

Fig. 3. Experimental site and view of aeroponics system of lettuce varieties at 10 days after transplanting.

height (cm) was measured from the ground level to the leaf apex, plant weight and leaf weight (g) were determined using a weighing machine and root length (cm) was measured with a scale. Stem diameter (mm) was recorded just above the ground using a Mitutoyo Digital Vernier Caliper. The total number of leaves per plant was counted, while shoot weight (g) was measured after root removal. Leaf width and leaf length (cm) were recorded from the middle and full length of leaves, respectively.

Leaf index was calculated as (19):

$$\text{Leaf index} = \frac{\text{Leaf length}}{\text{Leaf width}} \times 0.75$$

Finally, the average weight of 10 plants was recorded at harvest and yield was expressed in quintals per hectare. Dry matter content of leaves was estimated by oven-drying a 25 g fresh sample at 60 °C to constant weight and expressed as percentage (20). Ascorbic acid was determined by the 2,6-dichlorophenol-indophenol titration method (21) using 2 g fresh tissue homogenised in metaphosphoric acid and values were expressed in mg/100 g FW. Total carotenoids were quantified following Kemmerer and Frap (1943) by extracting a 5 g sample with acetone, separating into petroleum ether and recording absorbance at 452 nm. Chlorophyll a, b and total chlorophyll were estimated by the method of Ameel and Axler using 500 mg leaf tissue extracted in 85 % acetone, with absorbance at 600, 642.5 and 660 nm and calculated using standard equations.

Statistical analysis

The results were subjected to a two-way analysis of variance (ANOVA) using SPSS Statistics 19.0 to examine the impacts of cultivation systems, cultivars and their interaction. Mean values accompanied by standard error (SE) were provided for the results.

Results and Discussion

Growth parameters

Lettuce varieties showed significant variation with respect to growth parameters such as plant weight, plant height, leaf length, leaf width, total leaf weight, stem diameter, average stem weight, average root weight, root length, plant height, no. of leaves/plant, leaf area index and yield presented in Table 1. The maximum plant weight was observed in variety Bingo (345.50 g) followed by variety Summer Star (302.00 g) and least plant weight was recorded of variety Black Rose (155.42 g). Plant height showed significant differences among the varieties. The maximum plant height was observed in Tango (29.25 cm), followed by Black Rose (24.60 cm), while the minimum was recorded in Bingo (22.68 cm). Leaf length also showed significant differences, with the maximum leaf length recorded in Tango (23.01 cm), followed by Bingo (20.54 cm), whereas the minimum was observed in Grand Rapid (19.01 cm). Significant differences were also observed in leaf width, where the variety Summer Star recorded the maximum value (19.25 cm), followed by Bingo (18.71 cm), while the minimum was recorded in Tango (15.90 cm) (Fig. 4). Total leaf weight also varied significantly among the varieties, with the maximum recorded in Bingo (293.25 g), followed by Summer Star (261.42 g), whereas the minimum was recorded in Black Rose (134.33 g). Stem diameter showed significant differences among the varieties. The maximum stem diameter was observed in the variety Summer Star (14.26 mm), followed by Bingo (13.90 mm), while the minimum was recorded in Black Rose (11.05 mm). The presented data also showed significant differences in average stem weight. The maximum stem weight was recorded in the variety Tango (22.33 g), followed by Summer Star (20.50 g), whereas the minimum was recorded in Black Rose (9.67 g).

Table 1. Effect of 5 varieties on yield and yield attributing traits of lettuce

Varieties	Plant weight (g)	Leaf length (cm)	Leaf width (cm)	Total Leaf weight (g)	Stem diameter (mm)	Average stem weight (g)	Average root weight (g)	Root length (cm)	Plant height (cm)	No. of leaves/ plant	Leaf area index	Yield (q/ha)
Tango	229.33	23.01	15.90	185.75	12.91	22.33	11.33	41.23	29.25	25.83	1.03	141.61
SummerStar	302.00	19.88	19.25	261.42	14.26	20.50	19.92	33.85	24.20	21.00	0.72	213.15
Grand Rapid	235.52	19.01	17.46	199.83	13.56	17.75	19.58	36.73	23.35	23.25	0.76	159.52
Bingo	345.50	20.54	18.71	293.25	13.90	16.42	18.33	30.46	22.68	23.75	0.77	199.78
Black Rose	155.42	19.67	16.61	134.33	11.05	9.67	11.25	26.89	24.60	20.50	0.83	102.53
C.D at 5 %	14.1	2.54	2.94	4.97	1.90	1.31	2.58	1.65	1.82	1.88	0.17	2.89
S.E(d)	6.18	1.35	1.87	2.31	0.93	0.84	1.28	0.79	0.89	0.94	0.07	1.73
S.E(m)	3.98	1.23	1.37	1.72	0.86	0.73	0.89	0.52	0.61	0.79	0.04	0.91

Fig. 4. Experimental site and view of aeroponics system of lettuce varieties at 45 days after transplanting.

The data showed significant differences in average root weight among the varieties. The maximum root weight was recorded in the variety Summer Star (19.92 g), followed by Grand Rapid (19.58 g), while the minimum was recorded in Black Rose (11.25 g). The data also revealed significant differences in root length. The maximum root length was observed in the variety Tango (41.23 cm), followed by Grand Rapid (36.73 cm), whereas the minimum root length was recorded in Black Rose (26.89 cm). The data presented in Table 1 showed significant differences in the number of leaves per plant. The maximum number of leaves per plant was recorded in the variety Tango (25.83), followed by Bingo (23.75), while the minimum was recorded in Black Rose (20.50). Significant differences were also observed in the leaf area index. The maximum leaf area index was recorded in the variety Tango (1.03), followed by Black Rose (0.83), whereas the minimum was recorded in Summer Star (0.72). The data also revealed significant differences in yield. The maximum yield was recorded in the variety Summer Star (213.15 q), followed by Bingo (199.78 q), while the minimum yield was observed in Black Rose (102.53 q).

The maximum plant and leaf weight was recorded in the variety Bingo, which may be attributed to the compact arrangement of its leaves. Loose-leaf forms produce less dense heads than closed-leaf varieties, where overlapping leaves contribute to greater plant structure and weight. Similar observations were reported by earlier researchers in their varietal evaluation of leaf weight (22) (Fig. 5). The variety Tango recorded the maximum values for plant height, leaf length, stem weight, root length, number of leaves per plant and leaf area index, which may be attributed to its genetic characteristics. Recent studies highlight the crucial role of variety selection and environmental factors in maximising the nutritional quality and yield of leafy greens such as lettuce. The results are in conformity with the findings of previous researchers in their experiments (23, 24). The Summer Star variety exhibited a significantly higher yield (q/ha), leaf width, stem diameter and root weight comparable to other variety. This superior performance may be attributed to its higher overall biomass production and genetic makeup of variety compared to the other varieties. The present results are supported by the findings of earlier researchers who reported significant yield (q/ha) in their varietal evaluation (25). All yield and yield attributing traits exhibited significant variance among the 5 lettuce varieties, indicating a wide range of variability. "The variability observed in lettuce suggests that effective selection and genetic improvement are feasible. Such variation provides opportunities to identify superior genotypes with desirable traits for breeding programs (26, 27).

Quality parameters

The varieties recorded non-significant difference on dry matter content and the variety Black Rose (6.96 %) recorded maximum followed by Bingo (6.89 %) and least observed in Summer Star (6.29 %). Table 2 observed significant differences on vitamin C and Black Rose (15.80 mg) recorded maximum followed by Summer Star (11.98 mg) and in Grand Rapid (10.59 mg) findings least. The varieties manifested significant effect on total carotenoids and Black Rose (7.97 mg) observed maximum followed by Tango (7.18

Table 2. Effect of different varieties on quality attribute of lettuce

Varieties	Vitamin C (mg/100 g)	Total carotenoids (mg/100 g)	Chlorophyll a (mg/g FW)	Chlorophyll b (mg/g FW)	Total chlorophyll (mg/ g FW)	Dry matter content (%)
Tango	10.76	7.18	1.37	0.185	0.68	6.42
Summer Star	11.98	4.01	0.21	0.047	0.26	6.29
Grand Rapid	10.59	5.21	0.29	0.062	0.21	6.88
Bingo	11.28	5.99	0.31	0.090	0.42	6.89
Black Rose	15.80	7.97	0.38	0.122	0.51	6.96
C.D at 5 %	1.45	0.23	N.S	0.024	0.09	N.S
S.E(d)	0.74	0.11	0.57	0.009	0.05	0.46
S.E(m)	0.45	0.09	0.41	0.006	0.03	0.33

*N.S: Non significant. FW: Fresh weight.

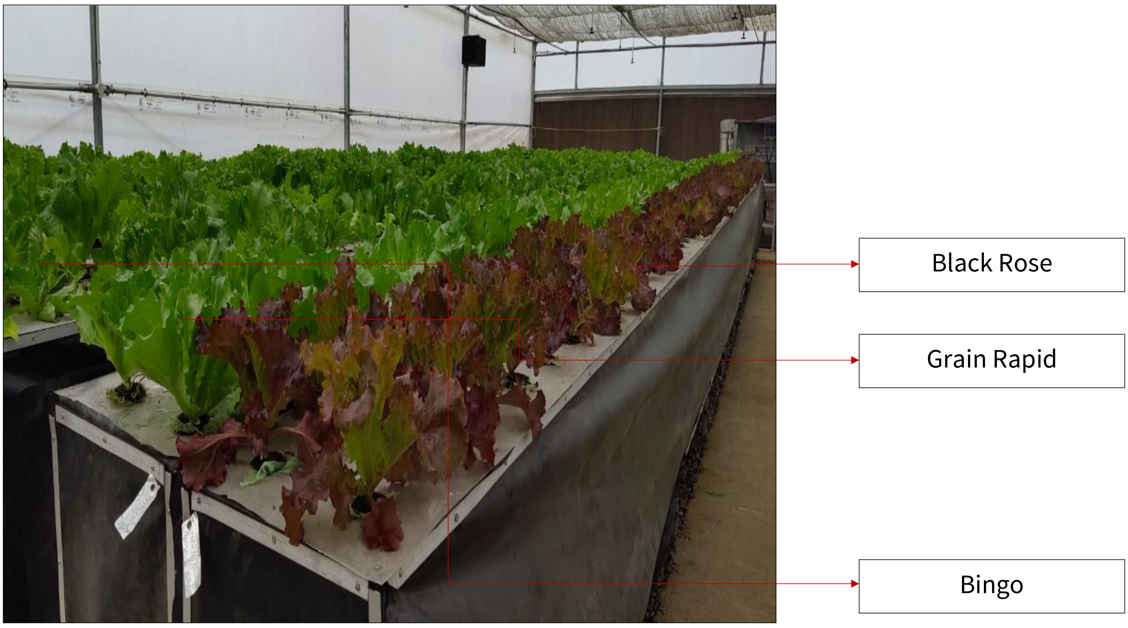

Fig. 5. Experimental site and view of aeroponics system of lettuce varieties at 45 days after transplanting.

mg) and least recorded in Summer Star (4.01 mg). The varieties observed non-significant effect on chlorophyll a and Tango (1.37 mg) recorded maximum followed by Black Rose (0.38 mg) and minimum recorded in Summer Star (0.21 mg). Chlorophyll b observed significant differences in all varieties and Tango (0.185 mg) observed maximum followed by Black Rose (0.122 mg) and minimum observed in Summer Star (0.047 mg). Significant differences in total chlorophyll content were observed among the varieties. The highest chlorophyll content was recorded in Tango (0.68 mg), followed by Black Rose (0.51 mg), whereas the lowest was recorded in Grand Rapid (0.21 mg). The findings of the study align with current practices, emphasising the importance of selecting suitable varieties to enhance the nutritional value of leafy vegetable. The dominant performance of the Black Rose variety in terms of dry matter, vitamin C and total carotenoids content likely due to its red coloration and unique character of the variety emphasised the influence of growth stages on antioxidant potential and mineral content, indicating the maturity plays a crucial role in determining nutritional profiles (28, 29). The ANOVA observed for 6 quality traits like vitamin C, total carotenoids, chlorophyll a, chlorophyll b, total chlorophyll and dry matter content divulged and reported significant genotypic variability among the 6 lettuce varieties. These findings emphasise the potential of selecting superior genotypes for strengthens nutritional) and functional quality in lettuce, which is imperceptibly valued for its health benefits in human diets (30).

Vitamin C content (mg/100 g)

Significant variation was reported among varieties of lettuce and indicating a strong genetic influence on ascorbic acid accumulation. Black Rose recorded the highest vitamin C content (15.80 mg/100 g), followed by Summer Star (11.98 mg/100 g) and Bingo (11.28 mg/100 g). These findings are consistent with the results reported in previous studies on strawberry (31), blueberry (32) and lettuce (33). Vitamin C (ascorbic acid) also plays a key role as a natural antioxidant, endowing to immune function and reducing oxidative stress in human beings (34).

Total carotenoids (mg/100 g)

Significant differences were observed in total carotenoid content among the varieties. The highest levels of carotenoid estimated in Black Rose (7.97 mg/100 g) followed by *Tango* (7.18 mg/100 g) which showed the antioxidant potential of lettuce. Carotenoids, particularly β-carotene, are reported as precursors to vitamin A, which are considered for improving eye health (35). The substantial variation suggests good scope for future breeding work in this crop. The same finding reported earlier strawberry (36) and in lettuce (37).

Chlorophyll a (mg/g FW)

No significant result was reported among varieties for chlorophyll a, it is the primary pigment embroiled in photosynthesis of plant (38) and it considered as relatively stable expression across genotypes under uniform growing conditions (39).

Chlorophyll b (mg/g FW)

Significant differences were observed in chlorophyll *b* content among the varieties; a higher concentration *was estimated in* Black Rose (0.122 mg/g FW) followed by Bingo (0.090 mg/g FW). Chlorophyll b complements chlorophyll a by expanding the spectrum of light absorption (40). The finding is supported by the result of previous studies in strawberry (41) and in lettuce (42).

Total chlorophyll (mg/g FW)

Total chlorophyll content also differed significantly with highest in Tango (0.68 mg/g) followed by Black Rose (0.51 mg/g). The high-level chlorophyll are evocative for higher photosynthetic potential and biomass accumulation in plant, which can translate into better growth and productivity (43). Varieties with high total chlorophyll may be good option for cultivation under dense planting systems under sub-tropical condition. Similar type result in strawberry plant (44) and (45) in lettuce, which are endorsed previously (46). Although future research in lettuce should integrate genotype × environment interactions to further validate these findings under diverse agro-climatic conditions (47).

Dry matter content (%)

Dry matter content showed no significant variation among genotypes; it may be less affected by genetic differences under uniform agronomic conditions (48). However, dry matter is a critical parameter for post-harvest processing and shelf life of fruits (49). Similar findings were also reported in previous studies (50).

Conclusion

The study revealed significant variation in both growth and quality parameters among 5 lettuce varieties growing under aeroponic system, indicating important scope for genetic improvement. Bingo showed the highest plant weight, while Tango excelled in plant height and leaf dimensions, reflecting superior vegetative growth. In terms of nutritional quality, Black Rose was richest in vitamin C and carotenoids, whereas Tango had the highest chlorophyll content. These diverse varietal strengths potential emphasise the important of phenotypic diversity and support the strategic selection of traits in breeding programs aimed at developing high-yielding, nutrient-dense and visually appealing lettuce cultivars under hydroponic system to meet market and nutritional demands of urban areas of local people.

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Authors' contributions

AS and SRS conceptualised the study and organized the data. VY, LPY, AKS and PY prepared the manuscript. DSM, AIP and AY critically revised the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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