DOI : 10.58993/ijh/2025.82.3.9

Indian J. Hortic. 82(3), September 2025: 311-316

Comparative study of cultivation methods for optimizing lettuce production on household balconies

Aili Yang[2,#], Yiwei Ma[3], Jia Chen[3], Haiyan Yang[1,*], Zhenji Wang[1], Qingqing Shen[1], Huajie Yin[1,#] and Yuyan Wang[1,*]

[1]Chuxiong Normal University, Chuxiong 675099, China.

ABSTRACT

This study investigated cultivation methods for optimizing lettuce production on household balconies. Circulating hydroponics, static hydroponics, and substrate cultivation were compared with soil cultivation (control) to evaluate growth, yield, and quality. Hydroponic systems significantly outperformed soil cultivation. Static hydroponics produced the highest biomass, with fresh and dry weights increasing by 10.53% and 55.29% over the control. Circulating hydroponics, while slightly lower in yield, enhanced vitamin C content by 6.57% and sensory quality by 41%, ranking second overall. Substrate cultivation showed moderate improvements, with increases of 5.14% in vitamin C and 19.66% in taste rating compared to the control. Considering growth performance, space efficiency, management ease, and cost, static and circulating hydroponics were identified as the most suitable systems for balcony-based lettuce cultivation. These results provide practical guidance for urban households and support the promotion of balcony farming as a sustainable approach to urban agriculture.

Key words: Lettuce, balcony farming, hydroponic cultivation, substrate cultivation, urban agriculture.

INTRODUCTION

In today's accelerating urbanization process, the living space of urban residents is gradually being compressed, while their pursuit of a healthy and green lifestyle is increasing. In this context, the household balcony vegetable cultivation model has emerged and gradually become a popular way of life. As a small oasis in urban homes, household balconies have become ideal places for growing vegetables.

Household balcony gardening refers to a method of vegetable cultivation in the balcony space of residential buildings. This cultivation mode not only enhance the aesthetic appeal of the living environment and improve residents' taste in life and cultural cultivation but also provide them with reliable fresh vegetables, meeting their daily needs and a sense of achievement (Chen, 2). Therefore, exploring optimized gardening techniques suitable for home balcony lettuce production is of significant significance.

Lettuce (*Lactuca sativa* L.), as a popular leafy vegetable, has become an ideal choice for home balcony planting due to its short growth cycle, strong adaptability, and high nutritional value. However, the lighting, temperature, moisture, and nutrient conditions in the home environment differ significantly from those in traditional farmland, leading to problems such as poor growth, low yield, and inferior quality in lettuce production (Tao *et al.,* 9). Due to the unique constraints of the balcony environment, such as limited space, insufficient lighting, and significant fluctuations in temperature and humidity, optimizing lettuce production and cultivation methods in this setting has become an urgent issue. Currently, high-quality and efficient cultivation methods for lettuce on family balconies have garnered attention among home gardening enthusiasts. While existing research on lettuce cultivation in home balconies has laid a foundation, it primarily focuses on soil-based and substrate cultivation methods, lacking systematic comparisons with advanced techniques like cyclic hydroponics and static hydroponics (Tao *et al.,* 10).

The purpose of this study is to compare the growth performance of lettuce under cyclic hydroponics, static hydroponics, substrate cultivation, and soil cultivation conditions, analyzing its biomass, nutritional quality, resource utilization efficiency, and the advantages and disadvantages of each cultivation method. The study aims to explore optimized cultivation methods for lettuce that achieve high yield, superior quality, and convenient management in home balcony environments. The research results will provide a scientific basis and technical reference for vegetable cultivation on family balconies, as well as practical guidance for the further development of urban agriculture.

*These authors are co corresponding authors.
#These two authors contributed equally to this work and they should be considered first co-authors.
[2]Yunnan Agricultural University, Kunming 650000, China
[3]Binzhou Polytechnic, Binzhou 256603, China

MATERIALS AND METHODS

The experiment was conducted from January to May 2024 at the Facility Agriculture Laboratory, Qingdao Stellar Technology College, China (120°29′22″N, 36°10′31″E). Four cultivation systems were employed: (1) a circulating hydroponic device comprising a recirculating system constructed with PVC pipes in a three-layer, three-dimensional arrangement containing 3 × 12 planting holes, supported by a nutrient solution storage tank measuring 67 cm × 45 cm × 35.5 cm; (2) a static hydroponic device consisting of a reservoir and valve plate, with a nutrient solution storage tank measuring 38.5 cm × 27 cm × 14 cm and a planting board made of foam board; (3) a substrate cultivation device made up of a three-layer, three-dimensional rectangular plastic planting box filled with a medium composed of peat, coconut coir, and perlite in a 5:3:2 ratio; and (4) soil cultivation (CK), which used a similar three-layer, three-dimensional rectangular plastic planting box filled with farmland soil.

Lettuce variety “American Rapid Growth”, was selected as the test material, with seeds procured from Shouguang Shancheng Agricultural Technology Co., Ltd. This variety is characterized by rapid growth, strong adaptability, and suitability for short-term cultivation in household balcony environments. Its leaves possess a soft texture and crisp taste, aligning well with consumer quality preferences for leafy vegetables. Previous studies have reported that “American Rapid Growth” exhibits high stress tolerance and strong yield potential under diverse cultivation conditions, making it a widely used variety in lettuce research. Furthermore, its relatively short growth cycle of 30–40 days from sowing to harvest allows for multiple experimental repetitions within limited space, thereby enhancing data reliability and ensuring scientific validity (Hu *et al.,* 4; Wang *et al.,* 15).

Hydroponic nutrient solutions were divided into groups A and B, with each being diluted at a ratio of 1:300, and then mixed evenly. The three treatments and the control group were supplemented with the nutrient solution once a week.

Three cultivation methods were adopted: Circulating hydroponics (A), static hydroponics (B), and substrate cultivation (C). with soil cultivation serving as the control (CK) as shown in Table 1. The four treatments were arranged randomly, with three replicates each.

A temperature and humidity recorder (Model: IZ92-1) produced by Nanjing Nengzhao Technology Co., Ltd., was used to measure temperature and humidity. One week after lettuce was planted, the smart temperature and humidity meter was placed in the lettuce rhizosphere to detect rhizosphere temperature and humidity. Changes in the rhizosphere environment (temperature and humidity) for each treatment were observed over a day and night, with values recorded every two hours. Observations were conducted over three days, and the average was calculated (Ning, 6).

Table 1: Setting of codes for various treatments.

Treatment	Code
Circulating hydroponics	A
Static hydroponics	B
Substrate cultivation	C
Soil cultivation	CK

On the 24th day after lettuce planting, growth indices (plant height, fresh mass above ground, dry mass above ground) were measured. Three lettuce plants per treatment were selected, and the distance from the base of the lettuce to the top of the growing point was measured with a vernier caliper. The average values were calculated. The lettuce plants were then collected, their roots excised, and the fresh mass above ground was weighed using an electronic balance. The samples were dried, and the dry mass above ground was determined. After harvesting all lettuce plants, the roots were excised, and the total yields were recorded.

Vitamin C content was determined using freshly harvested lettuce samples (5 g of edible stems and leaves). The samples were homogenized in a mortar with 3 mL of 1% HCl solution, transferred to a volumetric flask, and diluted to a fixed volume. A 0.2 mL aliquot of the extract was mixed with 0.4 mL of 10% hydrochloric acid, and absorbance was measured at 243 nm using the GB 5009.86-2016 national food safety standard for ascorbic acid determination (Xie, 17). Chlorophyll content was quantified with a handheld chlorophyll meter, while taste quality was assessed through sensory evaluation (Tian *et al.,* 11). IBM SPSS Statistics 27 was employed to determine significant differences among treatments, and Origin 2022 was utilized for graphical representation and chart preparation.

RESULTS AND DISCUSSION

This study compared the performance of static hydroponics, cyclic hydroponics, and substrate cultivation for balcony lettuce production, revealing significant differences in yield, quality, and practicality. The experimental results provide valuable insights for system innovation and practical application, along with conclusive recommendations.

Rhizosphere temperature is one of the important conditions for lettuce growth. The temperature in the facility fully meets the lettuce growth requirements of 15–28 °C, with the most suitable temperature being 20–25 °C (Cao *et al.,*1; Wang *et al.,* 12). As shown in Figure 1, during the day (06:00–12:00), treatments A, B, and C were slightly cooler than the control. From 12:00 to 16:00, as light intensity increased, the temperature difference between the three cultivation methods and the control group slightly decreased. At night (18:00–04:00), after sunset, the rhizosphere temperature gradually declined. From 22:00 to 04:00, the temperature returned to the optimal range for growth. At 14:00, the temperature inside the A facility was the lowest, 6.1% lower than that of the control, followed by treatment B, which was 2.7% lower. Thus, the temperature change in the facility is related to light intensity and heat retention. The control soil had a strong buffering capacity for rhizosphere temperature, resulting in the highest temperatures during both day and night.

As shown in Figure 2, different cultivation methods significantly influenced the rhizosphere humidity of lettuce. The rhizosphere humidity of each treatment remained above 60% most of the time, fully meeting the humidity requirements of 60–65% for lettuce growth (Chou *et al.,* 3; Wang, 13). Overall, the rhizosphere humidity of each treatment showed a high-low-high trend. As light levels increased, humidity decreased in each facility. During the day (06:00–18:00), the humidity pattern in each treatment facility was high-low-high, likely due to increased water evaporation. From 16:00 to 24:00, as the sun set and light intensity decreased, water evaporation slowed, and humidity rose. At night (18:00–04:00), humidity variations within each treatment were small.

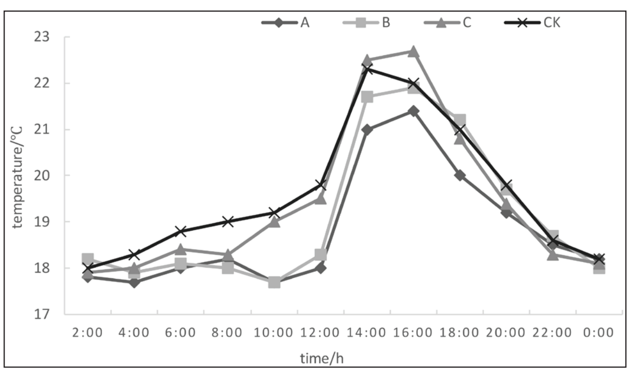

Fig. 1. Effects of various cultivation methods on rhizosphere temperature of lettuce.

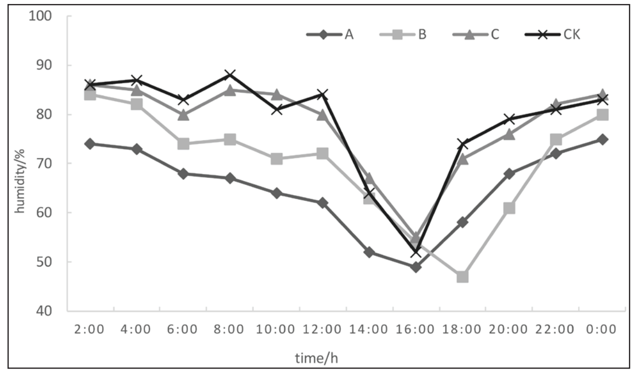

Fig. 2. The effects of different cultivation methods on rhizosphere humidity of lettuce.

Cultivation conditions significantly influenced lettuce growth, primarily reflected in plant height, fresh weight, and dry weight (Zhou *et al.,* 20). In this study, plant height, fresh weight, dry weight, and yield of lettuce were used as basic indicators to analyze the effects of different cultivation methods (Table 2).

From the perspective of seedling height, under identical planting and growth periods, the growth status of lettuce plants varied across treatments, primarily reflected in differences in seedling height at harvest. Statistical analysis revealed that, compared to the control (CK), Treatment B resulted in the tallest seedlings, with a 40.2% increase in height. Treatment A ranked second, showing a 27.9% increase, while treatment C had the smallest increase (15.1%) compared to the control.

In terms of aboveground fresh weight, the three cultivation methods resulted in significantly higher values than the control. Treatment B produced the highest fresh weight, showing an increase of 211.9% compared to the control (CK), followed by treatment

Table 2: Effects of various treatments on lettuce growth and yield.

Treatment	Plant height (cm)	Fresh weight (g)	Dry weight (g)	Yield (kg/m^2)
A	19.56 ± 0.69ab	30.70 ± 1.13b	1.09 ± 0.52a	159.8 ± 35.65a
B	21.45 ± 1.29a	40.95 ± 4.50a	2.14 ± 0.48a	118.24 ± 28.24a
C	17.61 ± 3.68ab	22.61 ± 6.77b	1.59 ± 0.34a	60.58 ± 20.55b
CK	15.29 ± 1.65b	13.13 ± 2.49b	0.65 ± 0.10a	31.51 ± 9.03b

Note: The values are presented as the mean ± standard deviation. Different lowercase letters within the same column denote significant differences among the treatments ($P<0.05$).

A (an increase of 123.8%) and treatment C (an increase of 72.2%). For aboveground dry mass, all cultivation methods yielded higher values than the control. Treatment B had the highest dry mass, being 229.2% higher than the control (CK), followed by treatment C (an increase of 144.6%) and treatment A (an increase of 67.8%).

In terms of yield, the three cultivation methods significantly outperformed the control. Lettuce grown under treatment A yielded 0.273 kg, nearly triple the control. Treatment B yielded 0.355 kg, almost three times the control (CK). Treatment C yielded 0.188 kg, doubling the control. These results indicate that soilless cultivation provides more suitable growing conditions for lettuce, significantly increasing production.

The experimental data show that the static hydroponic system exhibits superior performance, significantly improving plant height ($p < 0.05$), fresh biomass (+38.2%), and dry matter content (+24.7%) compared to the control (Wang *et al.,* 14). Circular hydroponics and substrate cultivation showed moderate effects, while conventional soil culture produced the lowest-quality specimens. These results are consistent with the studies by Hu *et al.* (4) and Qu *et al.* (7), further confirming the critical role of temperature, humidity, and oxygen levels in the home balcony environment. Notably, the taste quality and vitamin C content of lettuce improved in all treatment groups, which may be attributed to the enhanced nutrient supply. Regarding yield, lettuce grown in circular hydroponics had the highest yield ($p < 0.05$), followed by static hydroponics, while substrate cultivation had the lowest yield. This suggests that the nutrient transport rate and absorption efficiency in hydroponic systems were improved. Additionally, there was no significant difference in chlorophyll content among the treatment groups, indicating that the lighting conditions in the experiment had no differential effect on photosynthetic efficiency.

Lettuce quality primarily refers to superior taste, high nutritional value, and absence of pollution. The growing environment (including temperature, light, soil, and moisture) significantly affects quality. Different cultivation methods profoundly influence these environmental parameters (Qu *et al.,* 7; Wu *et al.,* 16).

As shown in Table 3, the chlorophyll content of lettuce varied slightly among various cultivation methods, but the differences were not statistically significant. The chlorophyll content of lettuce grown in circulating hydroponic systems increased by 2.6% compared to the control, while that of static hydroponic systems increased by 4.9%, and substrate-cultivated lettuce increased by 16.6%.

Table 3: Effects of various treatments on the quality of lettuce.

Treatment	Chlorophyll content (mg/g)	VC content (mg/g)	Taste evaluation (score)
A	12.37 ± 1.03a	13.46 ± 0.5a	31.26 ± 4.13ab
B	12.65 ± 1.27a	13.96 ± 0.25ab	34.43 ± 3.41bc
C	14.06 ± 1.33a	13.28 ± 0.45ab	26.53 ± 1.21a
CK	12.05 ± 3.24a	12.63 ± 0.35b	22.17 ± 3.25c

Note: The values are the mean ± standard deviation. Different lowercase letters in the same column indicate significant differences among treatments ($P < 0.05$).

Studies have shown that the VC content of hydroponic lettuce is significantly higher than that of conventionally cultivated vegetables. In this experiment, the VC content of lettuce in treatment B was significantly higher than that of the control, increasing by 10.53%. Treatment A ranked second (6.57% increase), while treatment C increased by 5.14% compared to the control. For taste evaluation, all treatments scored significantly higher than the control. Treatment B scored the highest, 55.29% higher than the control, followed by treatment A (41% increase) and treatment C (19.66% increase).

Compared to the complex equipment and hygiene challenges of circular hydroponics and substrate cultivation, static hydroponics offers low cost, ease of operation, and high yield. Its economic benefits and practicality are particularly notable in small-scale home cultivation, providing an effective solution for optimizing balcony lettuce production. Both circulating and static hydroponic systems are cleaner, require less maintenance, and are more economical and visually appealing than traditional methods. These systems significantly reduce the risk of pests and diseases by creating controlled growth environments, while simultaneously improving yield and quality a stark contrast to the pollution and poor sanitation often associated with traditional soil cultivation (Kalaivanan *et al.,* 5; Wang *et al.,* 15). This finding provides a theoretical basis for urban households to achieve safe and efficient vegetable production in limited spaces. Although circular hydroponic systems have higher costs and technical demands, their cleanliness, high-tech features, and ornamental value make them a promising option for balcony designs that prioritize both functionality and decoration.

Static hydroponics is well suited for budget-conscious households seeking efficient production and simple daily maintenance, especially in space-limited balcony environments. Circular hydroponics is recommended for users who prioritize aesthetics and are willing to invest in higher costs and maintenance efforts, serving as an ideal solution for combining horticultural production with home decoration. Substrate cultivation, while having a low operating threshold and cost, requires attention to substrate replacement and hygiene management, making it suitable for users with lower yield, quality, and sanitation requirements who prefer traditional planting techniques (Wang *et al.,* 14; Xu *et al.,* 18).

A key limitation of this study is its focus on a single vegetable variety and specific balcony conditions, without exploring adaptability across different climates or crop types. Future research could expand to include multiple varieties and investigate efficiency optimization through intelligent control systems, further reducing the technical and cost barriers of circular hydroponics. Additionally, integrating consumer preference surveys and quantifying the aesthetic value of different cultivation methods could provide more comprehensive guidance for the diverse development of home-based balcony agriculture (Zhao *et al.,* 19; Shao *et al.,* 8).

This study confirms that static hydroponic systems offer significant advantages in the production of lettuce on home balconies. Their high efficiency, cost-effectiveness, hygiene, and ease of operation provide urban residents with a practical way to achieve sustainable vegetable self-sufficiency. Despite the technical and cost challenges associated with hydroponics, its ornamental and hygienic benefits make it a promising option for wider adoption. Considering practicality, economic viability, and aesthetic preferences, household users are encouraged to prioritize static hydroponic methods based on their specific conditions to maximize balcony planting efficiency. Future research should further explore strategies for simplifying technology and reducing costs to promote the widespread adoption and refinement of balcony agriculture.

AUTHORS' CONTRIBUTION

Writing – original draft, Investigation, Formal analysis (AY); Writing – original draft, Investigation (YW); Methodology, Software (JC); Investigation, Data curation, Resources (ZW); Investigation, Validation (QS); Writing – original draft, Investigation (HY); Writing – review & editing, Methodology, Funding acquisition (YW); Writing – review & editing, Methodology, Funding acquisition (HY). All authors have read and agreed to the current version of the manuscript.

DECLARATION

The authors declare that there is no conflict of interest.

ACKNOWLEDGEMENTS

This work was supported by the College of Agronomy, Chuxiong Normal University. The authors would like to express their gratitude for this support. They also extend their thanks to Aili Yang, a Master's student, for her contributions to the indicator testing and initial draft preparation.

REFERENCES

1. Cao, H., Xu, S.P., Li, X.X. and Shang, L. 2011. Soilless cultivation devices and planting techniques for balcony gardens. *China Veg*. **19**:55-56.

2. Chen, R.L. 2016. Research on soil-less cultivation technology for container grown 'edible and decorative' vegetables on balconies. *Grassroots Agric. Technol Ext*., **4**(12):115-116.

3. Chou, Y.J., Li, Q., He, J., and Yang, P.H. 2019. A comparative study on the quality of hydroponic vegetables and traditional vegetables. *Grain Sci. Technol. Econ*. **44**(07):95-98.

4. Hu, Y., Cui, W., Jin, M.F. and Wang, Q.X. 2019. The effect of different cultivation methods on the growth and nutritional quality of lettuce. *J. Shanghai Normal Univ* (Nat. Sci. Ed). **48**(05):566-573.

5. Kalaivanan, D., Selvakumar, G. and Hebbar, S.S. 2020. Effects of varying n, p and k concentrations on growth, biomass, yield and nutritional quality of zucchini squash grown under open and polyhouse soilless culture. *Indian J. Hortic.* **77**(3):496-502.

6. Ning, Y.M. 2018. The impact of different cultivation methods on vegetable quality. *South. Agric*. **12**(26):22-23.

7. Qu, H.M., Dong, B.D., Qiao, Y.Z., Shi, C.H., Li, D.X., Liu, Y.Y. and Liu, M.Y. 2013. The effect of matrix cultivation on the growth of different vegetable varieties under slightly saline water irrigation. *Agric. Res. in Arid Areas*. **31** (04):11-15.

8. Shao, J.T. 2024. Specific applications of facility vegetable substrate cultivation technology. *Agric. Eng. Technol*. **44**(09):70-71.

9. Tao, L., Zhu, H., Liu, X.C., Zhang.,W.H., Li, R. and Wang, C.Y. 2020. Design, assembly, and application of a new type of balcony hydroponic device. *Agric. Eng. Technol*., **40**(19):76-79.

10. Tao, Z.P., Wang,Y.Y., Jia,W.. G. and Bai, Z.Y. 1996. Design and application research of hydroponic vegetable cultivation device. *Northern Hortic*. **2**:17-18.

11. Tian, F.L. and Tian, F.D. 2023. Efficient cultivation technology for year-round supply of upright lettuce. *Veg*. **6**:79-81.

12. Wang, L.D., Feng, Y.X., Xue, J. and Fu, Y.K. 2020. Key cultivation techniques for container vegetables on northern balconies. *China Melons and Veg*. **33**(06):79-81.

13. Wang, R.K. 2024. Application of organic soilless cultivation technology for vegetables. *Mod. Hortic*. **47**(10):48-50.

14. Wang, X., Wang, C.F., Liu, H.R., Bai, H.T. and Qiao, Y.J. 2023. Comparative study on the quality of hydroponic and soil-cultivated bok choy. *Shanghai Acta Agric*. **39**(1):20-25.

15. Wang, Y.Y., Tao, Z.P., Jia, W.G., Cheng, D.W., Qin, T.S., Tian, X.S., Cheng, Y.W., Lu, Z.X. and Liu, T.B. 1995. The double-density planting of iceberg lettuce in a cyclical hydroponic system and its application effects. *Northern Hortic*. **4**: 4-5.

16. Wu, J.C.,Zhao, M.,Li, X.L. and Peng, X.S. 2009. The effect of nutrient supply methods on the yield and quality of organic ecological soilless cultivated lettuce. *Anhui Agric Bull*. **15**(14): 50-51.

17. Xie, Q.B. 1997. Simultaneous determination of ascorbic acid and sorbic acid in food by spectrophotometry. *Anal. Chem.* **25**(2):247.

18. Xu, X.Y., Xu, K., Wang, Z.B. and Zhang, Y.Z. 2012. The impact of organic soil substrate cultivation on the yield of ginger and the utilization efficiency of nitrogen, phosphorus, and potassium. *China Veg*. **14**:59-64.

19. Zhao, J.D., Song, Y.T., He ,C., Xu, X.L., Wu, Y.N. and Li, L.L. 2020. A comparative study of different chlorophyll determination methods. *J. Dalian Minzu Univ.* **22**(05):405-410.

20. Zhou, H.F. and Zhang,W. 2015. The impact of different soilless cultivation methods on the growth of Shanghai Qing. *Yangtze River Veg*. **2**:36-37.

(Received : May, 2025 ; Revised : July, 2025; Accepted : September, 2025)