

Performance of Japanese mint genotypes in open field and vertical farming conditions

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Abstract

Japanese mint (*Mentha arvensis* L.), a perennial, herbaceous, aromatic plant that holds significant economic value as a leafy vegetable and, more importantly, as a primary source for natural menthol. This dual utility, along with its valuable metabolites, is driving the growing demand for *Mentha* products. However, global population growth and urbanization are rapidly reducing cultivable land, making it difficult to produce fresh, high-quality vegetables. In this context, vertical farming has emerged as a promising alternative, utilizing controlled environments that enable the year-round production of quality vegetables, regardless of the climatic conditions. In this study, nine genotypes of Japanese mint viz., Kosi (V₁), CIM-Kranti (V₂), Himalaya (V₃), Kalka (V₄), MAS-1 (V₅), Saksham (V₆), Gomti (V₇), Seelayampatti local (V₈) and Bangalore type (V₉) under open field (G₁) and vertical A-frame structure (G₂) were evaluated. Among them, Saksham (V₆) and Gomti (V₇) showed an increase in quality parameters in both growing conditions. Saksham in vertical A-frame structure (G₂V₆) recorded maximum protein content (1.99 mg 100 g⁻¹), total phenol content (22.86 mg 100 g⁻¹) and calcium content (9.62 %) and Gomti (G₂V₇) recorded maximum vitamin C content (27.5 mg 100 g⁻¹) and potassium content (2.17 %) when grown in vertical A frame structure. These findings underscore the immense potential of vertical farming, particularly A-frame structures, to not only mitigate land scarcity but also significantly enhance the nutritional and phytochemical quality of economically important crops, such as Japanese mint. Therefore, adopting vertical farming is crucial for consistently supplying high-quality mint products to meet growing global demands.

Key words: Genotypes, Japanese mint, open field, quality, vertical structure

Introduction

The genus *Mentha* comprises 25-30 species and is recognized as one of the most significant groups of aromatic plants worldwide (Taraseviciene *et al.*, 2019). Menthol mint, also known as Japanese mint (*Mentha arvensis* L.), is a herbaceous perennial plant that belongs to the family Lamiaceae. The plant is indigenous to temperate parts of Europe, Eastern Siberia, Western and Central Asia, North America, as well as the Himalayas exhibiting a circumboreal distribution (Verma *et al.*, 2025). Globally, countries such as India, China, Brazil, and Vietnam are the major producers of *Mentha arvensis*. More than 80% of the crop in India is produced in Uttar Pradesh, followed by Punjab, Madhya Pradesh, and Bihar, which are neighbouring states responsible for the remaining 20% of production (Desai *et al.*, 2019).

Mint leaves are valued for their refreshing flavour as well as their antispasmodic, anti-asthmatic, diaphoretic, and anti-inflammatory properties (Bozovic *et al.*, 2015). Furthermore, different mint species exhibit considerable variation in morphological traits, uses and chemical compositions. Its essential oil, particularly menthol, finds extensive use in pharmaceutical, cosmetic, food, and oral hygiene industries, contributing significantly to the agricultural economy. The increasing global demand for *M.*

arvensis products, coupled with its high natural invasion rates are driving the growing importance of its genetic diversity.

Consumer interest in the natural production of aromatic plants is steadily increasing due to the rising demand for sustainably grown, health-promoting crops. However, conventional open-field cultivation is often hindered by land limitations, declining soil fertility, water scarcity, and the unpredictability of weather patterns due to climate change (Magwaza *et al.*, 2020). Hydroponics and vertical farming are emerging as crucial alternatives for modern vegetable cultivation. At its core, vertical farming involves growing crops in vertically stacked layers, significantly optimizing space and boosting production (Naskoori *et al.*, 2021). These innovative, technology-driven approaches directly address the limitations of traditional farming by maximizing land-use efficiency and optimizing resource utilization (Panotra *et al.*, 2024). Growing crops in controlled, enclosed vertical systems not only improves yield but also minimizes environmental impact by significantly reducing water consumption, pesticide use, and carbon emissions (Touliatos *et al.*, 2016).

Driven by the urgent need for sustainable agricultural practices and the potential of vertical farming, this study evaluated the performance of various *Mentha* genotypes under different

cultivation systems. There is a need to compare open-field cultivation with a vertical A-frame structure, provide valuable insights into how specific *Mentha* genotypes respond in controlled, resource-efficient environments. This is vital for optimizing high-quality menthol mint production in the face of environmental challenges. We hypothesize that *Mentha* genotypes grown in a vertical A-frame system will show superior quality attributes compared to those in open-field conditions, primarily due to improved environmental regulation and more efficient nutrient uptake. With this background, the present study aimed to evaluate the variation in quality attributes among different *Mentha* genotypes cultivated under various growing systems, including open field and vertical A-frame structures.

Materials and methods

The study was conducted at the Department of Vegetable Science, Horticulture College and Research Institute, Periyakulam, during 2022-23 to evaluate the quality performance of various mint genotypes under different growing conditions. The trial was laid out in the Factorial Complete Randomized Block Design (FRBD) with three replications.

Genotypes: A total of nine genotypes of *Mentha arvensis* L. were collected from areas in and around Periyakulam, Theni district. The genotypes used in the study were: V₁ - Kosi, V₂ - CIM-Kranti, V₃ - Himalaya, V₄ - Kalka, V₅ - MAS-1, V₆ - Saksham, V₇ - Gomti, V₈ - Seelayampatti local and V₉ - Bangalore type.

Growing system: The collected genotypes were cultivated under two growing systems: G₁, an open field condition, and G₂, a vertical A-frame structure. The vertical A-frame structure used in this study was constructed according to the design outlined by Aneesha *et al.* (2023). The vertical A-frame structure was made of 4-inch PVC pipe, and fertigation was provided through a 1 hp pump, which was regulated by an electronic timer. Netted pots of 3-inch were used for growing the mint genotypes. The wick system was followed in a vertical A-frame to maintain the water level for the plants. The growing medium used was coir pith. TDS ranged from 40 to 50 ppm, pH ranged from 6.5 to 7.0, and EC ranged from 0.4 to 0.5 dSm⁻¹ in the water. Reverse osmosis water was used in this study.

Quality attributes: Quality parameters were assessed in five

randomly selected plants from each replication at 45 days after planting. Leaf protein content was measured using the biuret method described by Layne (1957), while vitamin C was determined following the procedure outlined by Harris and Leslie (1935), with results expressed in milligrams per gram (mg g⁻¹). The total phenol content of the plant extract was estimated using the Folin-Ciocalteu method and presented as mg/100 g (Bray and Thope, 1954). The concentrations of calcium (Jackson, 1973) and potassium (Sumner, 1944) were analyzed through standard laboratory procedures, which typically involved drying, homogenization, acid digestion, and expression of results as percentages (%).

Statistical analysis: Statistical analysis of the data was carried out using AGRES software. Analysis of variance (ANOVA) was performed, and standard error of difference (S.Ed) and least significant difference (LSD) values were calculated, with significance determined at the 5 % level of probability.

Result and discussion

The performance of nine genotypes was tested in two different growing systems *viz.*, open field (G₁) and vertical A Frame structure (G₂). The results obtained revealed significant variation among the genotypes and growing systems with respect to various biochemical parameters, including protein, vitamin C, phenolic content, calcium, and potassium, at 45 days after planting, and are presented in Tables 1 and 2.

Protein content: The *Mentha* genotypes grown on vertical A-frame structure (G₂) recorded the maximum protein content (1.60 mg 100 g⁻¹), while the open field condition (G₁) reported the minimum protein content with 1.56 mg 100 g⁻¹. Among the varieties, the highest protein content was noticed in Saksham (V₆) (1.91 mg 100 g⁻¹) followed by Gomti (V₇) with 1.91 mg 100 g⁻¹ protein. The genotype Kalka (V₄) recorded the lowest protein content (1.19 mg 100 g⁻¹) (Fig. 1a). Considering the interaction between the genotype and growing system, a significant increase in protein content (1.99 mg 100g⁻¹) was observed in the genotype Saksham (G₂V₆) in vertical A frame structure which was ensued by Gomti (G₂V₇) with 1.97 mg 100 g⁻¹ and the lowest protein content (0.98 mg 100 g⁻¹) was noted in Kalka (G₂V₄) in vertical A frame structure. The increased protein content in the vertical

Table 1. Effect of growing systems on protein, vitamin C and total phenol content in different *Mentha* genotypes at 45 Days After Planting (DAP)

Cultivars	Protein content (mg 100 g ⁻¹)			Vitamin C content (mg 100 g ⁻¹)			Total phenol content (mg 100 g ⁻¹)		
	Open field (G ₁)	Vertical A-frame (G ₂)	Mean	Open field (G ₁)	Vertical A-frame (G ₂)	Mean	Open field (G ₁)	Vertical A-frame (G ₂)	Mean
V ₁	1.58	1.38	1.48	26.3	28.3	27.3	21.94	19.66	20.80
V ₂	1.52	1.95	1.74	21.6	22.8	22.2	20.15	21.72	20.94
V ₃	1.47	1.45	1.46	24.7	25.2	25.0	19.77	18.84	19.31
V ₄	1.39	0.98	1.19	20.5	22.6	21.6	18.26	20.12	19.19
V ₅	1.33	1.23	1.28	19.3	22.8	21.1	17.57	19.19	18.38
V ₆	1.83	1.99	1.91	22.6	25.8	24.2	23.42	22.86	23.14
V ₇	1.75	1.97	1.86	26.4	27.5	27.0	20.56	20.79	20.68
V ₈	1.81	1.62	1.72	25.8	23.9	24.9	19.73	17.53	18.63
V ₉	1.69	1.51	1.60	22.1	21.6	21.9	17.38	16.03	16.71
Mean	1.56	1.60		23.5	24.3		19.64	19.86	
	S.Ed	C.D (0.05)		S.Ed	C.D (0.05)		S.Ed	C.D (0.05)	
G	0.050	0.102 (NS)		0.797	1.622*		0.627	1.275*	
V	0.106	0.217**		1.692	3.441**		1.330	2.704**	
G×V	0.150	0.306**		2.393	4.866 (NS)		1.881	3.825 (NS)	

Table 2. Effect of growing systems on potassium and calcium content in different *Mentha* genotypes at 45 Days After Planting (DAP)

Cultivars	Potassium content (%)			Calcium content (%)		
	Open field (G ₁)	Vertical A-frame (G ₂)	Mean	Open field (G ₁)	Vertical A-frame (G ₂)	Mean
V ₁	1.16	1.25	1.21	5.85	6.87	6.36
V ₂	1.87	2.09	1.98	6.21	7.42	6.82
V ₃	1.42	1.76	1.59	5.22	5.27	5.25
V ₄	1.21	1.34	1.28	4.46	5.84	5.15
V ₅	1.67	1.56	1.62	4.18	5.02	4.60
V ₆	1.83	1.59	1.71	7.38	9.62	8.50
V ₇	2.11	2.17	2.14	7.04	7.98	7.51
V ₈	2.01	1.85	1.93	6.82	6.23	6.53
V ₉	1.76	1.23	1.50	5.93	5.91	5.92
Mean	1.65	1.67	1.66	5.90	6.68	6.29
	S.Ed	C.D (0.05)		S.Ed	C.D (0.05)	
G	0.053	0.108 (NS)		0.199	0.405**	
V	0.113	0.230**		0.423	0.860**	
G×V	0.160	0.325*		0.598	1.217 (NS)	

A-frame structure might result from efficient utilization of light, prevailing aerial temperature, better oxygen availability in the roots and periodical supply of nutrients. Similarly, Ranawade *et al.* (2017) revealed that hydroponically grown spinach exhibited increased sugar and protein content than soil-grown spinach. Our findings align with previous research emphasizing the critical role of nutrient solutions in hydroponic systems. Kumar *et al.*, 2023. and Venkatasai *et al.* (2025) concluded that the precise formulation of macronutrients and micronutrients significantly influences plant growth and metabolite production. Collectively, the optimized availability of nutrients and stable pH conditions, as maintained in our study's vertical A-frame structure, likely contributed to enhanced protein metabolism in the *Mentha* genotypes.

Vitamin C content: The vitamin C content was higher in the vertical A-frame condition (G₂) (24.3 mg 100 g⁻¹) than the open field condition (23.5 mg 100 g⁻¹). The genotype Kosi (V₁) registered the maximum vitamin C content (27.3 mg 100 g⁻¹), followed by Gomti (V₇) whereas the minimum vitamin C content of 21.1 mg 100 g⁻¹ was registered in MAS-1 (V₅). Notably, the Kosi genotype grown in the vertical A-frame system (G₂V₁) recorded the highest overall vitamin C content at 28.3 mg 100 g⁻¹. In contrast, the MAS-1 type (G₁V₅) grown under open field conditions showed the lowest vitamin C content at 19.3 mg 100 g⁻¹ (Fig. 1b). This finding aligns with Korbee *et al.* (2025), who suggested that precise control over nutrient delivery in vertical A-frame systems, enhances the plant's metabolic processes, including the synthesis of vitamin C. This is because essential nutrients like nitrogen and phosphorus are supplied in optimal amounts in such systems (Sgherri *et al.*, 2010). Buchanan *et al.* (2013) reported that, ascorbic acid content was produced through photosynthesis and lighting and fertilizer application may also have an impact on ascorbic acid production in plants.

Total phenol content: Among the two growing systems, vertical A-frame structure (G₂) recorded the maximum total phenol content (19.86 mg 100 g⁻¹) and the open field condition (G₁) had the minimum total phenol content with 19.64 mg 100 g⁻¹. Out of all varieties, Saksham (V₆) attained a profound increment in the

total phenol content with 23.14 mg 100 g⁻¹ at 45 days after planting and Bangalore type (V₉) had the lower total phenol content with 16.71 mg 100 g⁻¹. Saksham grown under open field conditions (G₁V₆) registered the highest total phenol content (23.42 mg 100 g⁻¹) and the lowest total phenol content (16.03 mg 100 g⁻¹) was noticed in Bangalore type grown under vertical A-frame structure (G₂V₉). (Fig. 1c). The generally higher phenol content observed in the vertical A-frame structure can be attributed to several factors. Firstly, the vertical A-frame design ensures better light penetration and distribution across all plant layers, which is crucial as phenol biosynthesis is a light-dependent process (Liu *et al.*, 2023). Secondly, as Senizza *et al.* (2021) found, the nutritional eustress often experienced in vertical farming systems can activate physiological responses that promote the accumulation of health-promoting bioactive compounds, including phenols. Furthermore, the higher potassium uptake observed under the vertical A-frame system may also contribute to increased phenolic concentrations. This is likely due to the efficient allocation of excess fixed carbon towards the shikimic pathway, a key metabolic route for phenolic synthesis, as influenced by optimal nutrient availability.

Potassium content: The growing systems had no significant effect on the leaf potassium content. Among the varieties, Gomti (V₇) registered the highest potassium content of 2.14%, followed by CIM-Kranti (V₂) with 1.98%, and the lowest potassium content was found in Kosi (V₁) with 1.21%. Among the interaction effects, Gomti grown under vertical A-frame structure (G₂V₇), reported the highest potassium content (2.17%), which was followed by open field condition (G₁V₇) (2.11%). The lowest potassium content was found to be in Bangalore type under vertical A-frame structure (G₂V₉) (1.23%) (Fig. 1d). Studies have consistently demonstrated the critical role of potassium (K) in plant water relations, particularly in the regulation of stomatal function. For instance, Hafsi *et al.* (2011) demonstrated that a potassium deficiency directly reduces stomatal conductance, underscoring its importance for gas exchange. Furthermore, Caliskan and Çalışkan (2019) reported that potassium serves as a key osmotic regulator, playing a significant role in governing the opening and closing of stomata and thereby preserving the plant's water content. The mechanism for enhanced potassium accumulation in our study can be attributed to the continuous supply of a nutrient solution. This steady supply of water ensures a constant transpiration stream within the plant, which in turn facilitates the passive mass flow of dissolved potassium ions to the roots as the plant absorbs water for transpiration. Consequently, this leads to an observed increase in the plant's overall potassium content, contributing to improved stomatal regulation and water balance (Sardans and Penuelas, 2021).

Calcium content: A significant variation in calcium content was observed between the growing conditions, where, the vertical A-frame condition (G₂) registered maximum calcium content (6.68%) and in contrary, the minimum calcium content (5.90%) was observed in the *Mentha* genotypes grown under open field condition (G₁). Saksham (V₆) showed the highest calcium content at 8.50%, followed by Gomti (V₇) at 7.51%, and the minimum was observed in MAS-1 (V₅) at 4.60%. The interaction of Saksham and vertical A-frame condition (G₂V₆) recorded the highest calcium content (9.62%) while MAS-1 grown under open field condition (G₁V₅) registered the lowest calcium content (9.62%) (Fig. 1e). The controlled environment

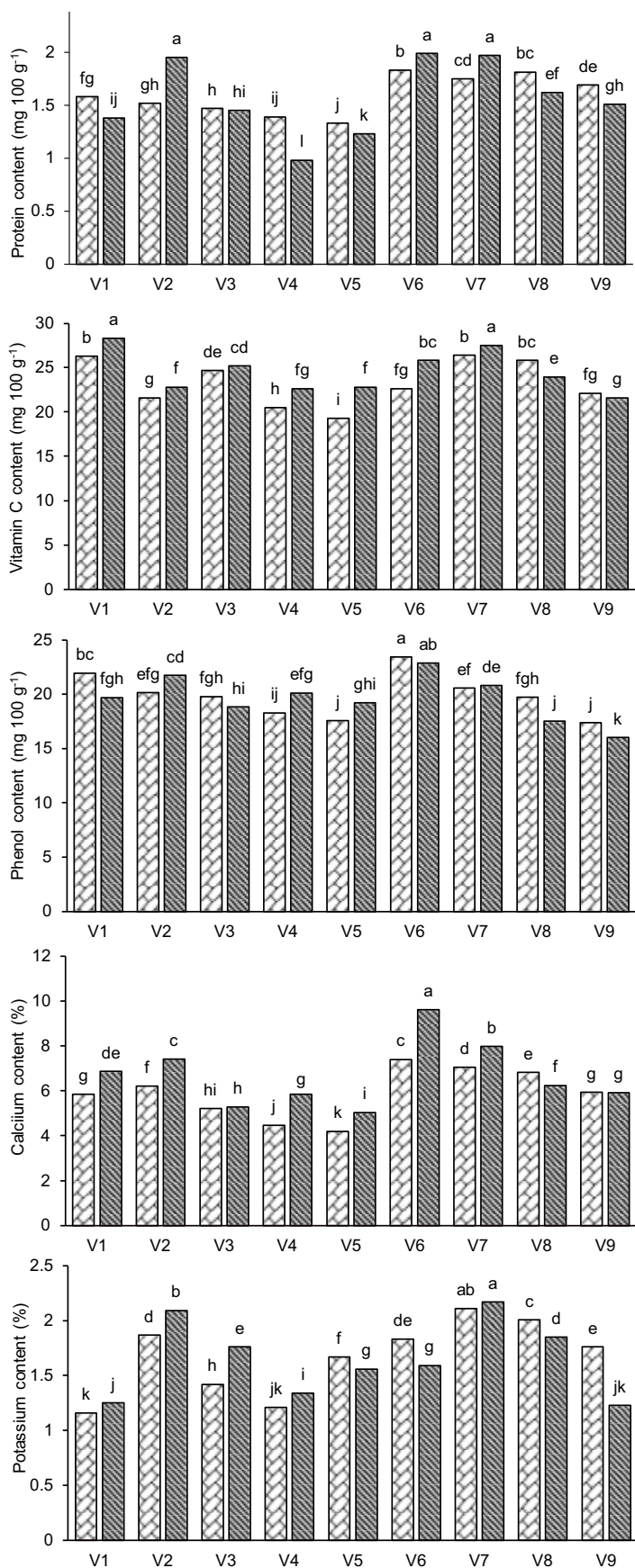


Fig. 1. Performance of different mint varieties under two growing systems (open field and vertical A-frame structure) on quality parameters at 45 days after planting (DAP): Protein content (a), Vitamin C content (b), Total phenol content (c), Potassium content (d) and Calcium content (e).

of the vertical A-frame system, particularly its stable pH and optimal EC, thus creates ideal conditions for the efficient uptake of key minerals like calcium and potassium. Our findings align with research by Gillespie *et al.* (2021), who also reported that pH plays a crucial role in calcium absorption. They noted that when calcium concentration is low, maintaining the pH closer to 6.5-7.0 can facilitate better uptake. Conversely, if the pH becomes too high, calcium may precipitate out of the solution, rendering it unavailable to plants and thereby reducing its absorption efficiency. Additionally, the Electrical Conductivity (EC) of the nutrient solution tends to be less than 2 dSm⁻¹, which fosters increased passive uptake by diffusion for these essential nutrients (Samarakoon *et al.*, 2017).

Among the nine genotypes evaluated for quality parameters Saksham (V₆) was superior in terms of protein, total phenol and calcium content under both open field and vertical A-frame structure. The variety Gomti (V₇) was found to be better for vitamin C and potassium content under both growing systems. The interactive effect of the vertical A-frame structure with these varieties (G₂V₆ and G₂V₇) resulted in enhanced quality attributes. This enhancement may be attributed to the improved microclimatic conditions, optimal pH range, and efficient nutrient and water management in the vertical A-frame system, which collectively promote better nutrient uptake and metabolic activity in plants.

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