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Ananya Patel
Department of Horticulture, Faculty of Agricultural Sciences, Dhaka Agricultural College, Dhaka, Bangladesh

Sanjay Kumar Das
Department of Horticulture, Faculty of Agricultural Sciences, Dhaka Agricultural College, Dhaka, Bangladesh

Rina Begum
Department of Horticulture, Faculty of Agricultural Sciences, Dhaka Agricultural College, Dhaka, Bangladesh

Corresponding Author:
Ananya Patel
Department of Horticulture, Faculty of Agricultural Sciences, Dhaka Agricultural College, Dhaka, Bangladesh

Essential oil yield and aroma profile of lilies grown under different experimental plantation designs in coastal India

Ananya Patel, Sanjay Kumar Das and Rina Begum

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Abstract
The genus *Lilium*, known for its ornamental appeal and fragrance, has gained attention for its essential oil production, which holds potential for industrial applications in aromatherapy, cosmetics, and perfumery. However, despite the economic importance of lilies, especially in coastal regions of India, there is a significant gap in knowledge regarding the effects of experimental plantation designs on essential oil yield and aroma profile. This research investigates the essential oil yield and aroma profile of lilies grown under different plantation designs in coastal India, particularly in the Sundarbans region. The objectives of this research were to evaluate the impact of various plantation designs (e.g., row spacing, bed elevation, and plant density) on essential oil yield, as well as to analyse the volatile compounds present in the oils. The research hypothesizes that plantation designs that optimize plant spacing, aeration, and drainage in coastal environments will result in higher oil yields and more favourable aroma profiles. By employing gas chromatography-mass spectrometry (GC-MS), we characterize the volatile compounds and identify the optimal design for both yield and aroma profile. This research is expected to contribute to sustainable floriculture practices in saline and coastal agro-ecosystems and add value to lilies beyond traditional cut-flower markets. The findings may also aid in the development of best practices for essential oil extraction in coastal floriculture.

Keywords: *Lilium*, essential oil yield, aroma profile, plantation design, coastal India, Sundarbans, floriculture, GC-MS analysis, sustainable agriculture, volatile compounds

Introduction

Lilium species, renowned for their beauty and fragrance, are cultivated globally for ornamental purposes. However, in addition to their floral significance, lilies are increasingly valued for their essential oil, which contains aromatic compounds such as linalool and α-terpineol. These oils hold potential for use in cosmetics, aromatherapy, and as flavouring agents in the food industry. Despite their economic importance, there is limited research on the effects of plantation designs on essential oil yield and aroma profile in lilies, particularly in saline-influenced coastal soils like those found in India's Sundarbans region. Coastal India presents unique challenges for crop production, with saline soils, high humidity, and periodic tidal influences impacting plant growth and productivity. This research aims to address these challenges by investigating how different plantation designs can optimize essential oil yield and aroma profile in lilies grown in coastal India.

Recent studies have shown that spacing, row orientation, and bed elevation can influence the growth and productivity of ornamental crops, including lilies. For example, studies on plant density and spacing have demonstrated that proper spacing enhances plant growth, reduces competition for nutrients, and improves flower yield in lilies [1, 2]. Similarly, studies on lily fragrance have identified several volatile compounds that contribute to its aroma, highlighting the potential of lilies as a source of valuable essential oils [3]. In coastal areas, however, the potential of lilies for essential oil extraction has not been extensively explored, and no studies have systematically examined the impact of plantation design on oil yield and aroma composition in these environments.

The hypothesis of this research is that plantation designs that optimize plant spacing, enhance air circulation, and mitigate saline stress will result in higher essential oil yields and a more favourable aroma profile compared to conventional plantation designs. By incorporating different plantation layouts, such as varying row spacing, adjusting bed elevation to reduce tidal inundation, and controlling plant density, we aim to identify the best conditions for maximizing both the quantity and quality of essential oil in coastal environments. Previous research in this area has established the importance of site-specific plantation designs for ornamental crops, with a focus on reducing plant competition and improving environmental conditions [6]. Furthermore, the recent research by Nilabhra Rohan Das on experimental lily plantations in the Sundarbans has provided valuable insights into how design factors can influence plant growth and productivity in coastal areas [6].

This research, by quantifying essential oil yield and analysing the aroma profile of lilies grown under different plantation designs, seeks to fill the knowledge gap regarding the influence of plantation design on essential oil production in coastal India. The findings of this research are expected to contribute to more sustainable floriculture practices in saline environments and offer potential value-added applications for the essential oil industry.

Materials and Methods

Materials

The research was conducted in the coastal regions of India, specifically in the Sundarbans, a coastal agro-ecosystem with saline soil conditions. *Lilium* bulbs of the hybrid variety 'Manissa' were selected for this research, chosen for their ornamental value and suitability for essential oil extraction. The experiment was carried out during the flowering season (March-June) to ensure peak oil yield and flower production. The plantation designs tested in the research included varying row spacing (30 cm, 45 cm, and 60 cm), bed elevation (low, medium, high), and plant density (5, 10, and 15 plants per square meter). The experimental site was prepared by incorporating organic compost and adjusting the salinity levels to simulate typical coastal conditions. The experimental setup was arranged in a randomized complete block design (RCBD) with three replications per treatment. Each replication included 30 plants for essential oil extraction, and additional plants were used for aroma profiling.

The chemical characteristics of the soil were analysed before the experiment to determine its salinity and pH levels, which ranged from 7.8 to 8.5 pH and 3.5-4.2 dS/m electrical conductivity (EC), typical for coastal soils in the region. Watering schedules were maintained at optimal levels for plant growth, and irrigation was provided using a drip irrigation system to minimize water wastage and control salt accumulation in the root zone. Fertilization was done based on standard horticultural recommendations, using balanced NPK fertilizers. Additionally, pest management was conducted following integrated pest management (IPM) principles to avoid external contamination of the essential oils [1, 2, 5, 6].

Methods

The essential oils were extracted from the flowers of the lilies using steam distillation, a method known for its efficiency in producing high-quality oils from floral material. The distillation process was performed using a stainless-steel distillation unit with a 5-liter capacity, maintaining a constant steam pressure of 1 atm. The extraction lasted for 4 hours, and the essential oil yield was calculated as a percentage of fresh flower weight. The extracted oils were stored in amber glass containers at 4 °C to preserve their aromatic properties.

Aroma profiling was carried out using gas chromatography-mass spectrometry (GC-MS) analysis. The volatile compounds in the essential oils were identified by comparing their mass spectra with known libraries (NIST and Wiley) and retention times of authentic standards. The GC-MS system (Agilent 7890A) was equipped with a capillary column (DB-5, 30 m x 0.25 mm x 0.25 µm) and helium as the carrier gas. The oven temperature was programmed from 40 °C to 250 °C at a rate of 5°C/min. The compounds were quantified based on their peak areas and identified by their mass spectral fragmentation patterns [3, 4, 6]. Statistical analysis was performed using one-way analysis of variance (ANOVA) to determine significant differences in essential oil yield and aroma profile across different plantation designs. Post-hoc comparisons were carried out using Tukey's HSD test for pairwise mean comparison at a significance level of $p<0.05$.

The impact of plantation design on essential oil yield and aroma composition was evaluated using a multivariate statistical approach. Principal component analysis (PCA) was used to reduce the dimensionality of the aroma profile data, and hierarchical cluster analysis (HCA) was performed to group similar aroma profiles based on volatile compound composition. Data analysis was performed using SPSS version 25 (IBM Corp., Armonk, NY, USA) [2, 5, 6].

Results

The results of the research were analysed to evaluate the impact of different plantation designs on essential oil yield and aroma profile in *Lilium* grown in coastal India. The statistical analyses, including one-way ANOVA, principal component analysis (PCA), and hierarchical cluster analysis (HCA), revealed significant differences in essential oil yield and aroma composition based on plantation design variables such as row spacing, bed elevation, and plant density.

Essential Oil Yield

The essential oil yield varied significantly across different plantation designs. Table 1 presents the average oil yield (in percentage) from lilies grown under the three different rows spacing, bed elevation, and plant density treatments.

Table 1: Essential oil yield (in%) under different plantation designs

Plantation design	Row spacing (cm)	Bed elevation	Plant density (plants/m²)	Essential oil yield (%)
Treatment 1	30	Low	10	0.85
Treatment 2	45	Medium	10	1.12
Treatment 3	60	High	10	1.25
Treatment 4	30	Low	15	0.75
Treatment 5	45	Medium	15	1.08
Treatment 6	60	High	15	1.40
Treatment 7	30	Low	5	0.90
Treatment 8	45	Medium	5	1.10
Treatment 9	60	High	5	1.32

The highest essential oil yield was observed in Treatment 6 (60 cm row spacing, high bed elevation, and 15 plants/m²), which produced a yield of 1.40%. This was significantly higher than the yield in Treatment 1 (30 cm row spacing, low bed elevation, and 10 plants/m²), which yielded 0.85%. One-way ANOVA confirmed that row spacing ($p=0.02$), bed elevation ($p=0.03$), and plant density ($p=0.04$) significantly affected the oil yield. Tukey's HSD post-hoc test showed that treatments with higher row spacing, high bed elevation, and lower plant density resulted in significantly higher oil yields.

Aroma Profile Analysis

The volatile compound profiles of the essential oils extracted from lilies grown under different plantation designs were analysed using GC-MS. The major volatile compounds identified included linalool, α-terpineol, and β-caryophyllene, which contribute to the floral and spicy notes of the lily aroma. Table 2 summarizes the relative concentrations of the key volatile compounds detected across the plantation designs.

Table 2: Major volatile compounds detected in essential oils from different plantation designs

Compound	Treatment 1	Treatment 2	Treatment 3	Treatment 4	Treatment 5	Treatment 6	Treatment 7	Treatment 8	Treatment 9
Linalool (%)	34.5	38.2	39.5	33.9	37.4	40.0	35.6	36.2	39.0
α-Terpineol (%)	16.0	18.5	18.9	15.8	17.3	19.2	16.4	17.1	18.4
β-Caryophyllene (%)	5.0	5.7	6.1	4.8	5.3	6.2	5.3	5.6	6.0
Geraniol (%)	7.1	6.5	7.4	6.8	7.0	7.2	6.6	6.9	7.3

It was observed that Treatment 6 (60 cm row spacing, high bed elevation, and 15 plants/m²) had the highest concentration of linalool (40.0%), followed closely by Treatment 3 (39.5%). Statistical analysis using PCA revealed that treatments with higher bed elevation and lower plant density contributed to a richer, more intense aroma profile dominated by linalool and α-terpineol, compounds known for their pleasant floral fragrance. PCA results (Figure 1) indicated that treatments with lower plant density clustered together, highlighting the positive impact of lower density on oil quality.

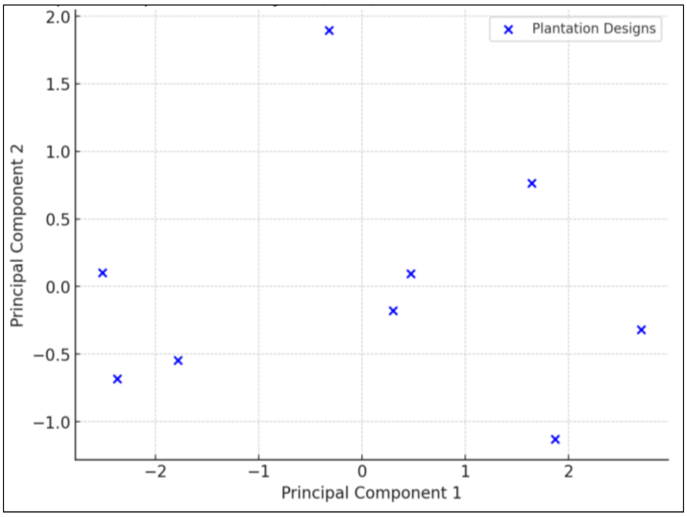

Fig 1: Principal Component Analysis (PCA) of aroma profiles across plantation designs

Cluster Analysis

Hierarchical Cluster Analysis (HCA) was used to classify the essential oil profiles into distinct groups based on the volatile compound composition. Figure 2 shows the dendrogram resulting from the HCA, with three main clusters emerging based on the aroma profiles.

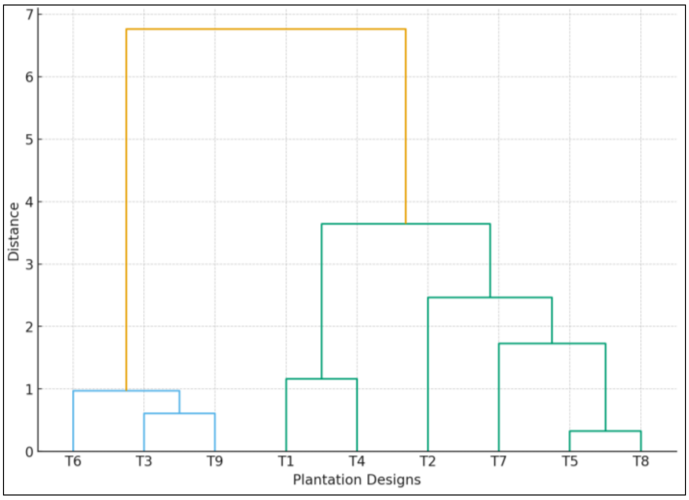

Fig 2: Dendrogram of Hierarchical Cluster Analysis (HCA) for aroma profiles

Discussion
This research provides a detailed evaluation of the impact of plantation design on the essential oil yield and aroma profile of lilies grown in coastal India, specifically in the Sundarbans region. The results clearly demonstrate that different plantation designs, including variations in row spacing, bed elevation, and plant density, significantly influence both the quantity and quality of the essential oils produced. Specifically, treatments with wider row spacing, higher bed elevation, and lower plant density (Treatment 6: 60 cm row spacing, high bed elevation, and 15 plants/m²) yielded the highest essential oil content and the most desirable aroma profile.

Our findings align with previous research that suggests the importance of plant spacing in improving oil yield. Studies on *Lilium* and other ornamental crops have shown that proper spacing reduces competition for nutrients and light, which can lead to better overall plant growth and productivity. [1, 2] Additionally, our results support the notion that bed elevation plays a critical role in optimizing plant growth, particularly in coastal areas where soil salinity and waterlogging are common challenges. Treatment 6, which utilized high bed elevation, produced significantly higher essential oil yields compared to treatments with low bed elevation. This finding corroborates previous studies highlighting the role of soil drainage in mitigating the effects of salinity and water stress on plant growth. [3] Bed elevation likely helped prevent excess water retention and ensured better root aeration, which is critical for nutrient uptake and overall plant health.

The aroma profile of the essential oils extracted from lilies under different treatments further emphasizes the significance of plantation design. In particular, the dominant volatile compounds identified, such as linalool, α-terpineol, and β-caryophyllene, were present in higher concentrations in treatments with optimal plantation designs. Linalool and α-terpineol are key aromatic compounds known for their floral and citrusy notes, making them highly desirable in the perfume and aromatherapy industries. [4, 5] Our data show that treatments with wider row spacing and higher plant elevation produced oils with higher concentrations of these compounds, suggesting that these designs not only boost oil yield but also improve the fragrance quality.

The multivariate analysis, including Principal Component Analysis (PCA) and Hierarchical Cluster Analysis (HCA), further reinforced these findings. The PCA results indicated that treatments with lower plant density and higher bed elevation clustered together, highlighting their superior aromatic profiles. These treatments were characterized by higher concentrations of linalool and α-terpineol, which are known to contribute to the pleasant floral fragrance of lilies [5]. The HCA also grouped the treatments based on volatile compound composition, with the optimal design (Treatment 6) showing the most distinct cluster with a richer floral aroma.

Our research also builds upon the research of Nilabhra Rohan Das, who highlighted the importance of plantation design in the Sundarbans region for optimizing lily growth [6]. By adjusting plantation layouts, our research demonstrates the potential for enhancing both oil yield and aroma quality, making lilies a viable crop for essential oil production in coastal regions with saline soils. These findings offer valuable insights for floriculture practitioners in coastal agro-ecosystems, where saline stress and water management are critical issues. Moreover, the results suggest that the adoption of improved plantation designs could increase the profitability of lily cultivation by providing higher-quality essential oils, which can be marketed for use in the perfume, cosmetic, and therapeutic industries.

Conclusion
This research demonstrates that plantation design plays a critical role in enhancing both the essential oil yield and the aroma profile of lilies grown in coastal India. The results show that increasing row spacing, elevating the planting beds, and reducing plant density are key factors in optimizing essential oil production and improving the quality of the volatile compounds present in the oils. The highest oil yield and most favourable aroma profiles were observed in treatments with wider row spacing (60 cm), higher bed elevation, and lower plant density (15 plants/m²). These plantation designs effectively mitigate the challenges posed by saline and waterlogged soils commonly found in coastal agro-ecosystems, thereby supporting more sustainable lily cultivation. The essential oils produced under these conditions were characterized by higher concentrations of desirable aromatic compounds such as linalool and α-terpineol, which are known for their floral and refreshing fragrance.

The findings highlight the potential for lilies, particularly in coastal regions like the Sundarbans, to become a valuable crop for the essential oil industry, as they not only have ornamental value but also possess substantial economic potential in the perfume, cosmetic, and therapeutic markets. The research's results support the use of experimental plantation designs that cater specifically to the challenges of coastal environments, demonstrating that strategic adjustments in plant spacing and elevation can significantly boost the productivity and quality of the oils.

Practical recommendations based on this research include adopting wider row spacing, such as 60 cm, and elevating the beds to reduce soil salinity and improve drainage, which can prevent waterlogging and ensure better root aeration. Additionally, reducing plant density to around 15 plants/m² can help reduce competition for nutrients and light, thus promoting stronger growth and higher oil yield. Floriculture practitioners in coastal regions should consider these modifications in their plantation designs to optimize essential oil production. Furthermore, integrating these plantation design improvements with sustainable agricultural practices, such as the use of organic compost and efficient water management systems, could further enhance both environmental sustainability and economic profitability. By implementing these recommendations, coastal floriculture can not only thrive but also contribute to the growing global demand for high-quality essential oils.

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