



RESEARCH ARTICLE

Nutrient growing media consortia with biocontrol agents enhance growth, physiological traits and flowering of tuberose [*Agave amica* (Medik.)] cv. Arka Prajwal

B Pavana¹, S Ganesh^{1*}, S Anandhi¹ & S Rageshwari²

¹Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu 603 201, Tamil Nadu, India

²Department of Plant Protection, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Baburayanpettai, Chengalpattu 603 201, Tamil Nadu, India

*Correspondence email - ganesh4u@gmail.com

Received: 18 June 2026; Accepted: 06 August 2026; Available online: Version 1.0: 15 September 2026

Cite this article: Pavana B, Ganesh S, Anandhi S, Rageshwari S. Nutrient growing media consortia with biocontrol agents enhance growth, physiological traits and flowering of tuberose [*Agave amica* (Medik.)] cv. Arka Prajwal. Plant Science Today. 2026; 13(sp5): 1-12. <https://doi.org/10.14719/pst.16189>

Abstract

Tuberose [*Agave amica* (Medik.)] cv. Arka Prajwal is a commercially important ornamental bulbous crop, yet suboptimal growing media constrain its productivity under pot culture. This study evaluated the influence of nutrient enriched growing media consortia comprising organic amendments (farmyard manure, vermicompost, cocopeat) combined with biocontrol agents-*Trichoderma viride*, *Pochonia chlamydosporia* and *Purpureocillium lilacinum* at 50 g pot⁻¹ on the growth, flowering and physiological traits (total chlorophyll and phenol content) of tuberose under pot culture conditions. A completely randomised design (CRD) with 17 treatments and 3 replications were employed, with fluopyram 34.48 % suspension concentrate (SC) at 0.1 % as the chemical check. Among all the treatments, T₁₁ (red soil + farmyard manure + vermicompost 1 : 1 : 1 + *P. chlamydosporia* at 50 g pot⁻¹) recorded maximum plant height (61.17 cm), leaf area index (2.71), chlorophyll content (1.61 mg g⁻¹) and phenol content (2.72 mg g⁻¹), spike length (91.70 cm), weight of florets per pot (95.22 g) and days to last floret withering (16.00 days). Principal component analysis identified spike length, weight of florets per pot and days to last floret withering as the primary determinants of treatment-level variation in tuberose productivity. Correlation analysis revealed strong associations between vegetative vigour and floral quality traits. The bio-organic consortia consistently outperformed both the untreated control and chemical standard, demonstrating their potential as sustainable, eco-friendly alternatives to conventional red soil-based cultivation for commercial pot-culture production of tuberose.

Keywords: *Agave amica*; biocontrol agents; bio-organic media; growing media; *Pochonia chlamydosporia*; sustainable floriculture

Introduction

Tuberose [*Agave amica* (Medik.) Thiede & Govaerts; syn. *Polianthes tuberosa* L.] is a highly valued bulbous ornamental crop cultivated worldwide for its attractive spikes, intensely fragrant florets and economically important essential oil. In India, tuberose occupies a prominent position in the floriculture industry and is extensively cultivated in Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, Uttar Pradesh and West Bengal for loose flowers, cut spikes and perfume extraction. As per recent estimates for 2025–26, the area under tuberose cultivation in India stood at 26.52 thousand hectares, with a production of 224.96 thousand metric tonnes of loose flowers and 111.21 thousand metric tonnes of cut flowers. Among the available cultivars, 'Arka Prajwal' is widely preferred for its superior spike quality, high flower yield and adaptability to diverse agro-climatic conditions (1–2).

The productivity of tuberose is strongly influenced by the physical, chemical and biochemical properties of the growing medium, particularly under pot culture conditions where root-zone volume is restricted. Red soil, commonly used in ornamental

production systems of South India, often possesses low organic matter content, poor nutrient buffering capacity and limited microbial activity, which can restrict root growth and nutrient acquisition. Incorporation of organic amendments such as farmyard manure (FYM), vermicompost and cocopeat has been reported to improve substrate porosity, water-holding capacity, cation exchange capacity and nutrient availability, thereby enhancing vegetative growth, flowering and bulb production in ornamental crops. Farmyard manure enhances soil fertility and microbial activity, vermicompost contributes rich humic substances and beneficial microbial communities that stimulate plant growth, while cocopeat improves aeration and moisture retention in the root zone (3–9). Such organic amendment-based media combinations have been shown to consistently enhance growth and flowering across several ornamental crops (5, 8, 9).

Biocontrol agents are increasingly recognised as essential components of sustainable growth media consortia. Biocontrol agents such as *Trichoderma viride*, *Pochonia chlamydosporia* and *Purpureocillium lilacinum* have gained importance in sustainable horticulture due to their ability to promote plant growth and

nutrient acquisition (10–14). Fluopyram 34.48 % suspension concentrate was included as a chemical standard for comparison, as it has been found to indirectly boost plant development through higher populations of phosphate-solubilising and nitrogen (N)-fixing bacteria in the rhizosphere (15). Studies combining organic media amendments with biocontrol agents have reported synergistic improvements in growth and flowering across ornamental crops, indicating potential for integrated substrate management in bulbous ornamentals. However, information on their combined effects with biocontrol agents on tuberose remains limited.

Despite the availability of individual studies on organic amendments and biocontrol agents in horticultural crops, comprehensive comparative studies integrating multiple growing media combinations with *T. viride*, *P. chlamydosporia* and *P. lilacinum* in tuberose under pot culture conditions are very limited. This study assessed the impact of different growing media combinations (red soil, FYM, vermicompost and cocopeat) combined with biocontrol agents at 50 g pot⁻¹ on tuberose cv. Arka Prajwal to enhance growth, physiological traits and flowering quality under pot culture conditions.

Materials and Methods

Experimental site and period

The present experiment was carried out at the Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, Baburayanpettai, Chengalpattu District, Tamil Nadu, India. The experimental site is situated in the tropical coastal agro-climatic zone and is characterised by warm weather conditions throughout the year. The geographical details of the experimental site are 12.38° N latitude and 79.73° E longitude, with an average elevation of 50 m above mean sea level (MSL). During the study period, the mean temperature ranged from 22–32 °C, with relative humidity varying between 65 and 85 % under open conditions.

Plant material, bulb priming and establishment

Medium-sized bulbs (3.5–5.0 cm in diameter, 35–45 g in weight) of cv. Arka Prajwal and bulbs free from visible injuries or diseases were selected as experimental material. To overcome bulb dormancy and ensure uniform sprouting across treatments, all bulbs were pre-soaked in gibberellic acid (GA₃) at 200 ppm by soaking them for 12 hr. Since GA₃ treatment was applied uniformly to all bulbs across all 17 treatments before planting, it did not differentially influence treatment comparisons; any subsequent variation in sprouting percentage and days to sprouting was therefore attributable to the growing media and biocontrol treatments applied post-planting. Subsequently, shade-dried and planted at two bulbs per pot, in pots measuring 28 × 28 × 50 cm (width × length × height), containing the respective growing media treatments.

Experimental details, design and development of nutrified growing media-biocontrol consortia

The experiment was laid out in a completely randomised design (CRD) comprising 17 treatments with 3 replications, with five pots constituting one replication, resulting in a total of 255 experimental pots. Each pot, containing two uniform tuberose bulbs, served as the experimental unit. The treatments comprised combinations of

red soil, organic amendments (FYM, vermicompost and cocopeat) in 1 : 1 or 1 : 1 : 1 ratios on a volume basis (v/v) and along with biocontrol agents - *T. viride*, *P. chlamydosporia* and *P. lilacinum* each at 50 g pot⁻¹ along with a chemical check (Fluopyram 34.48 % SC at 0.1 %). Talc-based formulations of *T. viride* (2 × 10⁶ CFU g⁻¹), *P. chlamydosporia* (TNAU-Pc001) (1 × 10⁸ CFU g⁻¹) and *P. lilacinum* (TNAUPI-001) (formerly *Paecilomyces lilacinus*) (2 × 10⁸ CFU g⁻¹) were used as biocontrol agents and 3 applications were made at 15-day intervals. Fluopyram 34.48 % SC was applied at 0.1 % (v/v). The fluopyram suspension was prepared and applied using the same protocol (1 mL formulation in 1000 mL water, 300 mL drench per pot, 3 applications at 15-day intervals) as the biocontrol treatments to ensure comparability across treatments. The details of the experimental treatments are given below.

Irrigation schedule

Irrigation was provided immediately after planting to facilitate bulb establishment. Thereafter, irrigation was applied at 2–3-day intervals during the initial establishment phase and subsequently at 3–5-day intervals depending on the moisture status of the growing media and prevailing weather conditions. Uniform irrigation was maintained for all treatments throughout the experimental period.

Irrigation quantity

Approximately 1.0–1.5 L of water per polybag was applied during each irrigation. The quantity was adjusted whenever necessary to maintain optimum moisture in the growing media without causing waterlogging.

Water quality

Clean borewell water available at the experimental farm was used for irrigation throughout the study. The water was suitable for horticultural crop production and was used uniformly for all treatments.

Fertiliser application

No chemical fertilisers were applied during the experimental period. Nutrient supply to the crop depended entirely on the respective growing media consortia consisting of red soil, FYM, vermicompost, cocopeat and the fungal bio-control agents included in each treatment. Hence, differences observed among treatments were attributed solely to the composition and biological activity of the growing media consortia. Treatment details are given in Table 1 below.

Physicochemical analysis of growing media

Before planting, the physicochemical characteristics of the growing media were analysed using standard soil analytical procedures. Parameters such as pH, electrical conductivity (EC), lime status, texture, available N, phosphorus (P), potassium (K) and soil organic carbon were determined. Soil pH and EC were measured using a calibrated digital pH meter and conductivity meter, respectively. Available N was estimated by the alkaline permanganate method (16), P by Olsen's method (17). Potassium in the extract was determined by using a flame photometer (17). Organic carbon content was determined by following the Walkley and Black wet oxidation method (18).

Assessment of growth parameters

Vegetative growth parameters were recorded at 30, 60 and 90 days after planting. Plant height, number of tillers per plant, leaf length,

Table 1. Details of experimental treatments

Treatment	Treatment details
T ₁	Red soil (control)
T ₂	Red soil + FYM (1 : 1)
T ₃	Red soil + FYM + vermicompost (1 : 1 : 1)
T ₄	Red soil + FYM + cocopeat (1 : 1 : 1)
T ₅	Red soil + <i>Trichoderma viride</i> at 50 g pot ⁻¹
T ₆	Red soil + FYM (1 : 1) + <i>Trichoderma viride</i> at 50 g pot ⁻¹
T ₇	Red soil + FYM + Vermicompost (1 : 1 : 1) + <i>Trichoderma viride</i> at 50 g pot ⁻¹
T ₈	Red soil + FYM + cocopeat (1 : 1 : 1) + <i>Trichoderma viride</i> at 50 g pot ⁻¹
T ₉	Red soil + <i>Pochonia chlamydosporia</i> at 50 g pot ⁻¹
T ₁₀	Red soil + FYM (1 : 1) + <i>Pochonia chlamydosporia</i> at 50 g pot ⁻¹
T ₁₁	Red soil + FYM + vermicompost (1 : 1 : 1) + <i>Pochonia chlamydosporia</i> at 50 g pot ⁻¹
T ₁₂	Red soil + FYM + vocopeat (1 : 1 : 1) + <i>Pochonia chlamydosporia</i> at 50 g pot ⁻¹
T ₁₃	Red soil + <i>Purpureocillium lilacinum</i> at 50 g pot ⁻¹
T ₁₄	Red soil + FYM (1 : 1) + <i>Purpureocillium lilacinum</i> at 50 g pot ⁻¹
T ₁₅	Red soil + FYM + vermicompost (1 : 1 : 1) + <i>Purpureocillium lilacinum</i> at 50 g pot ⁻¹
T ₁₆	Red soil + FYM + cocopeat (1 : 1 : 1) + <i>Purpureocillium lilacinum</i> at 50 g pot ⁻¹
T ₁₇	Red soil + Fluopyram 34.48 % SC at 0.1 %

FYM: farmyard manure; SC: suspension concentrate.

leaf width and leaf area index (LAI) were calculated using the formula:

LAI = leaf area per plant/ground area occupied by the plant at each observation stage

Determination of physiological and biochemical attributes

Physiological and biochemical analyses were carried out using fresh leaf samples collected at 90 days after planting (DAP), a stage that coincides with the vegetative-to-reproductive transition phase in tuberose. This stage was selected based on evidence that vegetative growth parameters at 90 DAP show strong correlation with the onset of reproductive development and that treatment-induced physiological differences become most pronounced around this period. This sampling window is consistent with prior studies on *A. amica* (tuberose), where key physiological parameters were also recorded at approximately three months after crop establishment. Total chlorophyll was extracted using 80 % acetone and quantified spectrophotometrically (19), while total phenol content was estimated by the Folin-Ciocalteu colourimetric method (20). Chlorophyll and phenol content were estimated from three independent replicate samples per treatment, corresponding to the 3 replications of the CRD.

Flowering and yield parameters

Flowering observations were recorded from spike initiation until completion of flowering. Days to spike emergence were calculated from the date of planting to the appearance of the floral spike. Spike length, spike girth, number of florets per spike fresh weight of florets per pot and days of last floret withering were measured at full peak flowering.

Statistical analysis

The experimental data were subjected to analysis of variance (ANOVA) appropriate for a CRD according to the statistical model $Y_{ij} = \mu + T_i + e_{ij}$, where Y_{ij} is the response of the j^{th} replication of the i^{th} treatment, μ is the general mean, T_i is the effect of the i^{th} treatment and e_{ij} is the random error associated with the j^{th} replication of the i^{th} treatment. Before ANOVA, the data were tested for the assumptions of normality of residuals and homogeneity of variance. Analysis was carried out using statistical software (OPSTAT). ANOVA was performed to determine treatment effects and treatment means were separated using the critical difference test at the 5% probability level ($p \leq 0.05$). The standard error of the mean (SEM $\pm$) and critical difference (CD at $p = 0.05$) for each parameter are presented

alongside the treatment means in the respective tables. Pearson's correlation analysis was performed among growth, flowering and biochemical parameters using treatment mean values ($n = 17$) to assess the degree and direction of association between traits. The experiment employed 3 replications per treatment, consistent with standard practice for CRD pot-culture studies involving many treatments (17); however, the authors acknowledge that higher replication would have provided greater statistical power to detect smaller treatment differences, particularly for parameters showing high within-treatment variability. Correlation analyses were based on treatment mean values and were interpreted as measures of association rather than cause-and-effect relationships.

Results

Physico-chemical properties of growing media

The physico-chemical properties of the growing media after harvest differed significantly among the treatments with respect to EC, organic carbon (OC), available N, P and K, whereas pH, lime status and soil texture remained non-significant (Table 2). Across treatments, pH remained stable (7.4–7.6) and all growing media retained a sandy clay loam texture, indicating that the applied organic amendments and biocontrol agents did not alter the inherent soil reaction or textural class. The EC ranged from 0.18–1.50 dS m⁻¹. The highest EC (1.50 dS m⁻¹) was recorded in T₁₁ (red soil + FYM + vermicompost + *P. chlamydosporia*), which was statistically on par with T₁₅ (1.10 dS m⁻¹) and T₁₃ (1.01 dS m⁻¹). The lowest EC (0.18 dS m⁻¹) was recorded in the untreated control (T₁). The pH of the growing media varied between 7.4 and 7.6 and the differences among treatments were non-significant. Likewise, lime status and soil texture remained unchanged, with all treatments exhibiting sandy clay loam (SCL) texture. Organic carbon content differed significantly among treatments and ranged from 0.18–1.60 %. The highest organic carbon (1.60 %) was recorded in T₁₁, followed by T₁₅ (1.50 %), T₁₃ (1.47 %) and T₃ (1.44 %), whereas the lowest value (0.18 %) was observed in T₁. Available N content varied significantly from 61.09–194.36 kg ha⁻¹. The maximum N content (194.36 kg ha⁻¹) was recorded in T₁₁, followed by T₁₅ (192.28 kg ha⁻¹), T₃ (190.85 kg ha⁻¹) and T₁₆ (189.28 kg ha⁻¹). The minimum N (61.09 kg ha⁻¹) was recorded in the control (T₁). Available P also differed significantly among treatments, ranging from 7.20–35.80 kg ha⁻¹. The highest P (35.80 kg ha⁻¹) was recorded in T₁₁, followed by T₁₅ (34.20 kg ha⁻¹), T₃ (32.50 kg ha⁻¹) and T₁₆ (29.10 kg ha⁻¹), while the lowest value

Table 2. Physicochemical properties of enriched growing media used for experimentation

Treatment	EC (dS m ⁻¹)	pH	Lime Status	Texture	OC (%)	Nitrogen (kg ha ⁻¹)	Phosphorous (kg ha ⁻¹)	Potassium (kg ha ⁻¹)
T ₁	0.18	7.6	N	SCL	0.18	61.09	7.20	148.69
T ₂	0.48	7.6	N	SCL	1.12	106.11	10.40	175.19
T ₃	0.85	7.5	N	SCL	1.44	190.85	32.50	210.76
T ₄	0.54	7.5	N	SCL	1.30	171.07	17.50	171.32
T ₅	0.49	7.5	N	SCL	0.84	160.14	8.80	184.28
T ₆	0.23	7.5	P	SCL	1.38	174.07	19.30	190.62
T ₇	0.68	7.6	P	SCL	1.36	180.92	24.10	201.08
T ₈	0.76	7.5	P	SCL	1.40	183.93	25.90	202.74
T ₉	0.35	7.6	N	SCL	0.84	127.55	14.80	177.32
T ₁₀	0.79	7.5	P	SCL	1.39	177.07	21.00	195.51
T ₁₁	1.50	7.4	P	SCL	1.60	194.36	35.80	221.98
T ₁₂	0.58	7.5	P	SCL	1.20	186.93	27.40	204.53
T ₁₃	1.01	7.6	N	SCL	1.47	151.78	13.20	195.89
T ₁₄	0.62	7.5	P	SCL	1.10	179.00	22.80	198.02
T ₁₅	1.10	7.4	P	SCL	1.50	192.28	34.20	215.53
T ₁₆	0.51	7.5	P	SCL	1.25	189.28	29.10	208.59
T ₁₇	0.21	7.6	N	SCL	0.25	66.04	11.90	177.90
SEm (±)	0.099	0.117	NS	NS	0.017	2.406	0.314	2.850
CD (p = 0.05)	0.028	NS	NS	NS	0.048	6.915	0.902	8.193

P: calcareous; N: non-calcareous soil; SCL: sandy clay loam; EC: electrical conductivity; OC: organic carbon.

(7.20 kg ha⁻¹) was observed in T₁. Available K ranged from 148.69–221.98 kg ha⁻¹. The highest K content (221.98 kg ha⁻¹) was recorded in T₁₁, followed by T₁₅ (215.53 kg ha⁻¹), T₃ (210.76 kg ha⁻¹) and T₁₆ (208.59 kg ha⁻¹). The lowest K (148.69 kg ha⁻¹) was recorded in T₁.

Influence of enriched growing media consortia on days of sprouting, plant height and number of tillers

Significant differences ($p \leq 0.05$) were observed among the enriched growing media consortia with respect to plant height and number of tillers per plant in tuberose cv. Arka Prajwal (Table 3). Plant height increased progressively with crop growth across all treatments; however, the magnitude of increase varied significantly depending on the growing media consortium. Days to 100 % sprouting and days to spike emergence differed significantly ($p \leq 0.05$) among treatments (Fig. 1). The shortest sprouting period (5.00 days, a 66.7 % reduction over control) and earliest spike emergence (85 days, a 36.1 % reduction over control) were recorded in T₁₁, followed by T₁₅ (6.00 days; 88 days) and T₁₃. The untreated control (T₁) took the longest for both sprouting (15.00 days) and spike emergence (133 days).

At 30 DAP, the highest plant height (12.43 cm) was recorded in T₁₁ (red soil + FYM + vermicompost (1 : 1 : 1) + *P. chlamydosporia* at 50 g pot⁻¹), representing a 103.8 % increase over the untreated control (6.10 cm), which was significantly superior to all other treatments, followed by T₁₃ (11.60 cm) and T₁₅ (10.36 cm). The lowest plant height (6.10 cm) was observed in the untreated control (T₁). At 60 DAP, T₁₅ recorded the highest plant height (33.20 cm), representing a 183.3 % increase over the control (11.72 cm), followed by T₁₃ (31.02 cm) and T₁₁ (28.64 cm). These treatments were significantly superior to the remaining treatments, whereas the control (T₁) recorded the lowest plant height (11.72 cm). At 90 DAP, T₁₁ produced the highest plants (61.17 cm), a 312.5 % increase over the untreated control (14.83 cm), followed by T₁₃ (58.83 cm), T₃ (56.40 cm) and T₁₅ (50.83 cm). The untreated control (T₁) recorded the lowest plant height (14.83 cm). The number of tillers per plant also differed significantly among treatments. The highest tiller production was recorded in T₁₁ (2.90 tillers plant⁻¹), a 147.9 % increase over the control (1.17 tillers plant⁻¹), followed by T₁₂ (2.80 tillers plant⁻¹). The lowest number of tillers (1.17 tillers plant⁻¹) was recorded in T₁.

Table 3. Influence of enriched growing-media consortia on plant height and number of tillers per plant in tuberose cv. Arka Prajwal

Treatments	Plant height (cm)			Number of tillers per plant 60 DAP
	30 DAP	60 DAP	90 DAP	
T ₁	6.10 ^l	11.72 ⁿ	14.83 ^o	1.17 ^l
T ₂	6.57 ^{hi}	19.83 ^f	32.77 ^g	1.77 ^e
T ₃	10.03 ^c	26.40 ^d	56.40 ^c	2.30 ^d
T ₄	8.17 ^{ef}	12.70 ^m	20.80 ^l	1.50 ^g
T ₅	6.67 ^h	17.42 ^{hi}	27.87 ^j	1.33 ^l
T ₆	7.37 ^g	14.20 ^l	18.87 ^m	1.43 ^{gh}
T ₇	8.42 ^e	15.30 ^k	18.13 ^m	1.17 ^l
T ₈	6.43 ^{hij}	18.30 ^g	34.83 ^f	1.67 ^f
T ₉	6.50 ^{hij}	12.48 ^{mn}	18.53 ^m	1.67 ^f
T ₁₀	9.33 ^d	17.85 ^{gh}	31.83 ^h	1.23 ^j
T ₁₁	12.43 ^a	28.64 ^c	61.17 ^a	2.90 ^a
T ₁₂	6.42 ^{hij}	16.28 ^j	28.93 ⁱ	2.80 ^b
T ₁₃	11.60 ^b	31.02 ^b	58.83 ^b	2.70 ^c
T ₁₄	9.98 ^c	24.70 ^e	49.17 ^e	1.70 ^{ef}
T ₁₅	10.36 ^c	33.20 ^a	50.83 ^d	1.77 ^e
T ₁₆	6.15 ^{ij}	16.75 ^{ij}	26.57 ^k	1.37 ^{hi}
T ₁₇	7.75 ^{fg}	13.77 ^l	16.83 ⁿ	1.77 ^e
SEm (±)	0.146	0.291	0.274	0.028
CD (p = 0.05)	0.421	0.834	0.787	0.079

DAP: days after planting.

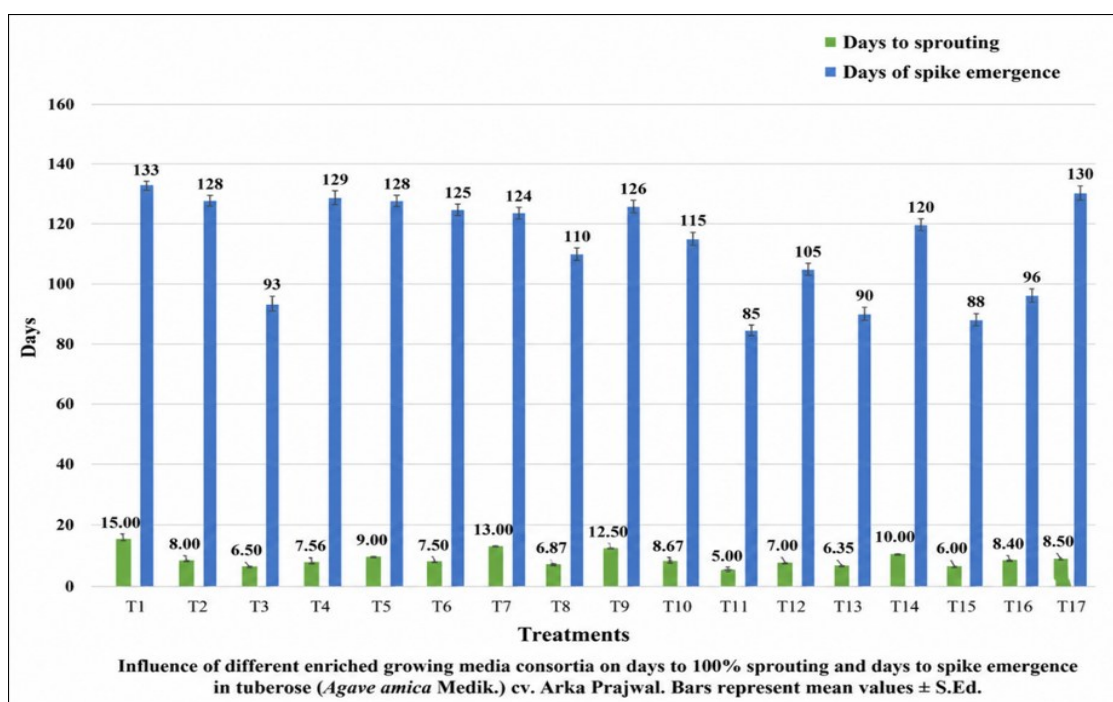


Fig. 1. Effect of different enriched growing media consortia on days to 100 % sprouting and days to spike emergence in tuberose *Agave amica* (Medik.) cv. Arka Prajwal. Vertical bars represent mean $\pm$ SE.CD ($p = 0.05$): days to 100 % sprouting = 0.361; days to spike emergence = 4.218.

Leaf morphological responses of tuberose to enriched growing media consortia

Significant differences ($p \leq 0.05$) were observed among the enriched growing media consortia with respect to leaf length, leaf width and LAI of tuberose cv. Arka Prajwal at all growth stages (Table 4).

At 30 DAP, the highest leaf length (13.50 cm) was recorded in T₁₅, a 382.1 % increase over the control (2.80 cm), followed by T₁₁ (12.50 cm), T₃ and T₁₄ (12.00 cm each), while the minimum leaf length (2.80 cm) was observed in the untreated control (T₁). At 60 DAP, T₁₃ recorded the highest leaf length (26.48 cm), followed by T₁₅ (24.59 cm) and T₁₁ (23.58 cm). At 90 DAP, T₁₁ recorded the highest leaf length (55.11 cm), which was significantly superior to all other treatments, representing a 461.2 % increase over the control (9.82 cm) followed by T₁₃ (50.71 cm), T₁₅ (49.24 cm) and T₃ (47.21 cm). The untreated control (T₁) recorded the shortest leaf length (9.82 cm).

Leaf width also varied significantly among treatments. At 30 DAP, the highest leaf width (1.40 cm) was recorded in T₁₁, followed by T₁₅ (1.05 cm) and T₁₆ (1.00 cm). At 60 DAP, T₁₁ recorded the maximum leaf width (2.85 cm), followed by T₁₅ (2.08 cm) and T₁₃ (2.00 cm). Similarly, at 90 DAP, T₁₁ produced the widest leaves (3.42 cm), a 144.3 % increase over the untreated control (1.40 cm) followed by T₁₅ (2.35 cm) and T₁₃ (2.28 cm), whereas the untreated control recorded the minimum leaf width (1.40 cm).

The LAI increased progressively with crop growth across all treatments. At 30 DAP, the highest LAI was recorded in T₁₁ (0.281), followed by T₁₅ (0.215) and T₁₃ (0.214). At 60 DAP, T₁₁ again recorded the maximum LAI (1.03), followed by T₃ (0.94) and T₁₅ (0.82). At 90 DAP, the highest LAI (2.71) was recorded in T₁₁, followed by T₁₅ (2.40), T₃ (2.33) and T₁₃ (1.86). The untreated control (T₁) consistently recorded the lowest LAI throughout the experimental period.

Table 4. Influence of enriched growing media consortia on leaf length, leaf width and leaf area index of tuberose cv. Arka Prajwal

Treatments	Leaf length (cm)			Leaf width (cm)			Leaf area index		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
T ₁	2.80 ⁿ	5.52 ^j	9.82 ^l	0.60 ^l	1.22 ^p	1.40 ^o	0.013 ⁿ	0.04 ^k	0.21 ^m
T ₂	8.00 ^f	15.91 ^d	26.06 ^f	0.65 ^k	1.30 ^o	1.48 ^{no}	0.049 ^j	0.28 ^g	0.73 ^j
T ₃	12.00 ^c	23.48 ^c	47.21 ^c	0.95 ^d	1.94 ^{cd}	2.20 ^c	0.180 ^c	0.94 ^b	2.33 ^c
T ₄	5.50 ^k	10.86 ^h	18.20 ⁱ	0.75 ^{hi}	1.47 ^{lm}	1.67 ^{kl}	0.048 ^{jk}	0.17 ^h	0.71 ^j
T ₅	8.50 ^e	16.61 ^d	25.08 ^{fg}	0.70 ^j	1.35 ^{no}	1.55 ^{mn}	0.060 ⁱ	0.28 ^g	0.97 ^h
T ₆	3.50 ^m	6.93 ⁱ	12.27 ^k	0.80 ^g	1.57 ^{jk}	1.79 ^{ij}	0.034 ^m	0.08 ^j	0.42 ^l
T ₇	6.00 ^j	11.81 ^g	15.65 ^j	0.85 ^f	1.72 ^{gh}	1.96 ^{fg}	0.065 ^h	0.09 ⁱ	0.42 ^l
T ₈	6.50 ^h	12.54 ^{fg}	25.08 ^{fg}	0.90 ^e	1.77 ^{fg}	2.01 ^{ef}	0.086 ^f	0.54 ^e	1.62 ^e
T ₉	5.00 ^l	10.68 ^h	17.16 ^{ij}	0.78 ^{gh}	1.52 ^{kl}	1.73 ^{jk}	0.042 ^l	0.14 ⁱ	0.80 ⁱ
T ₁₀	7.50 ^g	14.60 ^e	30.11 ^e	0.82 ^{fg}	1.63 ^{ij}	1.86 ^{hi}	0.079 ^g	0.53 ^e	1.48 ^f
T ₁₁	12.50 ^b	23.58 ^c	55.11 ^a	1.40 ^a	2.85 ^a	3.42 ^a	0.281 ^a	1.03 ^a	2.71 ^a
T ₁₂	7.80 ^{fg}	14.95 ^e	23.20 ^h	0.92 ^{de}	1.82 ^{ef}	2.07 ^{de}	0.080 ^g	0.34 ^f	1.43 ^f
T ₁₃	11.50 ^d	26.48 ^a	50.71 ^b	0.94 ^{de}	2.00 ^c	2.28 ^b	0.214 ^b	0.59 ^d	1.86 ^d
T ₁₄	12.00 ^c	23.03 ^c	40.08 ^d	0.85 ^f	1.68 ^{hi}	1.91 ^{gh}	0.129 ^d	0.58 ^d	1.82 ^d
T ₁₅	13.50 ^a	24.59 ^b	49.24 ^b	1.05 ^b	2.08 ^b	2.35 ^b	0.215 ^b	0.82 ^c	2.40 ^b
T ₁₆	6.80 ^h	13.17 ^f	30.05 ^e	1.00 ^c	1.88 ^{de}	2.13 ^{cd}	0.095 ^e	0.27 ^g	1.26 ^g
T ₁₇	6.20 ⁱ	12.39 ^{fg}	24.10 ^{gh}	0.72 ^{ij}	1.41 ^{mn}	1.61 ^{lm}	0.044 ^{kl}	0.15 ^{hi}	0.64 ^k
SEm ($\pm$)	0.149	0.273	0.561	0.016	0.023	0.029	0.001	0.009	0.019
CD ($p = 0.05$)	0.429	0.785	1.612	0.044	0.065	0.084	0.004	0.026	0.054

DAP: days after planting.

Influence of enriched growing media consortia on physiological and biochemical attributes

Significant differences ($p \leq 0.05$) were observed among the enriched growing media consortia with respect to total chlorophyll and total phenol content of tuberose cv. Arka Prajwal (Table 5).

Among the treatments, T₁₁ (red soil + FYM + vermicompost (1 : 1 : 1) + *Pochonia chlamydosporia* at 50 g pot⁻¹) recorded the highest total chlorophyll content (1.61 mg g⁻¹) a 130 % increase over the untreated control (0.70 mg g⁻¹), which was significantly superior to all other treatments. This was followed by T₁₅ (1.54 mg g⁻¹) and T₁₆ (1.41 mg g⁻¹). The untreated control (T₁) recorded the lowest chlorophyll content (0.70 mg g⁻¹).

Similarly, significant differences were observed for total phenol content. The highest phenol content was recorded in T₁₁ (2.72 mg g⁻¹), a 1260 % increase over the untreated control (0.20 mg g⁻¹) followed by T₁₅ (2.40 mg g⁻¹) and T₁₃ (2.29 mg g⁻¹). The untreated control (T₁) recorded the lowest phenol content (0.20 mg g⁻¹). Overall, treatments enriched with organic amendments and microbial inoculants exhibited significantly higher chlorophyll and phenol contents than the untreated control and chemical check.

Influence of enriched growing media consortia on flowering and floral quality attributes

Significant differences ($p \leq 0.05$) were observed among the enriched growing media consortia with respect to flowering and floral quality

attributes of tuberose cv. Arka Prajwal (Table 6, Fig. 1). Among the treatments, T₁₁ (red soil + FYM + vermicompost (1 : 1 : 1) + *P. chlamydosporia* at 50 g pot⁻¹) recorded the highest spike length (91.70 cm, 26.8 % increase over control), spike girth (20.68 mm), number of florets per spike (53.71, 111.8 % increase over control) and floret weight per pot (95.22 g), 204.7 % increase over control) which were significantly superior to all other treatments. This was followed by T₁₅, which recorded a floret weight of 84.50 g and showed superior flowering performance over the remaining treatments. In contrast, the untreated control (T₁) recorded the lowest spike length (72.30 cm), number of florets per spike (25.36) and floret weight per pot (31.25 g).

The number of days taken for spike emergence also differed significantly among treatments. The earliest spike emergence was observed in T₁₁ (85 days), a 36.1 % reduction relative to the untreated control (133 days), followed by T₁₅ (88 days) and T₁₆ (96 days), whereas the untreated control (T₁) required the maximum number of days (133 days) for spike emergence. Significant variation was also observed in floret longevity. The longest duration to last floret withering was recorded in T₁₁ (16.00 days), a 166.7 % increase over the untreated control (6.00 days), followed by T₁₅ (14.00 days), while the untreated control (T₁) recorded the shortest duration (6.00 days). Overall, treatments receiving integrated organic amendments and microbial inoculants produced superior flowering and floral quality attributes compared with the untreated control.

Table 5. Influence of enriched growing media consortia on physiological and biochemical parameters at 90 days after planting (DAP)

Treatments	Total chlorophyll (mg g ⁻¹)	Total phenol (mg g ⁻¹)
T ₁	0.70 ^j	0.20 ⁿ
T ₂	1.09 ^h	0.27 ^{lm}
T ₃	1.10 ^{gh}	2.09 ^d
T ₄	0.74 ^j	0.70 ^j
T ₅	1.03 ⁱ	0.24 ^{mn}
T ₆	1.02 ⁱ	0.32 ^l
T ₇	1.14 ^g	0.46 ^k
T ₈	1.32 ^d	1.37 ^{fg}
T ₉	1.00 ⁱ	0.99 ⁱ
T ₁₀	1.24 ^e	1.69 ^e
T ₁₁	1.61 ^a	2.72 ^a
T ₁₂	1.39 ^c	1.43 ^f
T ₁₃	1.30 ^d	2.29 ^c
T ₁₄	1.19 ^f	1.17 ^h
T ₁₅	1.54 ^b	2.40 ^b
T ₁₆	1.41 ^c	1.68 ^e
T ₁₇	1.13 ^{gh}	1.33 ^g
Sem (±)	0.015	0.022
CD ($p = 0.05$)	0.043	0.062

Table 6. Influence of enriched growing media consortia on flowering parameters

Treatments	Spike length (cm)	Spike girth (mm)	Number of florets per spike	Fresh weight of floret per pot (g)	Days of last floret withering
T ₁	72.30 ^j	13.72 ^j	25.36 ^k	31.25 ^j	6.00 ⁿ
T ₂	73.20 ^{ij}	14.00 ^{ij}	40.72 ⁱ	48.80 ^{gh}	8.10 ^{jk}
T ₃	86.80 ^{bc}	16.52 ^{de}	48.18 ^{cd}	64.07 ^c	10.10 ^{cd}
T ₄	76.40 ^h	14.90 ^{gh}	35.54 ^j	47.15 ^{hi}	7.90 ^{kl}
T ₅	73.50 ^{hij}	14.20 ^{ij}	41.29 ^{hi}	50.02 ^{fg}	8.40 ^{ji}
T ₆	79.50 ^g	15.56 ^{fg}	42.63 ^h	51.24 ^{fg}	8.80 ^{hi}
T ₇	80.20 ^{fg}	16.40 ^{de}	45.17 ^{fg}	58.48 ^e	9.70 ^{def}
T ₈	82.60 ^{def}	16.60 ^{de}	46.48 ^{ef}	61.25 ^d	9.60 ^{ef}
T ₉	74.30 ^{hij}	14.28 ^{hij}	44.82 ^g	44.88 ⁱ	7.30 ^m
T ₁₀	81.50 ^{efg}	16.20 ^{def}	46.25 ^{efg}	52.26 ^f	9.10 ^{gh}
T ₁₁	91.70 ^a	20.68 ^a	53.71 ^a	95.22 ^a	16.00 ^a
T ₁₂	83.30 ^{de}	16.80 ^d	47.39 ^{de}	55.86 ^e	9.40 ^{fg}
T ₁₃	88.60 ^b	16.00 ^{ef}	49.56 ^{bc}	64.35 ^c	10.50 ^c
T ₁₄	81.90 ^{efg}	16.10 ^{ef}	45.84 ^g	57.50 ^e	9.50 ^{efg}
T ₁₅	89.70 ^{ab}	18.64 ^b	50.21 ^b	84.50 ^b	14.00 ^b
T ₁₆	85.40 ^{cd}	17.64 ^c	48.67 ^{cd}	62.53 ^{cd}	9.90 ^{de}
T ₁₇	75.40 ^{hi}	14.60 ^{hi}	34.43 ^j	45.22 ⁱ	7.60 ^{lm}
Sem (±)	1.065	0.236	0.504	0.943	0.16
CD ($p = 0.05$)	3.061	0.679	1.448	2.709	0.459

Multivariate trait association and identification of key determinants of growth and flowering through principal component analysis (PCA)

Principal component analysis (PCA) provided an integrated assessment of the relationships among vegetative growth, flowering and biochemical parameters of tuberose cv. Arka Prajwal across the 17 treatments (Table 7 and 8). The first principal component (PC1), accounting for 84.30 % of the total variance, exhibited high positive loadings for all measured traits, including plant height (0.370), leaf length (0.382), spike length (0.391), weight of florets per pot (0.391), as well as total chlorophyll content and total phenol content, indicating a strong positive association among vegetative growth, flowering and biochemical attributes. The second principal component (PC2), explaining an additional 6.72 % of the variance (cumulative 91.01 %), was characterised by high positive loadings for plant height (0.531) and leaf length (0.501), whereas the number of florets per spike (-0.469) and weight of florets per pot (-0.315) showed negative loadings. This suggests a degree of divergence between vegetative growth and floral productivity within this component. The third principal component (PC3), contributing 3.86 % of the variance (cumulative 94.88 %), was mainly influenced by days to last floret withering (0.565) and weight of florets per pot (0.388), indicating that post-harvest floral longevity contributed substantially to the total variability. The fourth principal component (PC4), accounting for 3.58 % of the variance (cumulative 98.46 %) was predominantly associated with total phenol content (-0.728), demonstrating that biochemical characteristics explained an independent portion of the observed variation among treatments.

Together, PC1–PC4 accounted for 98.46 % of the total variance among treatments. Based on PC1 scores, treatments T₁₁, T₁₅, T₁₃, T₇, T₈, T₁₂ and T₁₆ were positioned toward the positive end of PC1, corresponding to higher values for plant height, leaf length, spike length, floret weight, chlorophyll and phenol content, while the untreated control (T₁) was positioned at the negative extreme, reflecting its clear separation from the treated group along PC1.

Correlation analysis of growth, physiological, biochemical and floral traits in tuberose cv. Arka Prajwal

Correlation analysis revealed significant positive relationships among vegetative growth, flowering and biochemical parameters of tuberose cv. Arka Prajwal (Table 9). Among the vegetative traits, plant height at 90 DAP showed a very strong positive correlation with leaf length at 90 DAP ($r = 0.961^{***}$). Plant height also exhibited significant positive correlations with spike length ($r = 0.796^{***}$), number of florets per spike ($r = 0.693^{**}$), weight of florets per pot ($r = 0.777^{***}$), days to last floret withering ($r = 0.764^{***}$) and total phenol content ($r = 0.78^{***}$). Leaf length at 90 DAP was positively correlated with spike length ($r = 0.816^{***}$), weight of florets per pot ($r = 0.817^{***}$), days to last floret withering ($r = 0.803^{***}$) and total phenol content ($r = 0.866^{***}$). Among the floral traits, spike length exhibited strong positive correlations with number of florets per spike ($r = 0.825^{***}$), weight of florets per pot ($r = 0.892^{***}$), days to last floret withering ($r = 0.885^{***}$) and total phenol content ($r = 0.891^{***}$). Likewise, weight of florets per pot showed an exceptionally strong positive correlation with days to last floret withering ($r = 0.987^{***}$). Total phenol content was positively and significantly correlated with all vegetative and floral traits evaluated.

Table 7. Principal component analysis (PCA) between growth, flowering and biochemical parameters

Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
Plant height 90 DAP	0.37	0.531	-0.037	0.436	-0.312	-0.54	0.025
Leaf length 90 DAP	0.382	0.501	0.017	0.148	0.288	0.705	-0.03
Spike length	0.391	-0.159	-0.099	-0.34	-0.775	0.286	-0.117
Number of florets per spike	0.353	-0.469	-0.687	0.359	0.189	0.013	0.137
Weight of floret per pot	0.391	-0.315	0.388	0.109	0.22	-0.141	-0.719
Days of the last floret withering	0.384	-0.288	0.565	0.047	0.052	-0.02	0.667
Total phenol	0.374	0.197	-0.216	-0.728	0.364	-0.331	0.066

DAP: days after planting.

Table 8. Eigenvalues

Principal component	Eigenvalue	Percentage of variance	Cumulative percentage of variance
PC1	5.901	84.29	84.29
PC2	0.47	6.71	91.01
PC3	0.27	3.86	94.87
PC4	0.25	3.58	98.45
PC5	0.08	1.21	99.67
PC6	0.016	0.22	99.9
PC7	0.007	0.1	100

Table 9. Correlation between growth, flowering and biochemical parameters

	Plant height 90 DAP	Leaf length 90 DAP	Spike length	Number of florets per spike	Weight of floret per pot	Days of last floret withering	Total phenol
Plant height 90 DAP	1	0.961***	0.796***	0.693**	0.777***	0.764***	0.78***
Leaf length 90 DAP	0.961***	1	0.816***	0.699**	0.817***	0.803***	0.866***
Spike length	0.796***	0.816***	1	0.825***	0.892***	0.885***	0.891***
Number of florets per spike	0.693**	0.699**	0.825***	1	0.823***	0.763***	0.714**
Weight of floret per pot	0.777***	0.817***	0.892***	0.823***	1	0.987***	0.797***
Days of last floret withering	0.764***	0.803***	0.885***	0.763***	0.987***	1	0.781***
Total phenol	0.78***	0.866***	0.891***	0.714**	0.797***	0.781***	1

*** Correlation is significant at 0.001 level (two-tailed)

** Correlation is significant at 0.01 level (two tailed)

* Correlation is significant at 0.05 level (two-tailed)

Discussion

Influence of enriched growing media consortia on physico-chemical properties of growing media

The improvement in the physico-chemical properties of the growing media observed in the present investigation can be attributed to the combined influence of organic amendments and fungal biocontrol agents. Among all treatments, T₁₁ (red soil + FYM + vermicompost + *P. chlamydosporia*) consistently maintained higher electrical conductivity, organic carbon and available NPK status, followed by T₁₅ (red soil + FYM + vermicompost + *P. lilacinum*) and T₃ (red soil + FYM + vermicompost). The incorporation of FYM and vermicompost increased the organic matter content of the growing media, which enhanced microbial activity, accelerated mineralisation and gradually released essential nutrients into plant-available forms. Vermicompost is well recognised for improving nutrient availability, cation exchange capacity and microbial biomass, thereby enhancing soil fertility and nutrient retention. These findings agree with the previous reports who demonstrated that vermicompost significantly improved substrate fertility and nutrient availability and enhanced soil biological activity and nutrient mineralisation following vermicompost application (21, 22).

The superior nutrient status recorded under T₁₁ and T₁₅ may also be attributed to the activity of the fungal biocontrol agents. *P. chlamydosporia* and *P. lilacinum* are known to colonise the rhizosphere effectively and produce extracellular enzymes and organic acids that facilitate nutrient solubilisation while improving root growth and nutrient uptake. In addition, these fungi function as plant growth-promoting microorganisms by enhancing N cycling and P availability in the rhizosphere. Similar observations were previously reported who described the rhizosphere competence and plant growth-promoting potential of *P. chlamydosporia* and reported improved nutrient acquisition and plant performance following root colonisation by *P. chlamydosporia* (23, 24).

The relatively lower nutrient status recorded in the control (T₁) may be attributed to the absence of organic nutrient sources and beneficial microbial inoculants, resulting in reduced microbial activity, lower organic carbon accumulation and limited nutrient mineralisation. Similar trends have been reported in studies comparing organically enriched growing media with untreated soils, where integrated organic amendments substantially improved soil fertility and nutrient availability.

Influence of enriched growing media consortia on days of sprouting, plant height and number of tillers

The earlier sprouting (5.00 days) and superior vegetative growth observed under T₁₁ may be attributed to the synergistic effect of organic amendments and the beneficial fungus *P. chlamydosporia*. The faster sprouting could be linked to improved moisture retention and nutrient availability in the FYM-vermicompost-enriched media, which likely facilitated quicker bulb hydration and mobilisation of stored reserves for early sprout initiation, while the fungal inoculant may have further supported root emergence through its rhizosphere activity (25). Farmyard manure and vermicompost improve the physical, chemical and biological properties of the growing medium by enhancing soil structure, water-holding capacity and nutrient mineralisation, thereby ensuring a continuous supply of essential nutrients required for rapid cell division and plant growth (26). In addition to improving nutrient availability, *P. chlamydosporia* has been reported as a rhizosphere-competent plant growth-promoting fungus that colonises root surfaces and produces extracellular

enzymes such as chitinases and proteases, contributing to biocontrol activity (27). In addition, the fungus is known to solubilise P and produce indole-3-acetic acid (IAA)-like compounds that stimulate root proliferation, thereby enhancing nutrient and water uptake. Improved root development could have facilitated greater water and nutrient absorption, resulting in earlier sprouting, vigorous shoot elongation and increased tillering. The superior performance of T₁₃ and T₁₅, which included *P. lilacinum*, further demonstrates the beneficial role of microbial inoculants in promoting plant growth. Previous studies have reported that *P. lilacinum* enhances nutrient mobilisation, improves rhizosphere competence and stimulates root development, thereby contributing to improved vegetative growth in horticultural crops (28). The relatively greater plant height recorded under T₁₅ at 60 DAP and its comparatively early sprouting (6.00 days) indicate that the microbial inoculant effectively supported active vegetative development from the earliest growth stage. The increased tiller production observed in T₁₁ may also be associated with a balanced nutrient supply and enhanced microbial activity resulting from the decomposition of FYM and vermicompost (29, 30).

Influence of enriched growing media consortia on leaf morphology

The enhanced leaf growth observed under T₁₁ may be attributed to the combined effect of organic amendments and the plant growth-promoting fungus *P. chlamydosporia*. Vermicompost and FYM improve soil structure, moisture retention and nutrient mineralisation, resulting in sustained availability of essential macro- and micronutrients required for leaf initiation, expansion and chlorophyll synthesis. These findings are consistent with early researchers who reported that combined application of vermicompost and beneficial microbes significantly enhanced vegetative growth parameters, including leaf development, in pea (29). Similarly, improved leaf growth and nutrient uptake in chilli (*Capsicum annum* L.) with vermicompost application, attributing this to enhanced nutrient mineralisation and micronutrient availability (31). In addition to the beneficial effects of organic amendments, *P. chlamydosporia* is recognised as a rhizosphere-competent fungus capable of improving root colonisation and nutrient acquisition, thereby enhancing vegetative growth (6). Although physiological parameters such as chlorophyll content and phytohormone production were not measured in the present study, the greater leaf dimensions and LAI recorded under T₁₁ may be associated with improved root function and nutrient uptake reported in earlier studies (6). The superior performance of T₁₃ and T₁₅, which included *P. lilacinum*, further demonstrates the positive role of beneficial microbial inoculants in stimulating vegetative growth. Previous studies have shown that *P. lilacinum* enhances nutrient mobilisation, improves rhizosphere competence and promotes root growth, thereby supporting greater leaf expansion and biomass accumulation in horticultural crops (32).

Leaf area index is an important indicator of canopy development and photosynthetic efficiency. The significantly higher LAI observed under T₁₁ indicates the development of a larger photosynthetically active surface capable of intercepting more solar radiation and producing greater assimilates for plant growth. Similar improvements in leaf morphology and canopy architecture following the integrated application of vermicompost, FYM and microbial inoculants have been reported in tuberose and other ornamental crops (6, 25, 28).

Influence of enriched growing media consortia on physiological and biochemical attributes

The increased chlorophyll content in T₁₁ and T₁₅ may be due to the synergistic effect of vermicompost, FYM and beneficial microbial inoculants. Vermicompost and FYM are rich in critical macro and micronutrients such as N, P, K, iron (Fe) and manganese (Mn), which are directly involved in chlorophyll production and photosynthetic efficiency (33). Furthermore, *P. chlamydosporia* and *P. lilacinum* have been shown to boost nutrient uptake, root activity and overall plant development under both optimal and stress conditions (13, 32). Previous research found that using *P. chlamydosporia* in horticultural crops resulted in significant increases in photosynthetic pigments and biomass production (13). The decreased chlorophyll concentration in the chemical standard T₁₇ demonstrates that bio-organic treatments enhance plant vigour and physiological performance to a greater extent than the chemical standard (27, 30, 31).

In addition to improving nutrient availability, *P. chlamydosporia* has been reported to enhance nutrient uptake, thereby promoting plant growth and physiological performance (13). Although chlorophyll fluorescence, photosynthetic rate and nutrient uptake were not directly assessed in the present study, the increased chlorophyll content observed under T₁₁ is consistent with the improved physiological status reported for plants colonised by *P. chlamydosporia* (13).

The highest phenol accumulation recorded under T₁₁ may be associated with enhanced nutrient availability together with microbial stimulation of plant defence metabolism. Organic amendments, particularly vermicompost, contain humic substances and biologically active compounds that promote the synthesis of phenolic metabolites involved in plant defence and stress tolerance (33). In addition, *P. chlamydosporia* has been reported to induce defence-related responses through activation of the phenylpropanoid pathway and induction of systemic resistance (ISR), mediated by jasmonic acid and salicylic acid signalling, which upregulates phenylalanine ammonia-lyase (PAL) activity - a key enzyme in phenolic biosynthesis (34). Since defence-related enzymes and signalling pathways were not evaluated in the present investigation, this mechanism should be considered a plausible explanation based on previous reports rather than direct evidence from the present study (34). The higher phenol content observed in T₁₃ and T₁₅ further supports the beneficial role of microbial inoculants in improving biochemical defence responses. These findings are consistent with early results reported that *P. chlamydosporia* inoculation increased total chlorophyll and carotenoid content in eggplant (13). Similarly, enhanced nutrient content in chilli following vermicompost application (31).

Influence of enriched growing media consortia on flowering and floral quality attributes

The superior flowering performance observed in T₁₁ may be attributed to the combined application of FYM, vermicompost and *P. chlamydosporia*. Organic amendments such as vermicompost and FYM improve soil physical properties, enhance moisture retention and provide a sustained supply of essential macro- and micronutrients required for flower initiation, spike elongation and floret development (35, 36). Improved nutrient availability under organically enriched growing media promotes assimilate production and translocation towards developing floral organs, resulting in longer spikes, greater spike girth and increased floret production (35–37).

The enhanced flowering response observed under T₁₁ may also be associated with the beneficial effects of *P. chlamydosporia* on root development and nutrient acquisition. Previous studies have demonstrated that *P. chlamydosporia* functions as a plant growth-promoting fungus by enhancing root growth, improving nutrient uptake and accelerating flowering in horticultural crops (38, 39). Although root colonisation and nutrient uptake were not directly measured in the present study, the earlier spike emergence and superior floral characteristics observed in T₁₁ are consistent with these reported mechanisms (38, 39).

The comparatively high flowering performance of T₁₅, containing *P. lilacinum*, further supports the role of beneficial microbial inoculants in improving reproductive growth. *Purpureocillium lilacinum* has been reported to enhance nutrient mobilisation, stimulate root activity and improve plant growth through better nutrient utilisation and production of growth-promoting metabolites (32). These effects may have contributed to the increased spike length, floret number and floret weight observed under T₁₅.

The significantly greater spike girth, floret production and floret yield observed in treatments receiving organic amendments together with microbial inoculants indicate a synergistic interaction between the growing media components and beneficial microorganisms. The combined application likely created a favourable rhizosphere environment that enhanced nutrient availability and plant growth, resulting in improved floral quality (40). However, rhizosphere microbial activity and nutrient dynamics were not directly evaluated in the present study; therefore, this explanation should be considered a plausible mechanism based on previous findings.

The extended floret longevity observed in T₁₁ and T₁₅ suggests that integrated bio-organic treatments improved not only flower production but also post-harvest floral quality. Enhanced nutrient balance and improved physiological status of plants receiving organic amendments have been associated with delayed senescence and improved water relations in ornamental crops (41, 42). Similar improvements in flowering, flower yield and post-harvest quality following integrated nutrient management have been reported in tuberose and other ornamental species (26, 41, 42).

Multivariate trait association and identification of key determinants of growth and flowering using principal component analysis (PCA)

The PCA clearly demonstrated a strong positive association among vegetative growth, flowering and biochemical traits, indicating that improvements in plant height, leaf development and physiological status were accompanied by enhanced floral yield and quality. This pattern suggests that treatments receiving integrated organic amendments and beneficial microbial inoculants promoted overall plant performance rather than improving individual traits independently, consistent with reports of similar vegetative-flowering associations in tuberose under integrated nutrient management (26, 43).

The superior grouping of treatments such as T₁₁, T₁₅ and T₁₃ can be attributed to the combined effects of FYM, vermicompost and beneficial microorganisms. Vermicompost improves soil physical properties, microbial activity and nutrient availability, thereby supporting vigorous vegetative growth and reproductive development (43). Likewise, cocopeat-based growing media

improve aeration, moisture retention and root-zone conditions, contributing to increased plant height, spike length and flower production (44).

Beneficial microorganisms, including *T. viride*, *P. chlamydosporia* and *P. lilacinum*, further enhance plant growth by improving root development, nutrient mobilisation and rhizosphere activity (45, 46). The favourable association of treatments containing these microorganisms with the principal components representing superior growth and flowering suggests that microbial inoculation contributed substantially to the overall crop performance. Although the production of growth-regulating substances and enhanced nutrient solubilisation were not directly measured in the present study, these mechanisms have been proposed in previous studies to explain the plant growth-promoting effects of beneficial microorganisms (47).

The positive association between flowering attributes and biochemical parameters further indicates that improved physiological status contributed to greater flower production and floral quality. Higher chlorophyll and phenol contents observed in the integrated treatments may have supported increased photosynthetic efficiency and improved metabolic activity, resulting in greater assimilate production for floral development. Similar relationships among physiological, vegetative and flowering traits have been reported in tuberose and other ornamental crops following the combined application of organic amendments and beneficial microbial inoculants (43, 44).

Correlation analysis of growth, physiological, biochemical and floral traits

The strong positive correlation between plant height and leaf length ($r = 0.961^{***}$) indicates that vigorous vegetative growth was accompanied by greater leaf development, resulting in an increased photosynthetically active canopy. Similar positive relationships among vegetative growth traits have been reported in tuberose, where increased plant height and leaf area contributed to improved assimilate production and subsequent flower development (48, 49). The significant positive association of plant height and leaf length with spike length, floret number and floret yield suggests that enhanced vegetative growth provided a stronger physiological foundation for reproductive development. Increased leaf area enhances light interception and photosynthetic efficiency, thereby increasing the availability of assimilates required for spike elongation and floret differentiation (48, 49). The strong positive correlations observed between spike length, weight of florets per pot and number of florets per spike demonstrate that improved spike architecture was closely associated with higher floral productivity. Previous studies have similarly reported that longer spikes generally produce more florets and greater flower yield in tuberose (50, 51). The positive relationship between floret weight and flower longevity ($r = 0.987^{***}$) further indicates that treatments producing heavier florets also maintained longer post-harvest floral life, reflecting improved flower quality (50, 51). The superior flowering performance observed in the integrated treatments may be attributed to the combined influence of organic amendments and beneficial microbial inoculants. Organic components such as vermicompost, FYM and cocopeat improve nutrient availability, aeration and water-holding capacity of the growing medium, thereby promoting vigorous plant growth and flower production (22, 44). In addition, beneficial microorganisms such as *T. viride*, *P. chlamydosporia* and *P. lilacinum* have been reported to enhance

nutrient solubilisation, root development and overall plant vigour, contributing to improved flowering characteristics (27, 28, 52, 53). Although microbial activity and nutrient uptake were not directly measured in the present study, these mechanisms provide plausible explanations for the observed improvements based on previous reports. The significant positive correlation between total phenol content and spike length ($r = 0.891^{***}$) indicates that treatments producing superior floral development also exhibited greater phenolic accumulation. Phenolic compounds play important roles in antioxidant activity, stress tolerance and plant defence and their increased accumulation has frequently been associated with improved physiological status and flower quality in horticultural crops (54). The positive correlations between phenol content and all major vegetative and flowering traits suggest that enhanced biochemical status contributed to the overall improvement in crop growth and floral productivity.

Conclusion

The present study demonstrates that enriched growing media consortia combining organic amendments (farmyard manure (FYM) and vermicompost) with biocontrol agents significantly enhance vegetative growth, physiological performance and flowering quality of tuberose cv. Arka Prajwal under pot culture conditions, outperforming both the untreated control and the chemical standard. Among the treatments evaluated, T₁₁ (red soil + FYM + vermicompost (1 : 1 : 1) + *Pochonia chlamydosporia* at 50 g pot⁻¹) consistently recorded the best overall performance across growth, physiological and floral parameters, followed by T₁₅ and T₁₃. Correlation analysis and principal component analysis (PCA) further confirmed that vegetative vigour was closely associated to floral quality, with spike length, floret weight and floret longevity emerging as key determinants of treatment performance. These findings highlight the potential of bio-organic growing media consortia as sustainable alternatives to conventional red soil-based cultivation for tuberose production. However, these results are based on short-term pot-culture trials and field-level validation under diverse agro-climatic conditions is necessary before recommending T₁₁ for large-scale commercial adoption. Future research should focus on: (i) field trials to confirm these findings under open growing conditions, (ii) mechanistic studies to elucidate how *P. chlamydosporia* and organic amendments interact to influence nutrient uptake and plant defence pathways and (iii) cost-benefit analysis to evaluate the economic feasibility of adopting T₁₁ for commercial tuberose cultivation.

Acknowledgements

The author expresses sincere gratitude to the Department of Floriculture and Landscape Architecture, SRM College of Agricultural Sciences, SRM Institute of Science and Technology, Chengalpattu, Tamil Nadu, for providing the necessary facilities and continuous support to successfully carry out this research work. The author places on record heartfelt gratitude to the Chairperson and Advisory Committee Members for their invaluable guidance, constant encouragement, constructive suggestions and unwavering support throughout the course of this investigation. The author also acknowledges the support and cooperation extended by the faculty members and technical staff of the department during the study.

Authors' contributions

BP conceived and designed the experiment, carried out the pot culture experiment, performed data collection on all vegetative, physiological and floral parameters, conducted statistical analysis and drafted the manuscript. SG supervised the experimental design, guided data interpretation and critically revised the manuscript for important intellectual content. SA co-supervised the study, participated in the coordination of the research and reviewed the manuscript for important intellectual content. SR contributed to the biological crop protection aspects of the study design, provided technical guidance on biocontrol agent application and reviewed the final manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

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

Ethical issues: None

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used Claude (OpenAI) to improve the grammar, language, sentence structure, clarity and readability of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

References

- Pocha PN, Mallikarjun M, Devi GN, Kumar MR. Assessment of improved variety of tuberose (*Polianthes tuberosa*) Prajwal for yield and economics in western parts of Chittoor District of Andhra Pradesh. *Trends Biosci.* 2019;12(9):2205–7. <https://doi.org/10.5958/2349-4433.2019.00062.X>
- Ganesh S, Soorianathasundaram K, Kannan M. Studies on effect of plant growth regulators and micronutrients on growth, floral characters and yield of tuberose (*Polianthes tuberosa* L.) cv. Prajwal. *Asian J Hortic.* 2013;8(2):696–700.
- Rehman SU, De Castro F, Aprile A, Benedetti M, Fanizzi FP. Vermicompost: Enhancing plant growth and combating abiotic and biotic stress. *Agronomy.* 2023;13(4):1134. <https://doi.org/10.3390/agronomy13041134>
- Pathma J, Sakthivel N. Microbial diversity of vermicompost bacteria that exhibit useful agricultural traits and waste management potential. *SpringerPlus.* 2012;1:26. <https://doi.org/10.1186/2193-1801-1-26>
- Nair SA, Bharathi TU. Standardisation of substrate composition for pot plant production of tuberose var. Arka Sugandhi. *Int J Curr Microbiol App Sci.* 2019;8(1):2197–203. <https://doi.org/10.20546/ijcmas.2019.801.229>
- Shaliha BA, Swarnakumari N, Anita B, Thiribhuvanamala G, Suganthi A, Saranya N. The mechanistic pathways of *Pochonia chlamydosporia*: A biology perspective on nematode suppression and plant promotion. *Plant Sci Today.* 2025;12:10330. <https://doi.org/10.14719/pst.1033>
- Elissen H, van der Weide R, Gollenbeek L. Effects of vermicompost on plant and soil characteristics: A literature overview. Wageningen: Wageningen Plant Research; 2023. <https://doi.org/10.18174/587210>
- Sarkar D, Hatibarua P, Borbaruah R, Talukdar MC, Naikwad D, Nath DJ. Effect of nursery growing media for quality seedling production of marigold, calendula, dianthus and salvia. *Plant Arch.* 2025;25(2):1092–102. <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.supplement-2.136>
- Tyskiewicz R, Nowak A, Ozimek E, Jaroszuk-Ścisiel J. *Trichoderma*: The current status of its application in agriculture for the biocontrol of fungal phytopathogens and stimulation of plant growth. *Int J Mol Sci.* 2022;23(4):2329. <https://doi.org/10.3390/ijms23042329>
- Dallemole-Giareta R, Freitas LG, Lopes EA, Silva MD, Kasuya MC, Ferraz S. *Pochonia chlamydosporia* promote crescimento de tomateiro e alface. *Acta Sci Agron.* 2015;37(4):417–23. <https://doi.org/10.4025/actasciagron.v37i4.25042>
- Khan M, Tanaka K. *Purpureocillium lilacinum* for plant growth promotion and biocontrol against root-knot nematodes infecting eggplant. *PLoS One.* 2023;18(3):e0283550. <https://doi.org/10.1371/journal.pone.0283550>
- Contreras-Cornejo HA, Schmoll M, Esquivel-Ayala BA, González-Esquivel CE, Rocha-Ramírez V, Larsen J. Mechanisms for plant growth promotion activated by *Trichoderma* in natural and managed terrestrial ecosystems. *Microbiol Res.* 2024;281:127621. <https://doi.org/10.1016/j.micres.2024.127621>
- Parveen A, Tanaka K, Khan M. Biocontrol efficacy of *Pochonia chlamydosporia* against root-knot nematode *Meloidogyne javanica* in eggplant and its impact on plant growth. *Sci Rep.* 2025;15(1):36990. <https://doi.org/10.1038/s41598-025-99527-2>
- Saravani M, Boogar AR, Aran M, Ramezan D, Zargar M, Diakite S. Optimizing tuberose (*Polianthes tuberosa* L.) production using mycorrhiza and biostimulants to enhance water-deficit tolerance. *Horticulturae.* 2025;11(1):34. <https://doi.org/10.3390/horticulturae11010034>
- Sun T, Li M, Saleem M, Zhang X, Zhang Q. The fungicide fluopyram promotes pepper growth by increasing the abundance of P-solubilizing and N-fixing bacteria. *Ecotoxicol Environ Saf.* 2020;188:109947. <https://doi.org/10.1016/j.ecoenv.2019.109947>
- Subbiah BV, Asija GL. A rapid procedure for estimation of available nitrogen in soils. *Curr Sci.* 1956;25:259–60.
- Jackson ML. Soil chemical analysis. New Delhi: Prentice Hall of India Pvt. Ltd.; 1973.
- Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Sci.* 1934;37(1):29–38.
- Arnon DI. Copper enzymes in isolated chloroplasts. Polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* 1949;24(1):1–15. <https://doi.org/10.1104/pp.24.1.1>
- Singleton VL, Orthofer R, Lamuela-Raventós RM. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. In: Packer L, editor. *Methods in enzymology*. Vol. 299. San Diego: Academic Press; 1999. p. 152–78. [https://doi.org/10.1016/S0076-6879\(99\)90017-1](https://doi.org/10.1016/S0076-6879(99)90017-1)
- Atiyeh RM, Arancon N, Edwards CA, Metzger JD. Influence of earthworm -processed pig manure on the growth and yield of greenhouse tomatoes. *Bioresour Technol.* 2000;75(3):175–80.
- Edwards CA, Arancon NQ. The use of earthworms in the breakdown of organic wastes to produce vermicomposts and animal feed protein. In: Edwards CA, editor. *Earthworm ecology*. 2nd ed. Boca Raton: CRC Press; 2004. p. 345–79.
- Kerry BR. Rhizosphere interactions and the exploitation of microbial agents for the biological control of plant-parasitic nematodes. *Annu Rev Phytopathol.* 2000;38:423–41. <https://doi.org/10.1146/annurev.phyto.38.1.423>
- Lopez-Llorca LV, Gómez-Vidal S, Monfort E, Larriba E, Casado-Vela J, Elortza F, et al. Expression of serine proteases in egg-parasitic nematophagous fungi during barley root colonization. *Fungal Genet Biol.* 2010;47(4):342–5. <https://doi.org/10.1016/j.fgb.2010.01.004>
- Karagöz FP, Dursun A, Tekiner N, Kul R, Kotan R. Efficacy of vermicompost and/or plant growth-promoting bacteria on the plant growth and development in gladiolus. *Ornam Hortic.* 2019;25(2):180–8. <https://doi.org/10.14295/oh.v25i2.2023>

26. Yadav R, Beniwal BS, Dalal RS, Kumar S. Influence of vermicompost and bio-fertilizers on growth and flowering of tuberose (*Polianthes tuberosa* L.) cv. Prajwal. *Int J Plant Soil Sci.* 2023;35(16):113–20. <https://doi.org/10.9734/ijps/2023/v35i163136>
27. Chaya MK, Rao MS. Bio-management of *Meloidogyne incognita* on okra using a formulation of *Pochonia chlamydosporia*. *Pest Manag Hortic Ecosyst.* 2012;18(2):170–3.
28. Rajamanickam C, Ravindran C. Bio-management of root-knot nematode (*Meloidogyne incognita*) in tuberose (*Polianthes tuberosa* L.). *J Pharmacogn Phytochem.* 2021;10(1):1693–5. <https://doi.org/10.22271/phyto.2021.v10i1x.13587>
29. Kumari M, Chakma J, Singh SP. Evaluation of synergistic effects of vermicompost and beneficial microbes on pea. *Curr J Appl Sci Technol.* 2020;39(1):137–47. <https://doi.org/10.9734/CJAST/2020/v39i130489>
30. Khatri R, Adhikari S, Pokharel NP, Adhikari S, Khanal Y, Thapaliya KP, et al. Evaluating the effect of biofertilizer dosages on growth and yield parameters of cauliflower in Mugu District, Nepal. *Int J Agric Environ Food Sci.* 2025;9(3):733–42. <https://doi.org/10.31015/2025.3.11>
31. Nawrin KS, Uddin MJ, Ali AH, Rahman MK. Effects of boron and vermicompost on growth, yield and nutrient content of chilli (*Capsicum annuum* L.). *J Biodivers Conserv Bioresour Manag.* 2021;6(1):31–6. <https://doi.org/10.3329/jbcbm.v6i1.51329>
32. Rigobelo EC, Nicodemo D, Babalola OO, Desoignies N. *Purpureocillium lilacinum* as an agent of nematode control and plant growth-promoting fungi. *Agronomy.* 2024;14(6):1225. <https://doi.org/10.3390/agronomy14061225>
33. Theunissen J, Ndadikemi PA, Laubscher CP. Potential of vermicompost produced from plant waste on the growth and nutrient status in vegetable production. *Int J Phys Sci.* 2010;5(13):1964–73.
34. Ghahremani Z, Escudero N, Saus E, Gabaldón T, Sorribas FJ. *Pochonia chlamydosporia* induces plant-dependent systemic resistance to *Meloidogyne incognita*. *Front Plant Sci.* 2019;10:945. <https://doi.org/10.3389/fpls.2019.00945>
35. Habib ZF, Hossain MI, Mazed HK, Sultana T, Yeasmin M. Assessment of different soil amendment effects on tuberose bulb quality and quantity. *IOSR J Agric Vet Sci.* 2016;9(8):16–9. <https://doi.org/10.9790/2380-0908021619>
36. Padaganur VG, Mokashi AN, Patil VS. Flowering, flower quality and yield of tuberose (*Polianthes tuberosa* L.) as influenced by vermicompost, farmyard manure and fertilizers. *Karnataka J Agric Sci.* 2005;18(3):729–34.
37. Sajjan G. Impact of bio-fertilisers and vermicompost on growth, flowering and vase life of gerbera (*Gerbera jamesonii*) under polyhouse conditions. *Int J Agric Extension Soc Dev.* 2023;6(1):117–22. <https://doi.org/10.33545/26180723.2023.v6.i1b.2987>
38. Nagesh M, Singh KP. Bio-management of *Meloidogyne incognita* on *Polianthes tuberosa* using *Glomus mosseae* and *Pochonia chlamydosporia* as bulb dressing in combination with neem cake. *J Ornament Hort.* 2004;7(1):45–51.
39. Zavala-González EA, Escudero N, López-Moya F, Aranda-Martínez A, Exposito A, Ricaño-Rodríguez J, et al. Some isolates of the nematophagous fungus *Pochonia chlamydosporia* promote root growth and reduce flowering time of tomato. *Ann Appl Biol.* 2015;166(3):472–83. <https://doi.org/10.1111/aab.12199>
40. Srivastava RK, Pareek N, Chand S, Bhuj BD, Pant K, Belwal S. Rhizospheric fungal and bacterial bio-agents in flowering and bulb of tuberose (*Polianthes tuberosa* L.). *Bangladesh J Bot.* 2022;51(3):565–72. <https://doi.org/10.3329/bjb.v51i3.62003>
41. Shirsat PR, Kuchanwar OD, Ingle SN, Zalte S, Abgad NP. Effect of integrated nutrient management on yield and quality of tuberose grown on Vertisol. *Asian J Soil Sci.* 2015;10(2):210–14. <https://doi.org/10.15740/HAS/AJSS/10.2/210-214>
42. Chawla SL, Patel MA, Patil S, Bhatt D, Patel RB. Effect of land configuration and integrated nutrient management on growth, quality and yield of tuberose (*Polianthes tuberosa*) var. Prajwal. *Indian J Agric Sci.* 2018;88(12):1854–8. <https://doi.org/10.56093/ijas.v88i12.85435>
43. Manisha, Beniwal BS, Sheoran S, Yadav R. Response of organic manures and their levels on growth and spike yield of tuberose (*Polianthes tuberosa* L.) cv. Prajwal. *Plant Arch.* 2025;25(2):1658–62. <https://doi.org/10.51470/PLANTARCHIVES.2025.v25.no.2.240>
44. Ikram S, Habib U, Khalid N. Effect of different potting media combinations on growth and vase life of tuberose (*Polianthes tuberosa* Linn.). *Pak J Agric Sci.* 2012;49(2):121–5.
45. Mazhabi M, Nemati H, Rouhani H, Tehranifar A, Moghadam EM, Kaveh H, et al. The effect of *Trichoderma* on *Polianthes* qualitative and quantitative properties. *J Anim Plant Sci.* 2011;21(3):617–21.
46. Nosir WS. *Trichoderma harzianum* as a growth promoter and bio-control agent against *Fusarium oxysporum* f. sp. *tuberosi*. *Adv Crop Sci Technol.* 2016;4:217. <https://doi.org/10.4172/2329-8863.1000217>
47. Wasim M, Gupta NK, Dubey S, Mohanty A. Effect of inorganic fertilisers in combination with bio-fertilisers on growth and yield of tuberose (*Polianthes tuberosa*). *Indian Hort J.* 2014;4(1):37–42.
48. Gogoi K, Talukdar MC, Talukdar P. Correlation coefficient and path analysis in tuberose (*Polianthes tuberosa* L.) genotypes. *Res Crops.* 2019;20(1):150–60. <https://doi.org/10.31830/2348-7542.2019.021>
49. Kayalvizhi K, Kannan M, Ganga M. Mean performance, correlation coefficient and path coefficient analysis for yield and yield attributing characters in F₁ population of tuberose (*Polianthes tuberosa* L.). *Madras Agric J.* 2023;103. <https://doi.org/10.29321/MAJ.10.001034>
50. Gandhi PD, Bharathi U. Correlation and path coefficient analysis in tuberose cultivars single. *Agric Sci Dig.* 2020;40(2):134–8. <https://doi.org/10.18805/ag.D-5028>
51. Ranchana P, Kannan M, Jawaharlal M. Correlation and path analysis studies in double type tuberose. *Asian J Hortic.* 2015;10(1):113–7. <https://doi.org/10.15740/HAS/TAJH/10.1/113-117>
52. Naznin A, Hossain MM, Ara KA, Hoque A, Islam M, Hasan T. Influence of organic amendments and bio-control agent on yield and quality of tuberose. *J Hortic.* 2015;2(4):1–8. <https://doi.org/10.4172/2376-0354.1000156>
53. Kavitha K, Thirukumaran K. Integrated management of nematode disease complex in tuberose (*Polianthes tuberosa* L.). *J Krishi Vigyan.* 2019;8(1):170–3. <https://doi.org/10.5958/2349-4433.2019.00091.6>
54. Rajaselvam M, Sudhagar R, Kumaresan M. Determining the effect of integrated nutrient management (INM) on growth and flower yield of tuberose (*Polianthes tuberosa* L.) cv. Prajwal. *Int J Plant Soil Sci.* 2024;36(6). <https://doi.org/10.9734/IJPSS/2024/v36i64600>

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc. See https://horizonpublishing.com/journals/index.php/PST/indexing_abstracting

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.