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RESEARCH ARTICLE

Foliar application of nutrient formulation enhances the post-harvest quality of tuberose (*Agave amica* Medik.) *cv*. Arka Prajwal

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Abstract

A study was conducted at the Department of Floriculture and Landscape Architecture Laboratory to investigate the influence of various nutrient formulations on the post-harvest quality of tuberose using a knapsack sprayer and drone. The treatments involved spraying macro and micronutrients along with growth regulators at different concentrations. Throughout the experiment, all parameters were recorded at 2 days intervals. Drone spray of MN mixture + 0.5 % poly feed + 0.6 % humic acid + 150 ppm GA_3 recorded the maximum plant post-harvest quality attributes over other treatments. It showed increased post-harvest quality attributes, including relative water content percentage of flower (95.15 %), physiological loss of weight percentage of flower (14.83 %), shelf life at room temperature (3.79 days) and vase life (12.45 days). Additionally, the treatment was found to be the best for parameters of water uptake (38.45 g) and percentage of floret opened (27.02). Plots treated with drone spray of MN mixture + 0.5 % poly feed + 0.6 % humic acid + GA_3 at 150 ppm showed a reduced rate of transpiration loss of water (14.89 g) and electrolyte leakage (12.52). The experimental findings demonstrated that foliar application of nutrients along with growth regulators at different concentrations using drones improved the post-harvest quality of tuberose.

Keywords

Tuberose; nutrient spraying; plant growth regulators; vase life; electrolyte leakage

Introduction

Tuberose is a perennial bulbous plant belonging to the Agavaceae family botanically known as *Agave amica*. This monocot genus is grown all over the world for its cut flowers, which are used in the floriculture business as well as for its essential oil, which is extracted in nations like Egypt, China, France and Morocco (1). Tuberose is highly valued in Indian-Hindu culture and is used in many facets of daily life. The flowers are especially significant and are made into garlands for marriage ceremonies, for generations, women in India have been adorned with tuberose. The plant originated in Mexico, where its essential oil was utilized by the Aztecs to improve the flavor of chocolate. Tuberose oil is prized for having a unique scent that is rich and sweet, with just a hint of spice (1). Traditional soil-based fertilization methods often suffer from inefficiencies due to nutrient losses through leaching, volatilization and run-off. In contrast, foliar nutrition has emerged as an effective approach to supplement crop growth by directly addressing nutrient deficiencies. This method has shown promising results in improving tuberose yield through the application of both macro and micronutrients. Foliar spraying, which involves direct application to the plant's aerial parts, offers a more efficient strategy compared to root fertilization, especially when rapid correction of nutritional deficiencies is required.

The use of NPK fertilizers is well-established for enhancing crop productivity and nutritional value. However, the timing and method of application are crucial for optimal nutrient utilization. Foliar spray applications during critical growth stages have been shown to significantly improve crop production (2). Building on this body of scientific knowledge, the current study intends to explore how tuberose post-harvest quality attributes are affected by the application of growth regulators and plant nutrients by drones.

Materials and Methods

Two successive seasons (2022–2024) of the current experiment were conducted in farmer fields at Sathiyamangalam, Erode, Tamil Nadu (June 2022- May 2023 and June 2023-May 2024). The soil texture is sandy clay loam and slightly alkaline (7.82 pH) in nature. Poly feed has a ratio of 19:19:19 NPK/kg, whereas the Micro Nutrient mixture has a composition of 0.25: 0.25: 0.3 $FeSO_4$, $ZnSO_4$ and H_3BO_3/kg. The research utilized tuberose cv. Arka Prajwal in both seasons, spaced 45 cm x 30 cm apart. A 1.0 IW/CPE ratio sprinkler watering system was implemented. Additionally, drip fertigation was used to supply a 200:200:200 kg/ha fertilizer dose to all treatments. Foliar spray was applied at 60 days intervals from 60 DAP using drone and knapsack sprayer with spraying solution of 50 and 500 L ha^{-1} respectively. UAV was operated at flying height of 1.5 m and flat fan nozzle was used with discharge rate of 1.5 L min^{-1}. Treatment details are given in (Table 1).

Pre-harvest spraying of different nutrient formulations on tuberose plants spike were collected and placed in holding solution at laboratory condition. The holding solution contained distilled water and 4 % sucrose concentration for all the post-harvest observations. In the laboratory of the Department of Floriculture and Landscape Architecture, the experiment was carried out at room temperature (26 ± 1 °C) and relative humidity (65 ± 4 %). The parameter observations are recorded in 2 days intervals throughout the vase life study period. In vase life study slanting cut into the stems at 45 cm length were made to easily observe the holding solution to maintain the water balance and turgidity of the stems (3). The differently treated stems were placed into the conical flask containing 200 mL of holding solution.

Further, to estimate other post-harvest quality parameters, the given procedure was followed.

The fresh weight of the spike, water absorption and water loss through transpiration were all measured and reported in grams. In addition, the following formula was used to get the water loss to uptake ratio: water loss to uptake ratio = transpiration loss of water/water intake. The percentage of florets that were open was stated. We evaluated electrolytic leakage by applying Poovaiah (4) approach. The number of days until more than 50 % of the florets showed signs of withering and senescence was used to calculate the vase life. Shelf-life study was conducted in lab condition florets were placed in open condition and florets were placed in refrigerated at 7 °C condition done in individually.

$$\text{RWC (\%)} = \frac{\text{Fresh weight (g)- Dry weight (g)}}{\text{Turgid weight (g)-Dry weight (g)}}$$

$$\text{PLW (\%)} = \frac{\text{Fresh weight of first day (g)- Weight of second day (g)}}{\text{Fresh weight of first day (g)}} \times 100$$

Two season data were pooled and averages were computed. The experimental results were subjected to analysis of variance (ANOVA) for a RBD design (5).

Results and Discussion

The findings demonstrated that the foliar application of nutrients and growth regulators had a major impact on the post-harvest characteristics of tuberose. Micronutrients are necessary for a number of plant physiological functions. For instance, iron is vital for the synthesis of chlorophyll and thylakoids, while also serving as a cofactor

Table 1. Treatment details.

Treatments	Treatment combinations
T_1	Drone spray of MN mixture + 0.5 % Poly feed + 0.4 % Humic acid + 100 ppm GA_3
T_2	Drone spray of MN mixture + 0.5 % Poly feed + 0.4 % Humic acid + 150 ppm GA_3
T_3	Drone spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 100 ppm GA_3
T_4	Drone spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3
T_5	Drone spray of MN mixture (control)
T_6	Knapsack spray of MN mixture + 0.5 % Poly feed + 0.4 % Humic acid + 100 ppm GA_3
T_7	Knapsack spray of MN mixture + 0.5 % Poly feed + 0.4 % Humic acid + 150 ppm GA_3
T_8	Knapsack spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 100 ppm GA_3
T_9	Knapsack spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3
T_{10}	Knapsack spray of MN mixture (control)

MN mixture – Micro Nutrient mixture

Poly feed – All 19:19:19 (N: P: K)

GA_3- Gibberellic acid

in enzyme activation. Zinc is essential for several functions, including nitrogen uptake and metabolism, promoting carbonic anhydrase activity, facilitating tryptophan synthesis and enhancing stress tolerance. Boron is fundamental in maintaining cell wall structure, supporting apical growth and aiding in sugar translocation within the plant. Humic acid, when applied as a growth promoter, affects stem development through multiple mechanisms. It influences root H-ATPase activity and alters the distribution of nitrates between roots and stems. These changes affect the distribution of plant hormones, such as cytokinins and polyamines as well as the stress hormone abscisic acid, throughout the plant. This redistribution of nutrients and hormones may be partially responsible for the growth-promoting effects on tuberose stems (6). Tuberose flowers have a short vase life after harvesting because their internal carbohydrates degrade and their bloom spikes lose their turgidity. To minimize post-harvest losses in tuberose flower spikes, foliar application of different nutrients is necessary (7).

Effect of different nutrient formulations on water uptake (g) of tuberose

Among all treatments, the nutrient formulation comprising Drone spray of MN mixture, 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3 (T_4) showed the highest water uptake on days 2, 4, 6, 8 and 10 (38.45, 21.11, 13.14, 5.66 and 2.10 g respectively), followed by the Knapsack spray of MN mixture, 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3 (Fig. 1).

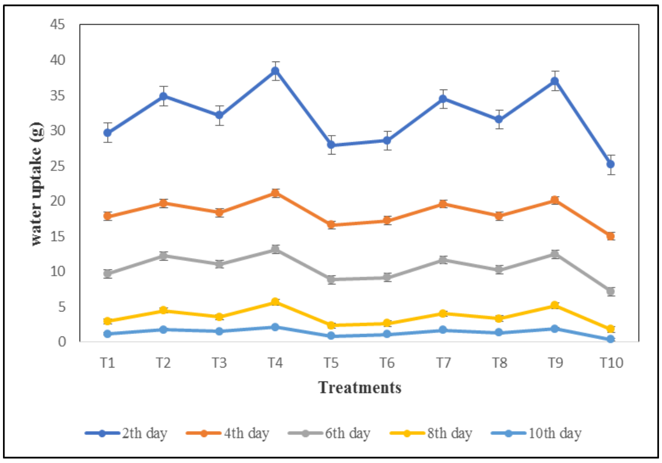

Fig. 1. Effect of different nutrient formulations on water uptake (g) of tuberose.

The flowers that were sprayed with a drone mixture of MN mixture, 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3 showed improved physiological efficacy. This is probably because the treated flowers had more leaves and more total chlorophyll, which would boost the rate of photosynthesis. Consequently, there could have been a higher build-up of respirable materials in the tissue of the flowers. Tuberose post-harvest quality was improved and blooming features were greatly enhanced by the application of micronutrients at appropriate doses through foliar application (8). The increased water absorption in the floral tissue could be attributed to the accumulation of sugars, which raised the osmotic potential and improved the spikes' ability to absorb water. Similar observations were previously reported (9) in Gladiolus. Micronutrient applications have been shown to enhance post-harvest quality, including water uptake, plant turgidity and water balance, in various flower crops such as Gladiolus, Chrysanthemum and Marigold (10, 11).

Effect of different nutrient formulations on transpiration loss of water (g) of tuberose

The data shown in (Fig. 2) regarding the foliar application drone spray of MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3 found that on days 2, 4, 6, 8 and 10 (i.e., 18.74, 15.33, 14.89, 14.32 and 11.61 g respectively) there was a significant reduction in water transpiration loss. This was followed by the application of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3. In contrast, the control group saw the most water transpiration loss (26.49 g) across the entire vase life span.

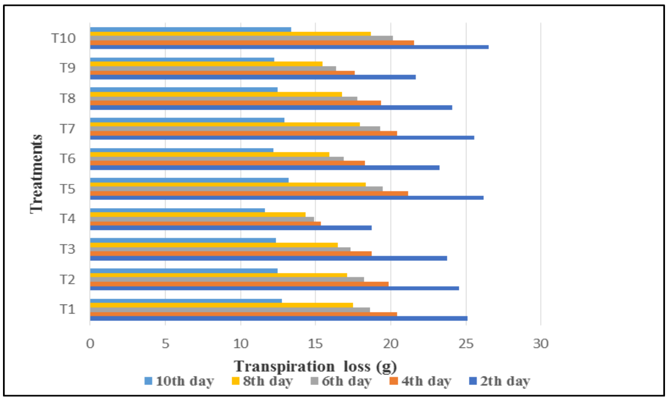

Fig. 2. Effect of different nutrient formulations on transpiration loss of water (g) of tuberose.

The rate of transpiration loss was positively impacted by the application of a drone spray containing an MN mixture, 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3, most likely as a result of the partial closure of stomata. Reducing transpiration rates in flower crops will improve the keeping quality (12, 13). Partial closure of stomata in tuberose flower petals was the main reason for the decrease in transpiration rate observed when sucrose was added to vase water (14). Humic acid increases the availability of minerals for plants to absorb, which in turn improves crop quality (15).

Effect of different nutrient formulations on water loss to uptake ratio of tuberose

In order to assess the impact on the postharvest parameters, the data shown in (Table 2) shows that substantial changes were seen in the tuberose spikes' water loss to absorption ratio with different field treatments. The treatments that recorded the lowest water loss to uptake ratio on days 2, 4, 6, 8 and 10 were drone spray of MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3. These treatments were followed by foliar application of Knapsack spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3. The foliar application drone spray of MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3 improved physiological activity, increasing water uptake and ensuring optimal maintenance of water-conducting tissue. Similar findings were observed in cut tuberose (16, 17).

Table 2. Effect of different nutrient formulations on water loss to uptake ratio of tuberose.

Traits / Days / Treatments	Water loss to uptake ratio				
	2th	4th	6th	8th	10th
T_1	0.84	1.14	1.92	5.98	10.81
T_2	0.70	1.01	1.49	3.83	7.02
T_3	0.61	1.18	1.57	4.68	8.72
T_4	0.48	0.73	1.13	2.53	5.52
T_5	0.78	1.05	1.84	7.58	15.03
T_6	0.82	1.47	1.85	6.04	11.41
T_7	0.75	1.04	1.66	4.55	7.64
T_8	0.75	1.08	1.73	5.05	9.31
T_9	0.57	0.87	1.31	2.98	5.59
T_{10}	1.05	1.43	2.81	10.32	32.26
CD (0.05)	0.009	0.014	0.021	0.064	0.152
SE(d)	0.004	0.006	0.010	0.030	0.072

Effect of different nutrient formulations on electrolyte leakage of tuberose

Data shown in (Fig. 3) Day 0, 2, 4, 6, 8 and 10 showed significantly lower electrolyte leakage (12.52, 16.68, 25.38, 31.50, 47.54 and 65.31 % respectively) in plots treated with drone spray of MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3 (T_4) during both seasons. This was followed by knapsack spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3. Day 10 had the considerably highest rate of electrolyte leakage across the days, whereas Day 2 had the significantly the lowest rate.

Over the course of the vase life span, a progressive rise in electrolyte leakage was noted at each subsequent monitoring interval. In contrast, the control group experienced a much higher electrolyte leakage. An improvement in the water balance resulted from a notable decrease in the rate of water transpiration and an increase in the rate of water uptake. This improvement may have supported the integrity of the cell membrane by reducing the amount of electrolyte leakage seen in the petal tissue. Similar findings were observed in (18, 19).

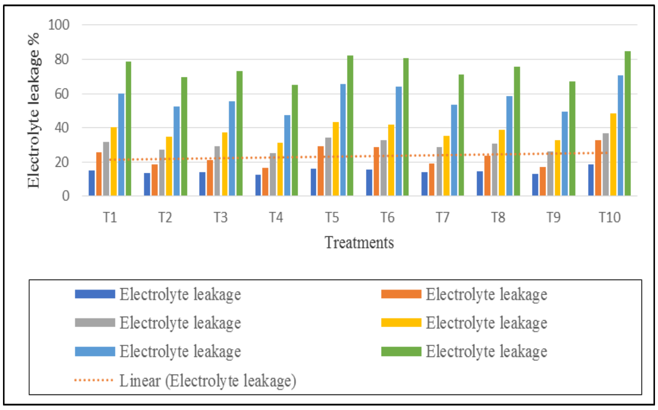

Fig. 3. Effect of different nutrient formulations on electrolyte leakage of tuberose.

Effect of different nutrient formulations on fresh weight change (g) of tuberose

The application of a drone spray containing MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3 (T_4) produced the significantly highest fresh weight of the flower spikes (123.17 g), according to the data shown in (Table 3). This was followed by a backpack spray containing MN mixture, 0.5 % poly feed, 0.6 % humic acid and 150 ppm GA_3 (121.18 g). Day 2 had the considerably largest fresh weight of cut tuberose spikes across the days, whereas Day 10 had the significantly lowest fresh weight.

At each subsequent observation interval recorded over the vase life period, a progressive decrease in the fresh weight change of the flower spikes was noted as time went on. Across all of the observation days, the application of treatment T_4 produced fresh weights that were noticeably highest. An increase in metabolic activity without a loss of quality could have been caused by increased water interactions in the floral tissue. The primary carbohydrate source that lowers water potential and increases floral spikes' fresh weight and water uptake is sucrose.

Table 3. Effect of different nutrient formulations on fresh weight change (g) of tuberose.

Traits / Days / Treatments	Fresh weight change (g)				
	2th	4th	6th	8th	10th
T_1	102.82	88.63	76.83	71.09	62.81
T_2	116.79	102.51	91.30	84.33	77.79
T_3	109.27	96.79	86.42	79.08	71.93
T_4	123.17	116.31	107.78	99.41	94.37
T_5	97.85	83.46	70.69	65.81	57.21
T_6	99.81	86.20	74.69	67.87	60.98
T_7	114.80	100.69	88.52	81.50	74.54
T_8	106.93	93.40	82.45	75.92	68.71
T_9	121.18	106.76	98.49	90.82	85.19
T_{10}	95.01	80.14	67.84	57.78	51.91
CD (0.05)	1.517	1.261	1.902	1.356	1.284
SE(d)	0.722	0.612	0.905	0.645	0.611

Similar findings were observed in cut gladiolus spikes (21), in cut rose (13) and in tuberose (14, 22). GA_3 enhances floret size by promoting metabolite translocation at the floret development site, potentially through cell elongation, leading to an increase in floret quality that will be enhance the post-harvest life of the florets. Gibberellins are recognized for their ability to boost the sink strength of actively growing parts. These observations align with findings reported (22) in tuberose and (23) in gladiolus. Iron increased the storage of carbohydrates through the increased in the rate of photosynthesis (24).

Effect of different nutrient formulations on percent of floret opened (%) of tuberose

The information shown in (Table 4) showed that from the second to the tenth day of the experiment, flower spikes collected from the application of MN mixture by drone spraying combined with 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3 recorded the significantly highest percentage of opened florets. These spikes were followed by spikes collected from MN mixture through knapsack spraying combined with 0.5 % Poly feed, 0.6 % Humic acid and 150 ppm GA_3. The opening of florets was found to be much higher, which might be explained by the possibility that flower spikes gathered from treatment T_4 plants had accumulated enough food material needed for their usual physiological activities. Furthermore, a higher proportion of opened florets would have resulted from avoiding vascular constriction and having more soluble carbohydrates in the floral tissue (21).

Additionally, a higher rate of water absorption and a lower rate of water loss through transpiration may have improved the water balance in the floral tissue, resulting in a higher fresh weight change and a decrease in electrolyte leakage, both of which may have contributed to a higher percentage of opened florets. Humic acid increases intracellular metabolism and leaf chlorophyll concentration, which results in longer-lasting leaves and larger leaf areas (25). An increased quality of spike might be caused by the drawing of photosynthesis to flower as a consequence of intensification of the sink which also increased cell division and cell elongation due to the foliar application of GA_3 which might have been utilized for the production of the better-quality spike in tuberose. A similar finding was observed in tuberose (26). Applying sucrose as a carbohydrate source in vase solutions may reduce stem blockage and maintain water conductivity. The presence of sucrose in the vase solution helps prevent moisture stress in floral tissues and enhances osmotic adjustment, improving water absorption. This maintains turgidity, promoting better floret opening. Similar findings were observed in tuberose (14, 27) and in gladiolus (20).

Effect of different nutrient formulations on post-harvest parameters of tuberose

The information shown in (Table 5) showed that significant effect for applying nutrient solution through Drone spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3 concentration recorded significantly highest relative water content percentage (95.15), reduced

Table 4 Effect of different nutrient formulations on percent of floret opened of tuberose.

Traits / Days / Treatments	Percent of floret opened (%)				
	2th	4th	6th	8th	10th
T_1	23.82	30.76	39.60	48.91	63.12
T_2	26.10	32.76	41.36	53.38	64.88
T_3	24.87	31.95	40.32	50.18	64.12
T_4	27.02	33.98	42.55	54.52	65.71
T_5	20.86	30.05	38.57	47.87	62.16
T_6	21.40	30.54	39.22	48.35	62.59
T_7	25.73	32.16	40.89	51.58	64.46
T_8	24.18	31.22	39.95	49.54	63.76
T9	26.53	33.51	42.18	54.09	65.24
T_{10}	18.67	28.30	36.43	45.74	59.27
CD (0.05)	1.171	1.158	0.825	0.889	0.620
SE(d)	0.556	0.561	0.397	0.446	0.301

Table 5. Effect of different nutrient formulations on post-harvest parameters of tuberose.

Treatments \Traits	Relative water content % on 2nd day	Physiological loss of weight % on 2nd day	Shelf-life at room temperature	Shelf-life at refrigerated (7 °C)	Vase life
T_1	91.45	19.06	3.54	6.96	10.76
T_2	93.89	16.11	3.65	7.71	11.74
T_3	93.18	17.18	3.61	7.44	11.28
T_4	95.15	14.83	3.89	7.92	12.45
T_5	90.22	19.41	3.48	6.76	9.62
T_6	91.29	19.32	3.52	6.87	10.31
T_7	93.46	16.38	3.64	7.64	11.79
T_8	92.15	17.98	3.58	7.37	10.99
T_9	94.46	15.77	3.71	7.82	12.11
T_{10}	87.38	20.27	3.42	5.98	8.61
CD (0.05)	0.876	0.671	0.109	0.045	0.422
SE(d)	0.413	0.319	0.051	0.021	0.198

physiological loss of weight % flower (14.83), highest shelf life at room temperature (3.89) and shelf life at refrigerated (7 °C) condition (7.92), vase life (12.45) whereas, control recorded significantly lowest relative water content %, shelf life and vase life.

Micronutrient foliar spray is useful for producing more floral crops with higher-quality blooms that last longer in vases (7). Zinc is necessary for the correct operation of the photosynthetic processes, nitrogen metabolism and uptake, carbon anhydrase activity, carbohydrate metabolism and synthesis, tryptophan synthesis, protein quality, the precursor of IAA, increased tolerance against oxidative stress and improved vase life of flowers (28). Higher relative water content kept spikes turgid due to increased water absorption and decreased water loss through transpiration; physiological weight loss also kept spikes turgid and water balanced. It is possible that the longer vase life and shelf life of tuberose flowers with greater GA_3 concentrations were caused by increased auxin activity, which has been shown to promote metabolite translocation and postpone senescence. Similar findings were observed in tuberose (26).

The increased nutrient absorption from drone spraying over manual application is responsible for the yield and quality gains. As a result of the propellers' downward airflow and turbulence, leaves flutter and flip more frequently, which increases the number of droplets that land on their active spots. Compared to hand spraying, this results in a more uniform distribution of finer droplets, facilitating improved penetrate and effective transfer of nutrients. The combined action helps improve crop quality, yield and growth. The concurrent results were obtained by (29, 30).

Multivariate analysis:

A PCA biplot was constructed to investigate the impact of different nutrient combinations on the phenotypic diversity of various plant traits. This multivariate statistical technique aims to identify the principal plant attributes responsible for the most significant variations observed among the treatments. The biplot representation of correlations (Fig. 4) was utilized to explore how different nutrient concentrations affect these parameters, revealing notable disparities across the treatments.

In the PCA results, the first principal component

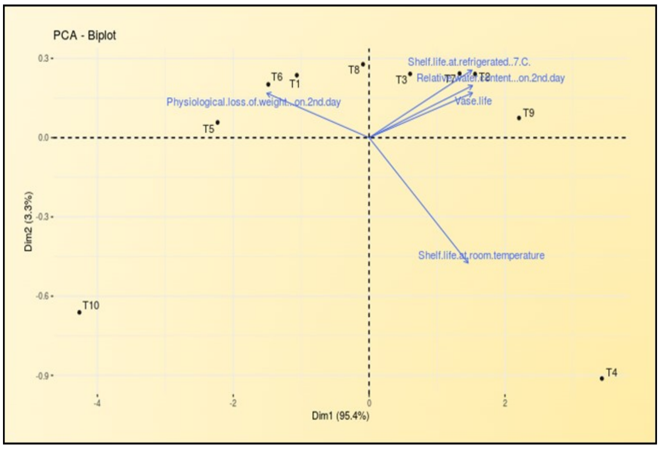

Fig. 4. Graph representing a PCA biplot.

(PC_1) exhibited eigenvalues greater than one, specifically registering at 4.77. This component accounted for a substantial 95.40 % of the total cumulative variance, indicating its significant role in explaining the differences observed. A graphical representation of these variances is provided in (Fig. 5).

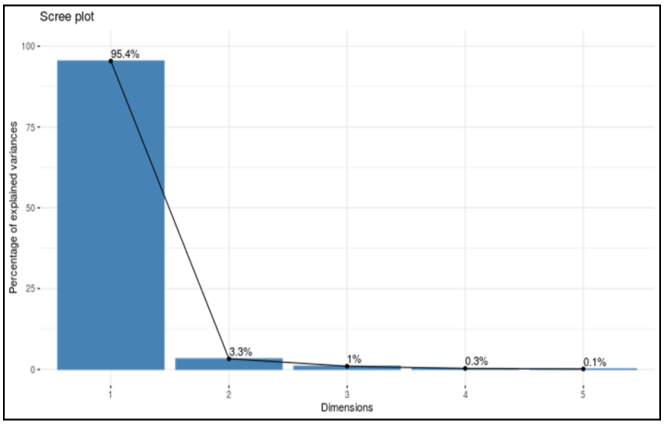

Fig. 5. Graph representing a percentage of variance.

Furthermore, a correlation plot (Fig. 6) was assessed to understand the relationships between the variables and the principal component groups. Interestingly, the physiological loss of weight on the second day showed negative correlations with the principal component groups. In contrast, the remaining physiological parameters were positively correlated with these groups. This suggests that while most physiological traits varied in a similar direction with nutrient changes with the weight loss on the second day showed negative correlation.

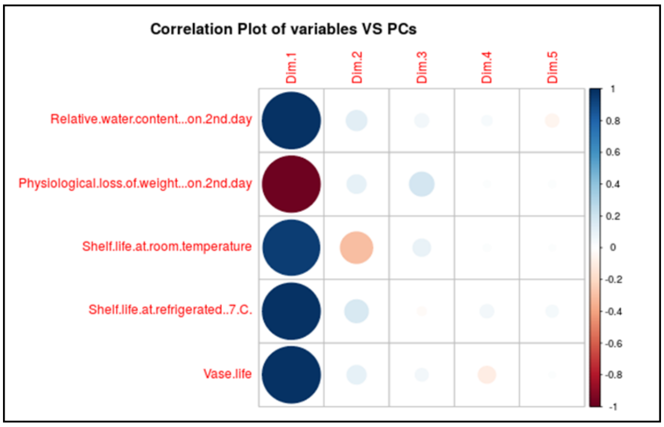

Fig. 6. A correlation plot between variables and PCs.

Conclusion

The study suggests that foliar application of various nutrient combinations, alongside growth regulators through UAVs, Drone spray of MN mixture + 0.5 % Poly feed + 0.6 % Humic acid + 150 ppm GA_3 (T_4) leads to enhanced post-harvest quality attributes likes water uptake, shelf life, vase life and reduce the electrolyte leakage of tuberose spikes. In essence, it highlights the potential of UAV technology to revolutionize agricultural practices, offering a more efficient and precise method for nutrient delivery and ultimately contributing to improved crop productivity and post-harvest quality in Tuberose cultivation.

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Authors' contributions

MA carried out the experiment, took observations and analysed the data. DK guided the research by formulating the research concept, helped in securing research funds and approved the final manuscript. RC contributed by developing the ideas, reviewed the manuscript and helped in procuring research grants. SP contributed by imposing the experiment, helped in editing, summarizing and revising the manuscript. MR helped in summarizing and revising the manuscript. VV helped in editing, summarizing and revising the manuscript.

Compliance with ethical standards

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

Ethical issues: None

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

During the preparation of this work the author(s) not used AI tools and the author(s) reviewed and edited the content as needed and take(s) full responsibility for the content of the publication.

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