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Influence of different bio-inoculants and potassium concentrations on the vegetative growth, flower quality and yield of Chrysanthemum (*Chrysanthemum morifolium* Ramat.) in a controlled environment

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Abstract
Bio-fertilizers are a cost-effective, renewable resource that plays a significant role in reducing the reliance on inorganic fertilizers, while simultaneously enhancing plant growth, flower quality, yield, and maintaining soil fertility. The combined use of potassium-solubilizing and mobilizing bio-inoculants with inorganic fertilizers has been shown to boost the effectiveness of organic inputs and improve the efficiency of chemical fertilizers, allowing for reduced application rates. With this context, this study was conducted at the Department of Horticulture, College of Agriculture, Navile, Keladi Shivappa Nayaka University of Agricultural and Horticultural Sciences, Shivamogga. The experiment consisted of 10 treatments laid out in a Randomized Complete Block Design (RCBD) with three replications. Data was collected on plant growth, flower characteristics, and yield factors. Among all treatments T_7 (100% N & P+ 75% K + KSB+ KSF) recorded highest plant height (60.04 cm), stem girth (6.57 mm), internodal length (2.80 cm), number of primary & secondary branches per plant (9.12 & 26.37), individual flower weight (6.36 g), flower diameter (6.69 cm), shelf life (7.17 days), number of flowers per plant (77.93), flower yield per plant (360.60 g), per m2 (4.16 kg) and per poly house (2.6 t/560 m2), number of suckers per plant (7.21), per m2(68.11) and per polyhouse (28607.6). In summary, the use of 75 percent potassium along with 100 percent nitrogen and phosphorus, combined with bio-inoculants, is the most beneficial for improving the vegetative growth, flower quality, and yield characteristics of chrysanthemum.

Keywords: Chrysanthemum, bio-inoculants, potassium, protected condition, vegetative growth, flower quality and yield

Introduction
Floriculture is rapidly evolving into a technologically advanced, interdisciplinary industry worldwide, with India emerging as a prominent participant. Recognized as a sunrise industry by the Indian government, commercial floriculture is now practiced in controlled greenhouse conditions, offering high returns per unit area. Among flower crops, Chrysanthemum (*Chrysanthemum morifolium* Ramat.), also known as the "Golden Flower," holds a significant place due to its aesthetic appeal, economic value, and historical importance. Native to Asia and Europe, it is cultivated across India under various regional names and is the second most important cut flower globally after the Rose. Chrysanthemums are valued for ornamental, religious, and medicinal uses and even serve as a source of essential oils and biological pesticides. Their year-round blooming potential, due to photoperiod sensitivity, has added to their popularity.

A major focus in floriculture is improving flower quality, yield, and post-harvest life, which are influenced by nutrition, particularly potassium (K^+). Potassium plays a crucial role in plant metabolic functions and overall health. While chemical fertilizers are effective, their excessive use has environmental drawbacks. The trend is now shifting towards sustainable practices, including the use of bio-fertilizers or microbial inoculants like Azotobacter, *Pseudomonas striata*, VAM fungi, and *Bacillus mucilaginosus*. These bio-inoculants enhance soil fertility, promote nutrient uptake, and reduce the need for inorganic fertilizers. Especially, potassium-solubilizing microorganisms (KSMs) are vital in improving flower production and maintaining ecological balance. Bio-inoculants, such as Azotobacter, phosphorus and potassium-solubilizing microbes, and VAM fungi, enhance nutrient uptake, improve soil structure, and increase productivity while reducing dependency on chemical fertilizers.

Bio-fertilizers are a cost-effective, renewable alternative that reduces the need for inorganic fertilizers while enhancing flower yield, and quality, and maintaining soil fertility. These include nitrogen fixers, phosphorus- and potassium-solubilizing microbes, and organisms that transform nutrients into plant-available forms. Frequently used bio-fertilizers in horticultural practices include Azotobacter, *Pseudomonas striata*, VAM fungi, *Bacillus mucilaginosus*, and *Aspergillus awamori*. K-solubilizing microorganisms (KSMs) improve potassium uptake and promote plant growth in both polyhouse and field conditions. When used with inorganic fertilizers, these bio-inoculants enhance nutrient efficiency, allowing a reduction in chemical fertilizer use.

Materials and Methods

The current investigation was conducted between 2021 and 2022 at the College of Agriculture in Shivamogga, Karnataka. Rooted terminal cuttings of chrysanthemum variety Kolar Local were utilized for planting in ridges and furrows, with a plot dimension of 3.3m x 1m and a spacing of 30 x 30cm (33 plants per plot). The experiment was organized in a Randomized Complete Block Design (RCBD) featuring three replications. A total of ten treatments were implemented, which included: T1 -100% RDF (control); T_2 -100% NPK + KSB; T_3 -100% NPK + KSF; T_4 -100% NPK + KSB+ KSF; T_5 -100% N & P+ 75% K+ KSB; T_6 -100% N & P+ 75% K+ KSF; T_7 -100% N & P+ 75% K+ KSB+KSF; T_8 -100% N & P+ 125% K+ KSB; T_9 -100% N & P+ 125% K+ KSF; T_{10} - 100% N & P+ 125% K+ KSB +KSF.

In this study, five types of bioinoculants were utilized, specifically *Bacillus mucilaginosus*, *Aspergillus awamori*, *Azotobacter chroccacum*, *Pseudomonas striata*, and *Glomus fasciculatum*, which were applied five days before planting. The bio-inoculants were combined with farm yard manure (FYM) and directly incorporated into the soil, with observations on vegetative growth, flower quality, and yield parameters recorded from the tagged plants; the data were then analyzed scientifically, and the results were interpreted and discussed as follows. Observation on vegetative growth parameters *viz*., plant height, stem girth, number of branches per plant, and internodal length, were taken at 120 days after transplanting (DAT). The observations on vegetative growth, flower quality, and yield parameters were recorded from the tagged plants. The data were scientifically analyzed, and the results were interpreted and discussed as follows. Vegetative growth parameters such as plant height stem girth, number of branches per plant, and internodal length were recorded at 120 DAT. Plant height was measured from the base of the plant (ground level) to the apex of the main stem on each tagged plant, and the average value was calculated. Stem girth was measured at three random points just above the ground using Vernier callipers, and the average was computed from all tagged plants. Internodal length was determined by measuring three randomly selected internodes per plant, and the mean value was taken. The number of primary and secondary branches per plant was recorded by counting the branches at 120 DAT, and the average was calculated.

For flower quality parameters, observations including flower weight - ten flowers at full bloom stage were harvested from tagged plants, individually weighed using an electronic balance, and the average was expressed in grams, flower diameter - ten fully opened flowers were randomly selected from the tagged plants, and their diameter was measured using Vernier calipers. The mean diameter was then calculated and shelf life - fully opened flowers were harvested and placed on plates under laboratory conditions. The number of days until they lost marketable quality was recorded.

Regarding flower and sucker yield parameters, the number of flowers per plant was determined by counting flowers from five tagged plants and calculating the average. Flower yield per plant was calculated by weighing the flowers from randomly selected individual plants and computing the mean yield. Flower yield per m² was estimated by harvesting flowers from ten plants and converting the total yield to a per-square-meter basis and flower yield per 560 m² was extrapolated from the per m² yield and used to assess cost economics. In the case of sucker yield parameters, the sucker yield per plant was assessed by counting the number of suckers from five tagged plants at 150 days after transplanting (DAT) and the average was calculated. For sucker yield per square meter (m²), suckers from ten plants were counted at 150 DAT and the average number was computed per m². Similarly, for sucker yield per 560 m², the total number of suckers recorded at 150 DAT was extrapolated to calculate the average yield over an area of 560 m².

Results and Discussion

Vegetative parameters

Vegetative growth is measured better way in terms of plant height, stem girth, internodal length, and number of primary and secondary branches are very crucial as they play an important role in deciding the ultimate crop yield. These are influenced substantially by the application of N, P2O5, and K2O fertilizers along with bio-inoculants. In the parameters of plant height, stem girth, internodal length, and number of primary and secondary branches, significant differences were observed among the treatments (Table 1).

Significantly, the highest plant height (60.04 cm) was observed in the plants which received 100 percent N and P2O5 + 75 percent K2O + KSB + KSF (T_7) compared to 100 percent RDF (T_1) (40.82 cm) being the recommended practice as check. The combined effect of fertilizers may have enhanced plant metabolism and photosynthesis, promoting better growth and development. Potassium plays a key role in energy production by forming Adenosine triphosphate (ATP), essential for biochemical and enzymatic processes. Bio-inoculants like *Aspergillus awamori* and *Bacillus mucilaginosus* aid in converting unavailable potassium into available forms, improving nutrient uptake and stimulating vegetative growth and yield traits. Some of the results suggest that the combined application of inorganic fertilizers and bio-fertilizers was superior concerning plant height compared to the individual application was noticed by Bhatia and Guptha, incarnation, Pandey *et al.*, in chrysanthemum, Verma *et al.*, 2011 [25] in chrysanthemum, Gotmare *et al.*, in marigold, Gayithri *et al.*, in Statice.

Similarly, the plants that received 100 percent N and P2O5 + 75 percent K2O + KSB + KSF (T_7) registered significantly higher stem girth (6.57 mm) compared with T1 (5.31 mm). The results indicate that the combined application of inorganic fertilizers and bio-fertilizers was more effective in promoting robust plant growth than RDF (T_1) alone. Bio-fertilizers aid in converting unavailable forms of potassium into plant-available forms, enhancing nutrient uptake. Additionally, mycorrhizal associations improve nutrient absorption, allowing crops to utilize potassium more efficiently and maintain optimal growth even at reduced fertilizer doses. These findings are in line well with the results of Fortuna in apple and plum, Deshmukh in gaillardia, Suresh in papaya and Chandra *et al.*, 2009 in chrysanthemum.

The internodal length was significantly higher in the plants inoculated with 100 percent N and P2O5 + 75 percent K2O + KSB + KSF (T7) (2.80 cm) and the least was observed in plants that were given 100 percent RDF (1.20 cm). The increase in plant height could be attributed to the elongation of internodes, likely influenced by improved nutrient availability and growth hormones such as gibberellins. These factors may have stimulated the production of growth-promoting substances, leading to enhanced cell division and elongation. These results are in confirmation with the earlier work of Bhatia and Guptha in Carnation.

The application of 100 percent N and P2O5 + 75 percent K2O + KSB + KSF (T7) has resulted in a significantly higher number of primary and secondary branches per plant compared to (T1) 100 percent RDF (9.12, 26.37, and 5.51, 16.01, respectively). This clearly shows that the increase in the number of branches per plant may be attributed to the positive effects of KSB, KSF, Azotobacter, VAM, and PSB when combined with inorganic fertilizers. Growth regulators such as NAA and cytokinins, produced by KSB and KSF, likely contributed to breaking apical dominance and promoting branch development. Additionally, the synergistic effect of biofertilizers and inorganic fertilizers may have improved nutrient availability, and support better root and shoot growth, which ultimately led to increased formation of primary and secondary branches. Similar findings were also reported by Raja, 2016 in Marigold, Thumar *et al.*, 2013 [24] in African marigold, Chaitra, and Patil in China aster.

Flower quality parameters

The main objective for any cultivator is to enhance crop yield and improve quality to optimize profits. Notable variations were detected among treatments concerning factors like flower weight, flower size, and longevity (as shown in Figures 1 to 3).

The flower weight was significantly affected by the different treatments applied. The plants that received 100 percent nitrogen and phosphorus along with 75 percent potassium, combined with KSB and KSF (T_7), exhibited the highest flower weight of 6.36 g, which was notably greater than all other treatments and statistically comparable to T_4 (6.01 g). In contrast, T_1 (100% RDF) showed the lowest flower weight at 4.10 g. The observed increase in average flower weight is likely attributed to enhanced potassium availability from KSMs and RDF, improved soil conditions, and better nutrient uptake driven by microbial activity. Additionally, biofertilizers generate growth hormones such as auxins, gibberellins, and cytokinins, which support vigorous growth, boost photosynthesis, and facilitate the movement of photosynthates to the flowers. The increased dry matter production and its distribution to various plant parts further led to greater flower yield, quantity, and size. These results align with the earlier research conducted by Swaroop (2011) [23] on Marigold and Kirar *et al.* (2014) [9] on China aster.

The different treatments significantly affected flower diameter, with the largest flower diameter of 6.69 cm recorded for plants treated with (100% N and P + 75% K + KSB + KSF) (T_7), which was statistically similar to T4 (6.13 cm). The smallest flower diameter of 4.13 cm was noted in T1 (100% RDF). This is likely due to the early disruption of apical dominance, which facilitates better nutrient transport to the flowers as a result of inoculation with beneficial microbial agents such as KSB and KSF. Adequate potassium in the soil promotes robust plant growth, leading to the formation of larger flowers. KSMs may have increased potassium availability by solubilizing its fixed forms in the soil and releasing enzymes that aid in producing larger flowers. Similar findings have been documented by Verma *et al.* (2011) [25] and Laishram (2013) [12] in studies on chrysanthemums.

The longevity of the flowers (Plate 1) varied significantly among the different treatments. T_7 (100% N and P + 75% K + KSB + KSF) exhibited the longest longevity at 7.17 days, which was statistically similar to T_4 at 6.15 days. In contrast, the RDF (T_1) displayed the shortest lifespan at 3.17 days. This could be attributed to the greater water retention in the floral cells and decreased desiccation, likely due to the positive impact of biofertilizers such as KSB, KSF, and FYM. These results are consistent with the findings reported by Mashaldi (2000) [13].

Flower and sucker yield and its attributing characters

The information regarding flower yield factors, including the count of flowers per plant, flower yield per plant, per square meter, and per 560 square meters, as well as the count of suckers per plant, per square meter, and per 560 square meters under various treatments, is shown in Table 2.

Different treatments significantly influenced the number of flowers produced per plant. Plants treated with 100 percent N and P + 75 percent K + KSB + KSF (T_7) yielded the highest flower count (77.93) and were statistically similar to T_4 plants (76.13). T_1 (100% RDF) resulted in the fewest flowers per plant (54.76). There was a notable difference in flower yield per plant depending on the treatment applied. Plants treated with 100 percent N and P + 75 percent K + KSB + KSF (T_7) achieved a higher flower yield (360.60 g) and were statistically comparable to T_4 plants (347.58 g). The least flower yield per plant was noted in T_1 (100% RDF) (248.41 g). The highest yield per square meter was found in T_7 (100 percent N and P + 75 percent K + KSB + KSF) at 4.16 kg, which was statistically similar to T_4 (100% NPK + KSB + KSF) at 3.86 kg and T_{10} (100 percent N and P + 125 percent K + KSB + KSF) at 3.65 kg. In contrast, T_1 (100% RDF) recorded the lowest yield per square meter at 2.81 kg. Among all treatments, T_7 (100 percent N and P + 75 percent K + KSB + KSF) achieved the highest yield over 560 m2 (2.68 t), which was comparable to T_4 (100% NPK + KSB + KSF) at 2.55 t. The lowest yield was observed in T_1 (100% RDF) at 1.99 t.

In treatment T_7, which included 100% nitrogen and phosphorus along with 75% potassium and both KSB and KSF, the highest number of suckers produced was 7.21, closely followed by T_4 (100% NPK with KSB and KSF) at 6.89. Conversely, T_1 (100% control) yielded the fewest suckers with a total of 4.81. Regarding the sucker yield per square meter, the plants treated with 100% nitrogen and phosphorus plus 75% potassium and both KSB and KSF (T_7) achieved a significantly higher yield of 68.11 and were statistically similar to those in T_4, which produced 65.11. The lowest yield per square meter was noted in T_1 (100% RDF), with a total of 38.06. When evaluating the overall sucker yield per 560 m², T_7 (100% N and P + 75% K + KSB + KSF) produced the highest output (38143.5) and was comparable to T_4 (100% NPK + KSB + KSF) (36460.7) and T_{10} (100% N and P + 125% K + KSB + KSF) (35338.5). On the other hand, T_1 (100% RDF) recorded the lowest sucker yield per 560 m² (21315.5).

The rise in flower production can be linked to the vigorous and swift proliferation of microorganisms in the rhizosphere, which fostered ideal conditions for nitrogen fixation and improved potassium solubilization. This was additionally reinforced by the application of nitrogenous fertilizers, increased nutrient availability, bacterial secretions, hormone synthesis, and the release of antibacterial and antifungal agents, all of which enhanced plant growth and ultimately increased marigold yield (Kumar *et al*., 2009) [10].

The enhancement in yield characteristics and increased flower production can be linked to the effectiveness of KSB, KSF, Azotobacter, VAM, and PSB in promoting nutrient and water absorption, along with facilitating a greater number of leaves and leaf area. This likely enhanced photosynthesis and food storage, which resulted in improved plant development and an elevated flower count per plant, thus raising the flower yield per hectare. Furthermore, the presence of growth-promoting compounds such as auxins, gibberellins, and cytokinins generated by biofertilizers may have aided in the development and accumulation of biomass, further leading to an increase in flower production and yield per 560 m². These findings align with previous research by Thumar *et al.* (2013) [24] and Jadhav *et al.* (2014) [8] in Marigold, Patanwar *et al.* (2014) [18] in chrysanthemum, Sheergojri *et al.* (2013) [20] in dahlia, and Meshram *et al.* (2008) [15] in chrysanthemum.

Table 1: Influence of different bio-inoculants and potassium concentrations on the vegetative growth of Chrysanthemum in a controlled environment

Treatments		Vegetative parameters (120 Days after transplanting)				
		Plant height (cm)	Stem girth (mm)	Internodal length (cm)	Number of primary branches per plant	Number of secondary branches per plant
T_1	100% RDF	40.82	5.31	1.20	5.51	16.01
T_2	100% NPK + KSB	51.70	6.13	2.10	7.77	20.48
T_3	100% NPK + KSF	45.13	5.81	1.32	6.44	17.01
T_4	100% NPK+ KSB+ KSF	56.47	6.41	2.50	8.52	22.69
T_5	100% N & P+ 75% K+ KSB	52.66	6.11	2.22	7.83	20.70
T_6	100% N & P+ 75% K + KSF	49.02	5.81	1.38	6.81	17.04
T_7	100% N & P+ 75% K + KSB+ KSF	60.04	6.57	2.80	9.12	26.37
T_8	100% N & P+ 125% K+ KSB	51.15	6.01	1.80	7.35	18.04
T_9	100% N&P+ 125% K + KSF	48.80	5.49	1.78	6.02	16.35
T_{10}	100% N&P+ 125% K+ KSB+ KSF	52.66	6.23	2.35	8.21	21.09
S.Em ±		0.63	0.25	0.06	0.21	0.66
C.D. @ 5%		1.86	0.73	0.18	0.63	1.95

Note:

- Recommended dosage of fertilizers- 40: 60: 40 kg NPK / acre
- Farm Yard Manure - 8 ton/acre (common for all treatments)
- Bio-inoculants: 5 kg/acre
- KSB- Potassium Solubilizing Bacteria (*Bacillus mucilaginosus*)
- KSF- Potassium Solubilizing Fungus (*Aspergillus awamori*)
- Farm Yard Manure, *Azotobacter chroccacum*, VAM - Vesicular Arbuscular Mycorrhiza (*Glomus fasciculatum*) and PSB (*Psudomonas striata*) at 5 kg/acre is common for all treatments.

Table 2: Influence of different bio-inoculants and potassium concentrations on flower and sucker yield of Chrysanthemum in a controlled environment

Treatments		Number of flowers per plant	Flower yield per plant (g)	Flower yield per m^2 (kg)	Flower yield per 560 m^2 (t)	Number of suckers per plant	Number of suckers per m^2	Number of suckers per 60 m^2
T_1	100% RDF	54.76	248.41	2.81	1.99	4.81	38.06	21315.5
T_2	100% NPK + KSB	65.11	270.45	3.41	2.38	6.29	58.10	32534.1
T_3	100% NPK + KSF	58.10	260.60	3.01	2.26	6.08	47.08	26363.9
T_4	100% NPK+ KSB+ KSF	76.13	347.58	3.86	2.55	6.89	65.11	36460.7
T_5	100% N & P+ 75% K+ KSB	71.12	290.48	3.61	2.45	6.41	61.10	34216.9
T_6	100% N & P+ 75% K + KSF	62.10	265.44	3.01	2.26	5.85	56.09	31412.3
T_7	100% N & P+ 75% K + KSB+ KSF	77.93	360.60	4.16	2.68	7.21	68.11	38143.5
T_8	100% N & P+ 125% K+ KSB	68.11	281.45	3.41	2.33	6.24	51.09	28607.6
T_9	100% N&P+ 125% K + KSF	62.10	260.43	3.31	2.18	5.30	44.07	24681.2
T_{10}	100% N&P+ 125% K+ KSB+ KSF	74.99	320.85	3.65	2.49	6.63	63.11	35338.5
S.Em ±		2.40	8.40	0.12	0.08	0.20	1.60	1273.14
C.D. @ 5%		7.12	24.95	0.36	0.23	0.61	4.75	3782.69

Note:

- Recommended dosage of fertilizers- 40: 60: 40 kg NPK / acre
- Farm Yard Manure - 8 ton/acre (common for all treatments)
- Bio-inoculants: 5 kg/acre
- KSB- Potassium Solubilizing Bacteria (*Bacillus mucilaginosus*)
- KSF- Potassium Solubilizing Fungus (*Aspergillus awamori*)
- Farm Yard Manure, *Azotobacter chroccacum*, VAM - Vesicular Arbuscular Mycorrhiza (*Glomus fasciculatum*) and PSB (*Psudomonas striata*) at 5 kg/acre is common for all treatments.

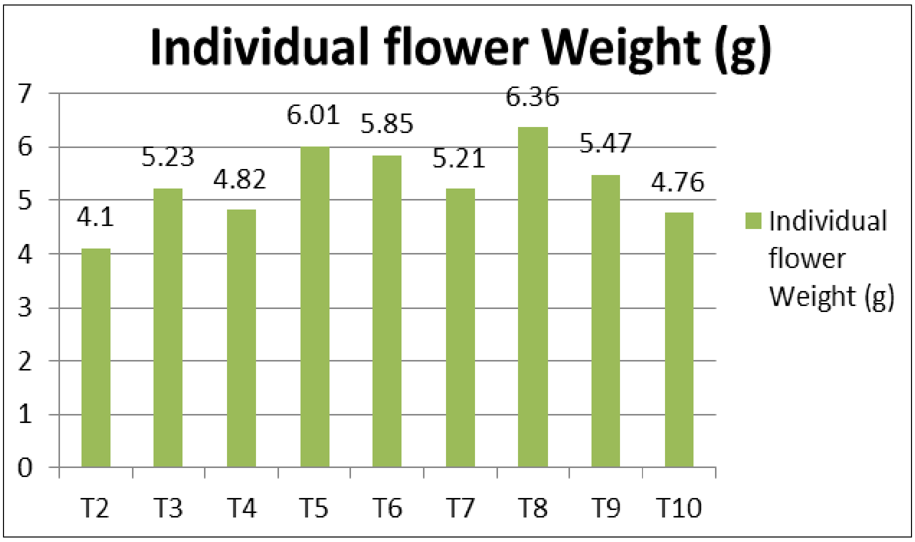

Fig 1: Influence of different bio-inoculants and potassium concentrations on Individual flower weight of Chrysanthemum in a controlled environment

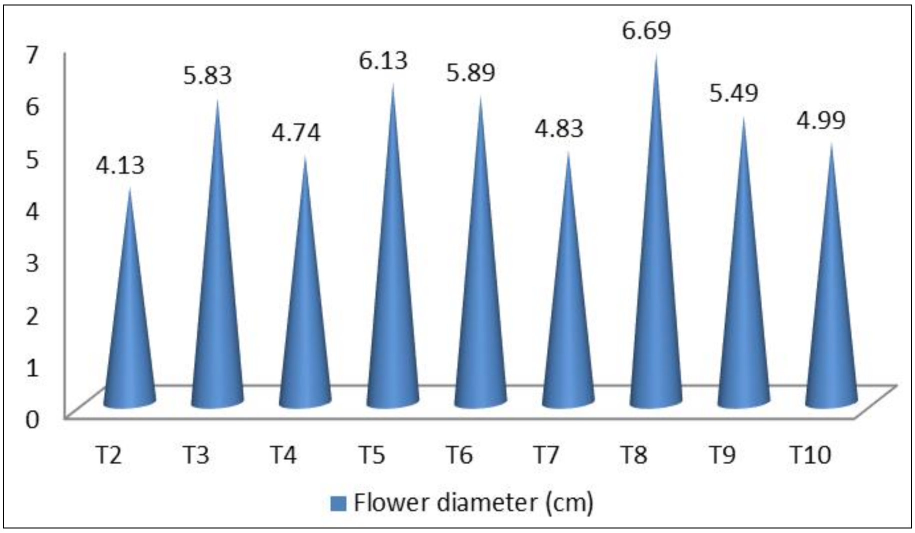

Fig 2: Influence of different bio-inoculants and potassium concentrations on flower diameter of Chrysanthemum in a controlled environment

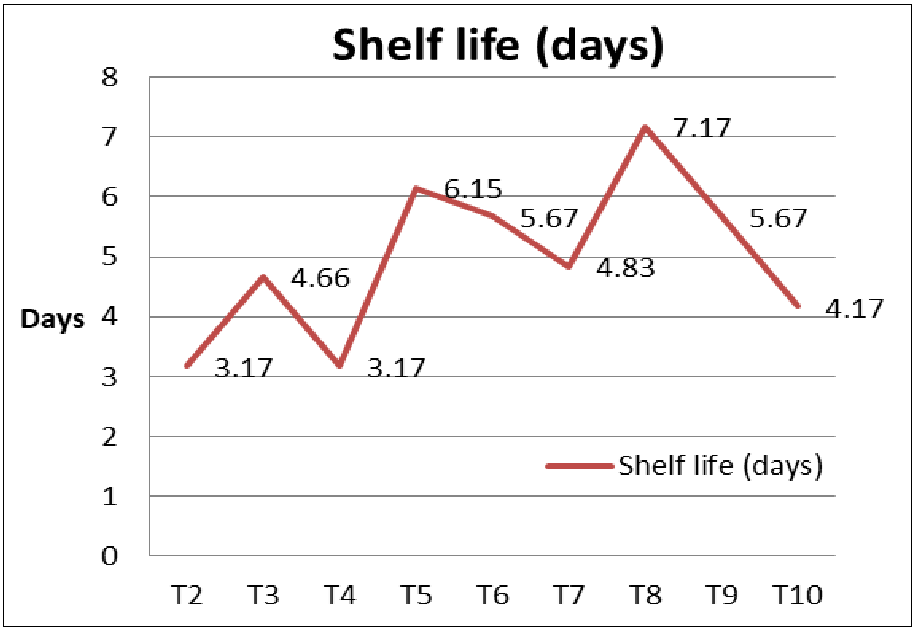

Fig 3: Influence of different bio-inoculants and potassium concentrations on shelf life of Chrysanthemum in a controlled environment

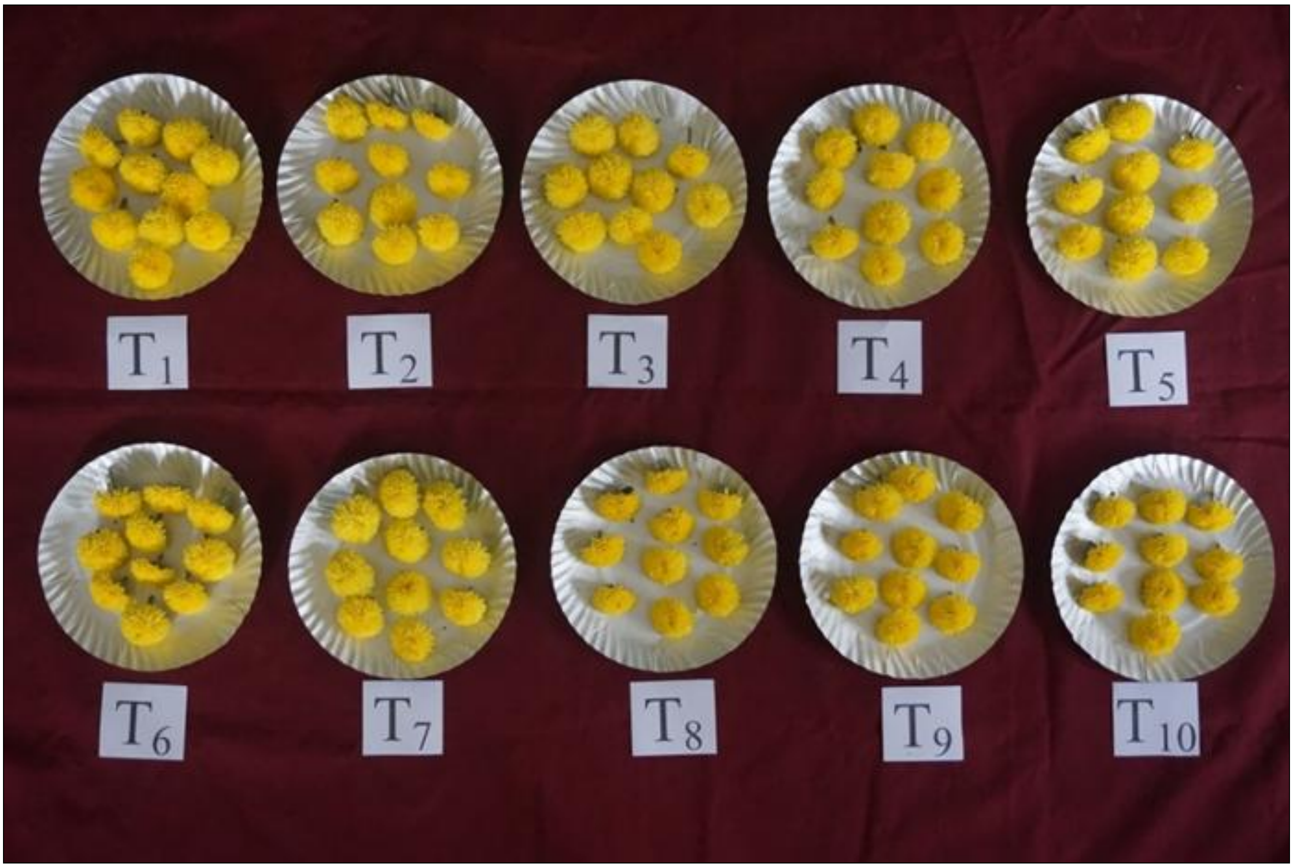

Plate 1: Shelf life of various bio-inoculants treated flowers

Conclusion

From the current study, it can be inferred that utilizing 75% of the suggested potassium, in conjunction with 100% nitrogen and phosphorus, along with the application of bioinoculants (KSB-*Bacillus mucilaginosus*, KSF-*Aspergillus awamori*, *Azotobacter chroococcum*, VAM-*Glomus fasciculatum*, and PSB-*Pseudomonas striata*), significantly enhances the vegetative growth, flowering, yield, and quality of chrysanthemums. This also emphasizes the possibility of reducing potassium fertilizer by 25% when integrated with bioinoculants, thereby making chrysanthemum farming more cost-effective and environmentally friendly.

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