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Effect of coconut water and *Moringa oleifera* leaf extract as holding solutions on antioxidant activity and vase life of Gladiolus (*Gladiolus hybridus* Hort.) cv. White Prosperity"

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Abstract

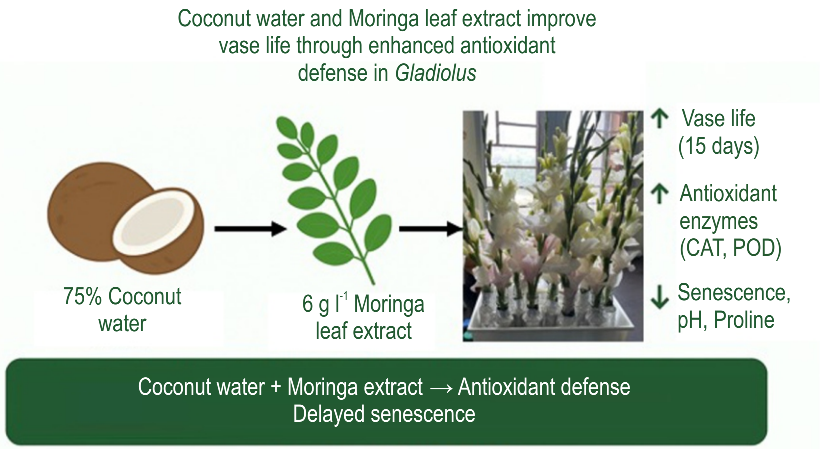
Aim: The objective of this study was to evaluate the effects of environmentally friendly preservative solutions, based on coconut water (CW) and *Moringa oleifera* leaf extract (MLE), as potential alternatives to synthetic chemicals for improving the postharvest quality and vase life of gladiolus cut spikes.

Methodology: A total of nine treatments containing different concentrations of coconut water (CW) and Moringa olifera leaf (MLE) extract were evaluated for postharvest quality of gladiolus under CRD design and replicated thrice. Various characteristics of postharvest quality and antioxidant activities were measured as per standard methods and statistically analyzed.

Results: Spikes held in T3 (75% CW) exhibited superior performance in the majority of postharvest quality characteristics, including fresh weight retention, water uptake, solution uptake, and related traits. In contrast, T7 (6 g l^{-1} MLE) recorded the longest vase life at room temperature, despite not outperforming T3 in most other parameters.

Interpretation: When spikes were treated with 75% CW, gladiolus's postharvest characteristics and antioxidant enzyme activities were optimized. In terms of MLE, spikes held in a solution containing 6 g l^{-1} of MLE can improve the biochemical performance of gladiolus flowers, resulting in longer-lasting and higher-quality blooms for sustainable floriculture.

Key words: Coconut water, Gladiolus, *Moringa olifera* leaf extract, Vase life



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Introduction

Gladiolus (*Gladiolus hybridus* Hort.), a monocotyledonous ornamental geophyte, is an important bulbous cut flower in the floriculture sector, belonging to the Iridaceae family that finds its origin in South Africa. Gladiolus is widely cultivated across Asia, Africa, Europe, and the Americas with countries like the Netherlands, India, and Colombia leading in production for its high ornamental and commercial value (Zulfiqar *et al.,* 2022; Sharma *et al.,* 2024). Gladiolus ranks among the top five specialty cut flowers in the global floriculture market. It is commonly propagated through corms and cormels. The wide spectrum of flower colors contributes to its popularity in floral arrangements, bouquets, and garden bedding. However, ensuring a continuous market supply requires increase vase life as consumers prefer flowers with extended postharvest longevity. One of the key challenges in floriculture research is developing methods to extend the vase life of cut flowers like gladiolus, especially to support long-distance marketing and transportation (Darras, 2021; Kumar *et al.,* 2024; Thakur *et al.,* 2023). In gladiolus, postharvest deterioration is primarily associated with water imbalance, microbial blockage and oxidative stress, leading to premature senescence and rapid decline in ornamental quality (Woltering and Van Doorn, 1988).

Senescence in cut flowers is associated with reduced turgidity, loss of cell wall strength and electrolyte leakage, reflecting membrane instability. Membrane deterioration is a major cause of senescence (Itzhaki *et al.,* 1990; Kumar *et al.,* 2014; Chauhan *et al.,* 2024). Excessive accumulation of reactive oxygen species (ROS) accelerates membrane lipid peroxidation and cellular degradation ultimately shortening vase life. Plants have a natural defensive mechanism that includes both enzymatic and non-enzymatic components to lessen the harmful effects of ROS (Saeed *et al.,* 2016; Zulfiqar *et al.,* 2022). To reduce postharvest losses in cut flowers like gladiolus, various synthetic chemicals including salicylic acid, sodium nitroprusside (SNP), silver thiosulfate (STS) and 8-hydroxyquinoline citrate (8-HQC) are commonly applied. These compounds help maintain water balance, inhibit ethylene effects and boost antioxidant activity (Saeed *et al.,* 2016; Sharma *et al.,* 2024; Chauhan *et al.,* 2024). However, despite their effectiveness, they pose significant environmental and health risks. Silver-containing compounds accumulate in soil and water, harming beneficial microbes and aquatic life, while SNP carries potential cyanide toxicity concerns (Tacuri *et al.,* 2016; EFSA, 2011; ATSDR, 2002). These drawbacks have driven growing research into safer, biodegradable and economically viable alternatives for sustainable postharvest handling of cut flowers.

In recent years, natural biostimulants like coconut water (CW) and *Moringa oleifera* leaf extract (MLE) have emerged as environmentally friendly alternatives to synthetic preservatives for cut flowers. Coconut water is abundant in cytokinins, sugars, amino acids, minerals, and vitamins, which support cell division, delay senescence, stabilize cell membranes and improve water uptake and retention (Fuglie, 1999; Yong *et al.,* 2009; Ge *et al.,* 2017). Studies have demonstrated that CW application extends vase life and preserves freshness in species such as orchids, roses, and chrysanthemums (Yong *et al.,* 2009; Padernal *et al.,* 2023). Likewise, *Moringa oleifera* leaf extract is rich in antioxidants, phenolic compounds, vitamins and bioactive molecules including quercetin and kaempferol. These components boost enzymatic activity, enhance stress tolerance, and maintain cellular integrity (Hassan and Fetouh, 2019; Mashamaite *et al.,* 2022; Pareek *et al.,* 2023). In cut flowers, MLE has been found to decrease lipid peroxidation, inhibit microbial proliferation, increase antioxidant enzyme levels and postpone senescence, ultimately prolonging vase life in crops such as tuberose and rose (Hassan and Fetouh, 2019; Hassan *et al.,* 2020).

Although coconut water and *Moringa oleifera* leaf extract have shown notable benefits in enhancing postharvest quality for various ornamental cut flowers (Hassan *et al.,* 2020; Padernal *et al.,* 2023; Rathnayake *et al.,* 2024), their application to gladiolus remains largely understudied. In particular, data on their impact on antioxidant activity and vase life regulation in gladiolus are scarce. Consequently, this study was conducted to assess the efficacy of CW and MLE as natural vase solutions in extending vase life, maintaining physiological performance, and improving biochemical parameters in cut spikes of gladiolus (*Gladiolus hybridus* Hort.) cv. White Prosperity. The results are intended to offer safe, eco-friendly and sustainable alternatives to synthetic preservatives for enhancing the postharvest quality of cut gladiolus flowers.

Materials and Methods

Plant material and spikes: Gladiolus (*Gladiolus hybridus* Hort.) cv. "White Prosperity" corms were grown in the field during the Rabi season of 2024–2025 at the Horticultural Research Centre (HRC) of SVP University of Agriculture & Technology, Meerut. Cut spikes of gladiolus were harvested at the full bloom stage (2^{nd} stage) and placed in a half-filled water bucket to ensure an upright position. For further postharvest treatment and analysis, they were transferred to a laboratory. Laboratory conditions were controlled at 22 ± 2 °C, 60–70% relative humidity and a 12-hour photoperiod under cool white fluorescent lighting (1000–1500 lux) for subsequent pulsing/treatment application and vase life evaluation.

Treatments of coconut water and *Moringa oleifera* leaf extract: For postharvest treatment, Moringa leaf extract and coconut water were purchased from the local retail market. Various treatment combinations prepared for determining the effect of MLE and CW on gladiolus are as follows: T_1: Distilled water with 10% Sucrose (control); T_2 : 100% coconut water (CW); T_3: 75% coconut water (CW); T_4 : 50% coconut water (CW); T_5: 25% coconut water; T_6: *Moringa oleifera* leaf extract (4g l^{-1}) (MLE); T_7: *Moringa oleifera* leaf extract (6g l^{-1}) (MLE); T_8 : *Moringa oleifera* leaf extract (8g l^{-1}) (MLE) and T_9: *Moringa oleifera* leaf extract (10g l^{-1}) (MLE). Sucrose solution (10%) was used as a control (T_1). Cut spikes were equally cut down to make them equal in length (~80 cm). The study examined the effects of nine treatments using a completely randomized methodology. For each treatment 15 spikes were selected and were suspended in the prepared solutions (~100 ml) for 12 hr within glass bottles in such a way that the basal portion of the flower stem was fully dipped (Naing *et al.,* 2017; Shabanian *et al.,* 2018). For morpho-physiological and biochemical analysis of full-bloom stage, fully opened florets were selected. At this stage biochemical parameters associated with peak metabolic activity, such as antioxidant enzyme activity and secondary metabolites like phenolics, are influenced by biostimulants (Mashamaite *et al.,* 2022; Zulfiqar *et al.,* 2020).

Vase life (days): The number of days from the time the cut stems were placed in solution until they were terminated was used to calculate the vase life, defined as the stage when 50% wilting and bent neck occurred, petals lost turgor or petal abscission was observed.

Final pH of vase solution: The pH meter (Digital pH meter, pH 5652A, Electronics Corporation of India Ltd.) was used to monitor the pH of vase solutions every day until the spikes vase life was over.

Solution uptake (ml day^{-1}): In order to calculate the solution absorption, flower stems were taken, and the water evaporation from a flask of the same volume that did not contain any cut flowers was deducted (Chamani *et al.,* 2005). By weighing the vase solution and the cut flower separately, the absorption of the vase solution was typically assessed every day.

Maximum flower head diameter (MFHD) (cm): Flower bud diameter of four cut flowers was measured daily at the full-bloom stage using the digital vernier caliper.

Number of opened and unopened florets: Each spike number of opened and unopened florets was counted every day from the full-bloom stage until the vase life began to decline.

Relative fresh weight of flower: Daily measurements of the fresh weight of cut spikes were made from the full-bloom stage to the conclusion of the vase life Relative fresh weight (RFW) of spikes was estimated according to He *et al.* (2006).

Membrane stability index (MSI %): The modified Sairam *et al.* (1997) methodology was used to estimate MSI at the full-bloom stage. Once the third floret's petal tissue weighed one gram, it was thoroughly cleaned with double-distilled water and put in a test tube with twenty-five milliliters of distilled water. A conductivity meter (CM 180, Digital Conductivity Meter, Elico Pvt. Ltd., Hyderabad, India) was used to monitor the solution's conductivity (C1) following a 5-hour incubation period. The same sample spent 30 minutes in a boiling water bath (100°C). A measure of the conductivity (C2) was made.

The MSI was computed using the formula below:

$$\text{MSI (\%)} = [1 - (C1/C2)] \times 100$$

Senescence: Senescence was determined at the full-bloom stage utilizing the leaf senescence index 1-4, where 1 denotes no wilting and is green, 2 denotes mild wilting (less than 25%), 3 denotes moderate wilting (between 25% and 50%) and 4 denotes severe wilting (more than 50%) (Guo *et al.,* 2021). In addition, the average of daily measures in the case of MFHD, the relative fresh weight of the flower the number of opened and unopened florets, and the senescent flower were all taken into account for statistical analysis.

Estimation of antioxidative enzymes: Catalase (CAT) activity was assayed from the third floret at the base of gladiolus (*Gladiolus* spp.) spikes. In a 5 ml of 0.05 M potassium phosphate buffer, 1 g of floret tissue was homogenized (pH 7.8) that contained 10 ml of KCl, 0.5% (w/v) polyvinylpyrrolidone (PVP), 2 ml of dithiothreitol, and 0.1 ml of EDTA. After filtering and centrifuging the homogenate for 15 min at 4°C at 20,000 rpm, the supernatant was utilized for enzyme tests. The activity of CAT (EC 1.11.1.6) was measured using spectrophotometry by monitoring H_2O_2 decomposition at 240 nm (Clairborne, 1985) and expressed as units g^{-1} f.wt. min^{-1} with one unit defined as a 0.01 decrease in absorbance per 60 sec.

Peroxidase (POX; EC 1.11.1.7) activity was estimated by the method of Shanon *et al.* (1966). The process was started with 0.1% H_2O_2 and included 0.1 M sodium acetate buffer, 0.5% guaiacol, and enzyme extract. Using spectrophotometry, the rise in absorbance was measured at 470 nm. Enzyme activity was expressed as units g^{-1} f.wt. min^{-1}, where one unit was defined as a change in absorbance of 0.01 H_2O_2 per 60 s.

A modified version of the Bates et al. (1973) procedure was used to determine the free proline content. Using a mortar and pestle, a 10 ml of 3% (w/v) aqueous sulfosalicylic acid was combined with 500 mg of fresh tissue. With the homogenate centrifuged at 5,000 × g for 15 min at 4°C, 2 ml of the supernatant was added to a test tube along with 2 ml of acid ninhydrin reagent and 2 ml of glacial acetic acid. To stop the reaction, the reaction mixture was cooled on ice for 5 min after being kept for an hour in a bath of boiling water. Toluene was used to extract the chromophore, and also used as a blank to measure the absorbance of the toluene phase at 520 nm. The data were expressed as µmol g^{-1} f.wt. and were quantified against an L-proline standard curve.

Statistical analyses: All experiments were conducted in triplicate using biological replicates, and data recorded from individual flower spikes within each replicate were averaged prior to statistical analysis. Before performing analysis of variance (ANOVA), the data were tested for normality (Shapiro–Wilk test) and homogeneity of variance (Levene's test) and all datasets satisfied the assumptions of ANOVA. Statistical analysis was performed using the web-based software Agri Analyze (Popat *et al.,* 2024; www.agrianalyze.com). Mean separation was carried out by Duncan's Multiple Range Test at a significance level of P = 0.01. Results are presented as mean ± standard error of three independent biological replicates for each parameter.

Results and Discussion

The results, presented as the means of three replicates, are discussed below with comparisons to relevant literature to elucidate the probable reasons for the observed trends. The current study demonstrates the potential of MLE and CW can greatly extend the life of spikes and preserve the quality of harvested cut gladiolus spikes. The pathways via which MLE and coconut water treatments achieved these results are most likely associated with the preservation of water relations, antibacterial activity and preservation of cut spike overall quality, membrane integrity, and oxidative stress decrease.

The use of several chemical solutions and their combinations in the current study had an impact on the gladiolus flowers' longevity in vase solutions. Among the treatments, T_7 treatment recorded the maximum vase life (15.35 days), which was statistically comparable to T_3 (15.10 days), T_2 (14.35 days) and T_6 (12.75 days) treatments (Table 1). In contrast, the control treatment exhibited the minimum vase life, with flowers lasting only 7.10 days The extended vase life under T_9 and T_3 treatments is consistent with earlier reports on gladiolus, anthurium, chrysanthemum and other ornamental crops, where plant-based extracts delayed senescence by improving water uptake and reducing microbial blockage (Akhtar *et al.,* 2021; Padernal *et al.,* 2023). The pH of the vase solutions varied significantly among treatments, ranging from 7.10 to 4.20 (Table 2). The highest pH was recorded in T_1 treatment (7.10) followed by T_5 (6.85), while the lowest pH (4.20) was observed in T_3 treatment. Similarly, Sarhan *et al.* (2022) found that control treatments exhibited higher pH levels than those supplemented with Moringa leaf extract or coconut water in Gladiolus plants. The comparatively lower pH of the coconut water and Moringa leaf extract based solutions might be due to limited microbial proliferation and enhanced absorption of the solution.

The percentage of solution uptake showed a significant difference ($p < 0.05$) by gladiolus cut flowers when held in different floral preservative solutions containing coconut water and Moringa leaf extract. The highest solution uptake was recorded in treatment T_3 with 77.56 ml day^{-1}, followed closely by T_7 with 77.55 ml day^{-1}. The control group had the lowest solution absorption (72.44 ml day^{-1}). Similarly, the use of coconut water as a holding solution for tuberose (*Polianthes tuberosa*) flowers was investigated by Hasanuzzaman *et al.* (2019), who reported that tuberose flowers treated with coconut water exhibited a higher solution uptake percentage compared to those treated with plain water. The sugar and mineral content which helps maintain vascular conductivity and osmotic balance, thereby prolonging their vase life (Hasanuzzaman *et al.,* 2019). In contrast, the lowest solution uptake was reported for 5% Moringa leaf extract, while the highest uptake was observed in coconut water at 20% concentration (Rathnayake *et al.,* 2024).

There were notable differences in the maximum flower head diameter across treatments, ranging from 6.15 cm to 8.74 cm (Table 2). The widest flower head diameter was recorded in treatment T_3 at 8.74 cm followed by T_7 at 8.33 cm. The control had the shortest flower head diameter at 6.15 cm. The larger flower diameter observed under MLE and CW treatments indicates enhanced nutrient availability and delayed senescence. Similarly, Younis *et al.* (2018) reported comparable results in two gladiolus cultivars, where application of Moringa leaf extract resulted in significantly greater flower diameter than the control treatment.

The maximum number of open flowers was recorded in treatment T_3 with an average of 8.67 flowers, followed by T_7 with 8.33 flowers. The control group had the fewest open blooms with 6.35 flowers. Improved floret opening under MLE and CW treatments enhanced carbohydrate availability and hormonal

Table 2: Physio-biochemical analysis of spikes held in various concentrations of coconut water and Moringa leaf extract

Treatment	Vase life	pH of vase solution	Solution uptake (m l day^{-1})	Maximum flower head diameter (cm)	No. of open flowers	No. of unopened flowers	Fresh weight of flower (g)	Membrane Stability Index (%)	Senescence
T_1	7.10^{f}	7.10^{a}	72.44^{c}	6.15^{g}	6.35^{f}	4.75^{a}	36.29^{c}	53.63^{f}	3.67^{a}
T_2	14.35^{b}	4.35^{e}	76.30^{ab}	8.03^{c}	7.97^{c}	4.15^{c}	38.90^{a}	58.45^{e}	1.67^{cd}
T_3	15.10^{a}	4.20^{e}	77.56^{a}	8.74^{a}	8.67^{a}	3.35^{e}	39.21^{a}	77.67^{a}	1.33^{d}
T_4	10.55^{d}	6.55^{c}	75.27^{b}	7.97^{c}	7.53^{d}	4.67^{a}	36.30^{c}	65.13^{cd}	3.33^{ab}
T_5	9.20^{e}	6.85^{ab}	73.59^{c}	6.57^{f}	7.13^{e}	4.33^{bc}	37.96^{b}	66.25^{bc}	3.67^{a}
T_6	12.75^{c}	6.75^{bc}	73.42^{c}	7.15^{e}	7.43^{d}	4.33^{bc}	36.79^{c}	76.72^{a}	2.67^{abc}
T_7	15.35^{a}	4.25^{e}	77.55^{a}	8.33^{b}	8.33^{b}	3.67^{d}	39.11^{a}	63.98^{d}	1.33^{d}
T_8	12.85^{c}	5.10^{d}	76.22^{ab}	7.53^{d}	7.67^{d}	4.25^{bc}	37.81^{b}	65.45^{c}	2.33^{bcd}
T_9	9.25^{e}	5.35^{d}	75.76^{b}	7.33^{de}	7.47^{d}	4.50^{ab}	36.50^{c}	66.97^{b}	2.33^{bcd}
SeM	0.200	0.08^{5}	0.465	0.092	0.088	0.085	0.217	0.431	0.333
SeD	0.283	0.120	0.653	0.130	0.125	0.112	0.307	0.610	0.471
CD at 5%	0.605*	0.253*	1.371*	0.274*	0.262*	0.251*	0.646*	1.281*	0.990*
C.V.	2.927	2.623	1.061	2.118	2.002	3.471	0.999	1.131	23.266

regulation. Akhtar *et al.* (2021) obtained similar results, where they observed the highest number of open flowers in gladiolus treated with Moringa leaf extract compared to the control. Hassan and Fetouh (2019) also documented comparable results further supporting the positive influence of Moringa leaf extract and coconut water on flower opening and overall floral quality (Table 1).

The study revealed significant differences in the number of unopened flowers among treatments (Table 1). Treatments T_3 and T_7 recorded significantly fewer unopened flowers as compared to the control. The highest number of unopened flowers was observed in the control (T_1), whereas the lowest values were recorded in T_3 and T_7, indicating enhanced floret opening under these treatments. This reduction in unopened flowers under Moringa leaf extract (MLE) and coconut water (CW) treatments may be attributed to improved assimilate translocation, enhanced water uptake and the presence of natural cytokinins that promote bud opening and delay senescence. These findings are in agreement with the reports of Akhtar *et al*. (2021) and Hassan and Fetouh (2019), who also observed a higher number of unopened florets in the control treatments compared to MLE-treated spikes likely due to the absence of growth-promoting substances and reduced physiological activity in untreated flowers.

The fresh weight of gladiolus spikes varied significantly among treatments. The highest fresh weight gain was recorded in T_3, followed closely by T_7, while the lowest fresh weight was observed in the control (T_1). The greater weight loss in the control treatment, which contained only distilled water may be attributed to reduced solution uptake and limited floret opening. In contrast, treatments supplemented with Moringa leaf extract (MLE) and coconut water (CW) showed higher fresh weight likely due to improved water uptake, better maintenance of cellular turgidity, and enhanced floret opening. These results are consistent with the findings of Akram *et al*. (2021), who reported increased fresh weight in Gladiolus spikes treated with Moringa leaf extract and sucrose, attributed to improved physiological activity and water relations. The membrane stability index of third flower petals was measured under various treatments involving coconut water and MLE. Treatment T_3 exhibited the highest MSI value (77.67%), followed by T_6 (76.72%). These results demonstrate that both coconut water and MLE significantly enhance membrane stability in flowers compared to the control. Enhanced MSI indicates reduced lipid peroxidation and improved membrane integrity under CW and MLE treatments. Similarly, Hassan *et al.* (2020) observed that MLE treatments in cut roses reduced malondialdehyde (MDA) content, indicating a decrease in lipid peroxidation and improved membrane stability. This reduction in lipid peroxidation, as also described by Bailly *et al.* (1996), reflects the protective role of MLE in maintaining membrane integrity. The present findings are consistent with those of Hassan and Fetouh (2019) and Latif and Mohamed (2016), who reported that Moringa leaf extract effectively decreases lipid peroxidation and enhances MSI in floral tissues.

The highest senescence rate was recorded in T_1 and T_5 treatments both at 3.67, while the lowest senescence was observed in T_8 (2.33). Reduced senescence under Moringa leaf extract treatments is mainly attributed to the presence of cytokinins such as zeatin, which delay aging by maintaining cellular integrity and antioxidant activity. Similar results were reported in roses, where Moringa leaf extract improved leaf retention compared to the control (Telebric and Bendanillo, 2024). Moringa leaf extract also enhances floral quality and vase life by improving antioxidant systems, water relations, hormonal balance and membrane stability while reducing microbial blockage (Hassan and Fetouh, 2019). Since endogenous cytokinin levels decline during senescence, the external application of cytokinins effectively delays this process (Tetley and Thimann, 1974).

Values are presented as mean; alphabets in superscript indicate significance measured by DMRT; SeM- Standard error mean; SeD- Standard Error of Difference; CD- Critical Difference; C.V.- Coefficient of Variation; *- Significant at 5%. The highest catalase activity (0.90 unit g^{-1} f.wt. min^{-1}) was recorded in treatment T_3 followed by T_7 (0.89 unit g^{-1} f.wt. min^{-1} (Fig. 1). The lowest CAT activity was observed in the control treatment (0.63 unit g^{-1} f.wt. min^{-1}. Akhtar *et al.* (2021) reported significantly higher catalase activity in gladiolus flowers treated with *Moringa oleifera* leaf extract compared to the control indicating enhanced antioxidant defense and reduced oxidative stress. Similar increase in oxidative enzyme activity have been observed in other cut flowers, including decorative sunflower (Shatoori *et al.,* 2020). Elevated CAT activity under MLE treatment enhances reactive oxygen species scavenging, which is critical for protecting cut spikes from oxidative damage (Zhou *et al.,* 2014; Hassan and Fetouh, 2019).

The data revealed that peroxidase (POD) activity in gladiolus florets ranged from 0.85 - 0.62 units g^{-1} f.wt. min^{-1} across the nine treatments (Fig. 2). Treatment T_3 produced the maximum POD activity, measuring 0.85 units g^{-1} f.wt. min^{-1}, followed by T_7 (0.82 units g^{-1} f.wt. min^{-1}). The lowest activity was observed in the control (0.62 units g^{-1} f.wt. min^{-1}), indicating a reduced antioxidant capacity in the absence of biostimulant treatments. Hassan *et al.* (2020) reported lower peroxidase (POX) activity in control treatments and significantly higher activity in flowers supplemented with Moringa leaf extract. Similar enhancements in antioxidant systems following Moringa leaf extract application have been documented under stress conditions (Rady *et al.,* 2013). The increased POX activity observed in the present study indicates improved scavenging of reactive oxygen species in cut spikes, while reduced malondialdehyde accumulation under MLE treatment further confirms its antioxidative role (Elansary, 2020). Collectively, these findings suggest that MLE delays floret senescence by minimizing oxidative stress in cut gladiolus spikes (Hassan and Fetouh, 2019).

The proline content in gladiolus florets varied significantly across the nine treatments, ranging from 1.20 to 0.36 µmol g^{-1} f.wt. (Fig. 3). At 1.20 µmol g^{-1} f.wt., treatment T_1 (control) had the greatest proline content followed by T_5 (25% CW) at 1.10 µmol g^{-1}

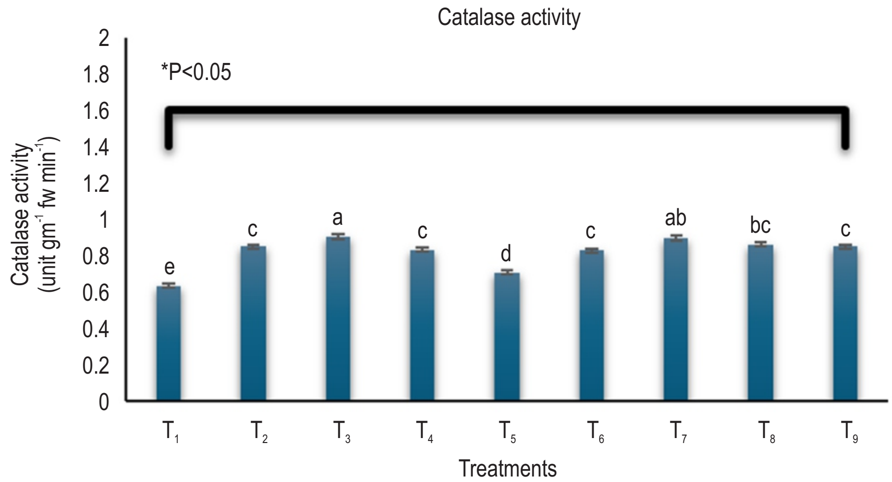

Fig. 1: Effect of gladiolus spikes held in various concentrations of coconut water and Moringa leaf extract on catalase activity.

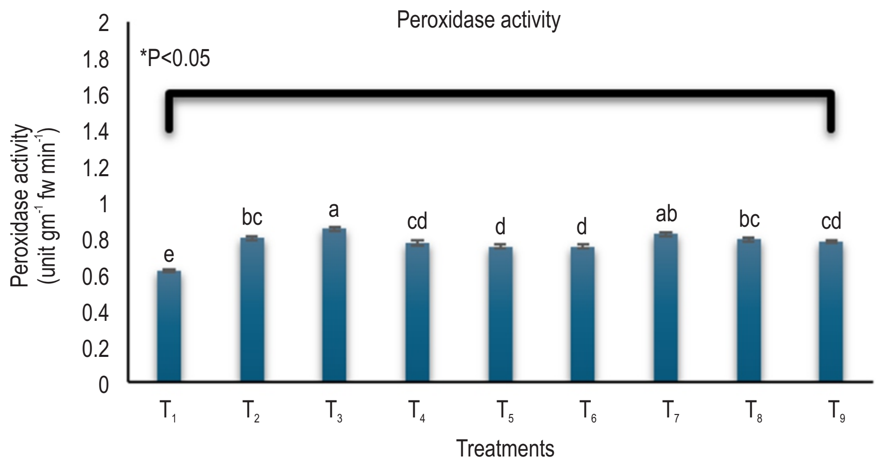

Fig. 2: Effect of gladiolus spikes held in various concentrations of coconut water and Moringa leaf extract on peroxidase activity.

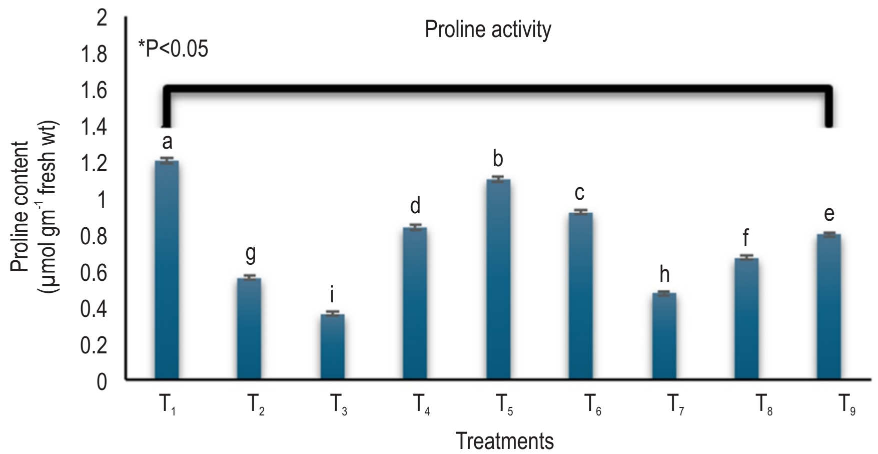

Fig. 3: Effect of gladiolus spikes held in various concentrations of coconut water and Moringa leaf extract on proline activity.

f.wt., while the lowest was observed in T_3 (0.36 μmol g^{-1} f.wt.). Zulfiqar *et al.* (2020) reported the highest proline accumulation in gladiolus under control conditions. In contrast, *Moringa oleifera* leaf and seed extract treatments enhanced proline-mediated stress tolerance, contributing to delayed senescence through reduced lipid peroxidation, improved membrane stability, ROS scavenging and osmotic adjustment (Ashraf and Harris, 2004; Kamiab *et al.,* 2014; Mansour and Ali, 2017). As senescence is closely linked to oxidative damage and membrane deterioration (Hassan *et al.,* 2014), the limited proline accumulation in untreated flowers appears insufficient to prevent senescence-related injury (Hassan *et al.,* 2020).

The present experiment demonstrates that spikes held in coconut water or Moringa leaf extract consistently excelled across all postharvest gladiolus flower quality parameters. Coconut water's variable effects indicate that dilution optimizes nutrient delivery without promoting excessive microbial growth. The study also revealed significant enhancements in biochemical parameters in post-harvested flowers, indicating improved stress tolerance and metabolic activity. These findings suggest that 75% CW (T_3) and MLE at 6 g l^{-1} (T_7) were the most effective treatments for optimizing antioxidant enzyme activity and osmo-protectant accumulation. These results advocate for the integration of CW and MLE, which can enhance gladiolus flowers biochemical performance, improving flower quality and longevity for sustainable floriculture.

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Authors' contribution: R. Motla: Execution of field experiment and data collection, Laboratory analysis, Writing-original draft; **C. Chauhan:** Contribution of experimental materials; **R. Kumar:** Resource person; **M. Sharma:** Data analysis of data and interpretation, **A. Vedwan:** Laboratory analysis and data curation; **M. Kumar:** Conceptualization of research idea, Methodology, Resources, Writing and editing of manuscript;

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