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Unravelling physiological and biochemical attributes influencing post harvest quality of gladiolus spikes after packaging and low temperature storage

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The perishable nature of flowers urge for their appropriate post harvest management especially storage and packaging that keep the quality and potential vase life for better value. Gladiolus, commonly called as Sword lily, is a commercially important cut flower crop with elegant spikes, bright florets and good keeping quality. In the present study, we investigated the physiological and biochemical attributes affecting post harvest life of gladiolus spikes after packaging and storage. The spikes of four gladiolus cvs. Punjab Glance, Punjab Glad-1, Punjab Glad-2 and Punjab Pink Elegance were harvested at tight bud stage and packed in PP sleeves (25 µm) and stored vertically at 4-5°C for 6, 9 and 12 days. After storage, the post harvest quality of both packed and unpacked spikes declined with more adverse effect on unpacked spikes. Among different storage durations, the spikes stored for 9 days showed good keeping quality parameters *viz*., vase life, per cent flower opened, floret size, days to opening of basal floret, maximum number of florets open at one time and water absorbed per spike which were at par with spikes stored for 6 days. The spikes stored for 12 days were found to be unacceptable in comparison to freshly harvested spikes and spikes stored for 6 and 9 days. The improved quality of spikes stored in sleeves could be accounted due to higher membrane stability index, relative water content, catalase and peroxidase activity as compared to unpacked spikes. Thus, loss in quality of spikes as compared to fresh during storage up to 9 days in PP sleeves is better than the complete loss of produce during transportation and gluts. Hence, the spikes of gladiolus could be stored dry at 4±0.5°C in PP sleeves for 9 days without much influence on its post harvest quality.

Keywords: Antioxidant enzymes, Modified Atmosphere Packaging, Sword lilies, Vase Life

Commercial floriculture is widening up its horizon and emerging as a profitable agro industry. India ranks 14th in exporting floriculture products and shares 0.4% in global floriculture exports in 2018[1]. Earlier, the traditional flowers such as marigold, rose, jasmine and chrysanthemum were commercialised by floricultural industry in India, but now high economic importance of cut flowers such as gladiolus, carnation, gerbera, etc. on global scale had made them to come in forefront. Gladiolus is an important commercial cut flower especially known for its brilliant coloured florets. It is a flower of glamour and perfection with elegant spikes having wide array of colours, size and good keeping quality that leads to its versatile utility for decoration purposes.

The post harvest management of cut flowers plays a determining role towards the net profitability of the produce. The post harvest loses from harvesting to marketing pose a major threat to the growers and this threat is due to perishable nature of fresh flowers. Market losses in the cut flower owing to inefficient post harvest storage and packaging are estimated around 20-40% at different levels from grower to consumer[2]. The flower senescence involving increased activity of hydrolytic and respiratory enzymes, imbalance of water relations, deterioration of macromolecules, etc marks the end of keeping quality[3,4]. Thus, post harvest management leading to improved post harvest quality of cut flowers is the major thrust area of floricultural research.

Several studies pertaining to pre or post harvest application of plant growth regulators and chemicals have been done to improve the post harvest life of flowers[5]. But for retention of quality and regulation of supply of flowers in markets for better remunerative prices, packaging and storage methods need to be focused[6].

Among the different storage methods *viz*. refrigerated storage (wet or dry), controlled atmosphere and low pressure storage, refrigerated storage is the most widely practiced method as it extends the vase life of

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flowers and widens the market window especially when production exceeds the demand. Refrigerated storage provides low temperature that lowers respiration rate and other metabolic activities in flowers, providing "time" for proper handling and marketing[7]. In dry refrigerated storage or modified atmosphere (MA) storage, the flowers are packed in water retentive plastic films at low temperature. This technology holds most promising among different post harvest technologies for transportation and storage of flowers[8]. For successful MAP of fresh flowers, it is necessary to use film of suitable permeability to gases like CO_2, O_2, water vapour, etc so that optimal Modified Atmosphere is reached in package that keeps a check on metabolic activities. The important polymeric sleeves used for packaging include polyethylene, polypropylene, polybutylene, polystyrene, ethylene vinyl acetate etc that have good water vapour barrier properties, relatively high gas permeability and favourable response to heat sealing[9]. Each of these materials had specific ranges of permeabilities of O_2 and CO_2[10].

The increase in storage duration leads to decline in the post harvest quality of spikes and considerable variations in the response w.r.t. storage duration, packaging material and temperature by different species and cultivars have been reported[11-13]. But the studies pertaining to physiological and biochemical aspects influencing the post harvest quality of flowers during packaging and storage are mearge[14].

Thus, keeping in view the flourishing floricultural industry, constraints in post harvest management and importance of gladiolus among different cut flowers, we investigated the morpho-physiological and biochemical attributes influencing the post harvest quality of gladiolus spikes packed in polypropylene sleeves for different storage durations. The choice of using polypropylene sleeves was based on the results of our earlier study with packaging of gladiolus[13].

Material and Methods

The plants of four gladiolus cultivars *viz*., Punjab Glance, Punjab Glad-1, Punjab Glad-2 and Punjab Pink Elegance were raised in the field area of the Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana from the uniformly sized corms (3.5-4.0 cm diameter) following all recommended cultural practices. The spikes were harvested at tight bud stage (when 1-2 basal florets showed colour) to study the effect of modified atmosphere storage on post harvest quality of gladiolus spikes. The harvested spikes of different cultivars were divided into two groups. One group was sealed in polypropylene (PP) sleeves of 25 µ thickness without perforations and other group was kept unpacked. The results from our earlier study found PP sleeves to be better than LDPE (Low density polyethylene)[13]. Three spikes per replication and three replications for each treatment were stored vertically in cold room at 4-5°C for 6, 9 and 12 days. The permeability of PP sleeves for oxygen (O_2) and carbon di oxide (CO_2) at 5°C was 6.52×10^{-6} and 29.46×10^{-6} mL-m/m^2 h-kPa, respectively[15]. The freshly-harvested spikes served as control. Thus, there were 2 packaging treatments that included unpacked spikes and PP packed spikes and three storage treatments of 6, 9 and 12 days. After storage, the stems were kept in water for evaluation of keeping quality. The following observations were recorded:

Days to opening of basal floret in vase

The days taken for complete opening of basal floret were recorded from the day of placing the stored spikes in water.

Vase life (days)

Vase life was measured in days from the day of placing the stored spikes in water till the wilting of 50% of total number of opened florets.

Florets on the spike and their size

The number of fully opened florets were counted daily throughout the duration of the experiment and expressed as per cent opening of florets on the spike. The maximum diameter of the 2nd fully opened floret from the base was measured in cm and expressed as floret size. The number of fully opened florets that were open before wilting of first floret was also recorded.

In addition, the total volume of water absorbed by the spike till the end of vase life was also measured in mL and expressed as water absorbed per spike.

The following physiological and biochemical parameters were recorded from tepals following mentioned standard methods.

Membrane stability index (MSI)

The tepals were excised from the florets and incubated in 25 mL of deionized water for 30 min at 25°C[16]. The leakage of electrolytes into incubation medium was estimated by conductivity measurement using conductivity meter. The conductivity was again measured after boiling the samples for 30 min. The following formula was used to calculate membrane stability index (MSI):

$$\text{MSI} = \left(1 - \frac{\text{C1}}{\text{C2}}\right) \times 100$$

Relative water content (RWC)

The florets were kept in distilled water in a pre-weighed sealed test tube. The tubes were again weighed and the increased weight of the tubes was used to calculate fresh weight (FW). After 28 h, the saturated florets were again weighed to determine turgid weight (TW). Dry weight (DW) was then obtained after oven-drying at 70°C for 48 h[17] and RWC was calculated using following formula:

$$\frac{\text{FW} - \text{DW}}{\text{TW} - \text{DW}} \times 100$$

where FW is the fresh weight, TW is the turgor weight and DW is the dry weight of the florets.

Catalase activity

The enzyme was extracted and estimated following standard method given by Aebi[18]. Petal tissue was homogenized in 100 mM phosphate buffer (pH 7.0, containing 1% polyvinyl pyrrolidone). Enzyme extract (0.2 mL) was taken in a test tube and volume was made to 2.0 mL with the buffer. Reaction was started by addition of 30 mM H_2O_2 solution (1.0 mL). The decrease in absorbance was recorded after every 10 s. interval at 240 nm on a UV spectrophotometer. The activity of catalase was expressed as change in absorbance $min^{-1}g^{-1}$ tissue.

Peroxidase activity

Peroxidase activity was determined by Shannon *et al.*[19]. The petals were homogenized in 0.1M phosphate buffer. Enzyme was assayed from reaction mixture containing guaiacol in 0.1M phosphate buffer (3 mL) and enzyme extract (0.1 mL). Reaction was initiated by addition of 0.8M hydrogen peroxide (0.1 mL) and rate of change in absorbance was recorded at 470 nm after every 15 s for 3 min on spectrophotometer. The activity of peroxidase was calculated as change in absorbance $min^{-1}g^{-1}$ tissue.

Statistical analysis

The statistical design of the experiment was factorial completely randomized design (FCRD) in which storage duration and packaging were two factors. The data were subjected to analysis of variance (ANOVA) to evaluate difference between treatment means. Least significant difference (LSD) was used for all comparisons where significant F-probabilities ($P \leq 0.05$) were found. Since different cultivars showed no significant results at different storage durations for different parameters and also the prime concern of the study was to find appropriate storage duration for gladiolus spikes for which they could be stored with acceptable quality, and hence, the mean value of four cultivars for particular parameter along with standard deviation was used for all comparisons[20].

Results

The days to opening of basal floret is an important parameter determining the vase life of spikes. The freshly harvested spikes (without storage) took 4.33 days to open their basal florets that declined to 3.52, 3.03 and 0.54 days, respectively after 6, 9 and 12 days of storage when packed in sleeves whereas corresponding values for unpacked spikes were 3.23, 2.76 and 0.38 days, respectively (Table 1). A sharp decline from 4.33 days to 0.46 days to open basal floret was observed after 12 days of storage.

The vase life of freshly harvested spikes of gladiolus was found to be 14.26 days. The storage duration significantly influenced the vase life. The vase life of spikes was 12.58 days after 6 days and 11.96 days after 9 days of storage that were at par but significant decline to 7.37 days was observed after 12 days of storage. The packaging of spikes significantly improved the vase life during storage as vase life of packed spikes was 11.84 days compared to 9.42 days of unpacked spikes (Table 1). From this, it could be further inferred that by storing spikes in PP packaging the life of spikes could be enhanced as

Table 1 — Effect of duration of low temperature storage on days to opening of basal florets and vase life (days) of gladiolus spikes (Two way ANOVA followed by comparison of means with LSD)

Storage duration	Days to opening of basal floret [Packing (P)]			Vase life (days) [Packing (P)]		
(days, S)	Unpacked	Packed	Mean	Unpacked	Packed	Mean
6	[#]3.23±0.82	3.52±0.80	3.37	11.47±2.10	13.69±1.82	12.58[b]
9	2.76±0.75	3.03±0.87	2.89	10.70±1.77	13.21±2.08	11.96[b]
12	0.38±0.17	0.54±0.23	0.46	6.11±0.71	8.63±1.32	7.37[a]
Mean	2.12[a]	2.36[a]		9.42[a]	11.84[b]	
	Control (0 day storage) = 4.33±0.84			Control (0 day storage) = 14.26±1.59		
LSD	S= NS; P=0.71; S×P=NS			S=1.79; P=1.46; S×P=NS		

[[#] a ± b; where a = mean of replicates of four cultivars and b = Standard Deviation of mean. Different lower case letters in the vertical column represent significant differences between storage durations and in the horizontal row represent significant differences between packing treatments. NS = Non significant]

their post harvest life would be vase life plus the days of storage. Irrespective of varieties, the post harvest life of spikes enhanced by 8 days as for averaged control the vase life was 14.26 days and the corresponding value after 9 days of storage was 22.21 days (Fig. 1).

The per cent opening of florets in freshly harvested spikes ranged from 57 to 71 in different treatments. The per cent opening of florets significantly declined with increase in storage duration (Table 2). The per cent of opened florets from freshly harvested spikes declined from 70.29 to 66.47 to 64.46 to 59.77, respectively after 6, 9 and 12 days of storage. The percent (%) of florets that opened after 6 and 9 days of storage were at par whereas significant decline was recorded after 12 days of storage. Packaging of spikes significantly improved the per cent opening of florets than unpacked spikes after different storage durations.

The floret size showed significant decrease with increase in storage duration (Table2). The highest diameter of floret (9.29 cm) was recorded in control spikes which decreased to 6.17 cm after 12 days of storage. The floret size of packed spikes was about 8 percent (%) higher than unpacked spikes irrespective of storage duration as fully expanded floret of packed spikes was 7.93 cm and of unpacked spikes was 6.70 cm.

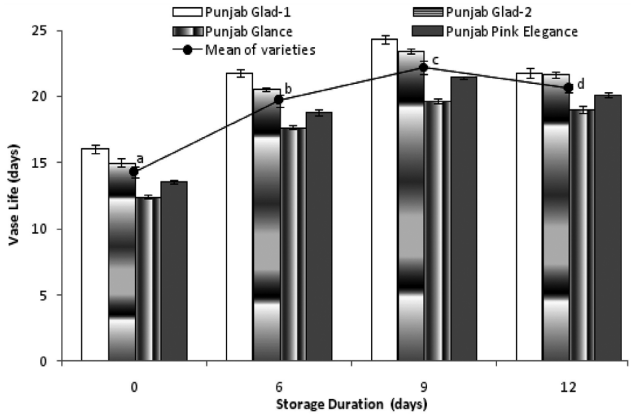

Fig. 1 — Effect of different storage durations (6, 9 and 12 days) on postharvest life of spikes packed in PP sleeves as compared to fresh spikes (0 days). The bars represent the means 3 replicates of particular variety ± standard errors. The markers in line graph depicts mean of four varieties ± standard errors and different alphabets in lower case represents significant difference in postharvest life after different storage durations.

The maximum number of florets opened at one time is an important factor determining the quality of spikes. The data depicted that the storage duration significantly influenced the number of florets opened at one time (Table 3). The number of florets opened at one time declined by 61% after 12 days of storage as compared to control. The maximum number of florets opened at one time after 6 and 9 days of storage were at par but showed sharp decline after 12 days. The spikes packed in sleeves had significantly higher number of florets opened i.e. 4.58 as compared to 3.59 for unpacked spikes.

The water absorbed per spike also showed significant decline with increase in storage duration (Table 3). The freshly harvested spikes absorbed 49.16 mL of water that declined to 41.12, 38 and 29.06 mL after 6, 9 and 12 days of storage. The amount of water absorbed was at par after 6 and 9 days but significant decline of 41% was recorded after 12 days of storage as compared to control. The decline in absorption of water was pronounced in unpacked spikes than packed spikes during different storage durations.

Tepals excised from florets of freshly harvested spikes exhibited higher membrane stability index of 71.46. The MSI decreased with increase in the storage duration and was 66.62, 65.04 and 61.22 after 6, 9 and 12 days of storage, respectively (Table 4). The tepals excised from florets of spikes stored for 9 days showed 9% and for 12 days showed 14% decline in MSI as compared to control spikes. The MSI of tepals from

Table 2 — Effect of duration of low temperature storage on per cent opening of florets and floret size (cm) of gladiolus spikes (Two way ANOVA followed by comparison of means with LSD)

Storage duration (days, S)	Percent opening of florets [Packing (P)]			Floret Size (cm) [Packing (P)]		
	Unpacked	Packed	Mean	Unpacked	Packed	Mean
6	64.96 ([#]46.44±1.92)	67.98 (55.54±2.14)	66.47[b](50.98)	7.68±0.44	8.82±0.54	8.25[b]
9	62.57 (45.81±2.03)	66.34 (54.53±1.99)	64.46[b](50.17)	6.99±0.56	8.09±0.35	7.54[b]
12	57.84 (43.45±2.47)	61.69 (51.76±2.38)	59.77[a](47.60)	5.44±0.68	6.90±0.45	6.17[a]
Mean	61.79[a](45.23)	65.34[b] (53.95)		6.70[a]	7.93[b]	
	Control (0 day storage) = 70.29 (56.97±1.83)			Control (0 day storage) = 9.29±0.70		
LSD	S= 1.84; P=1.51; S×P=NS			S=0.79; P=0.54 ; S×P=NS		

[[#] a ± b; where a = mean of replicates of four cultivars and b = Standard Deviation of mean. [#] Different lower case letters in the vertical column represent significant differences between storage durations and in the horizontal row represent significant differences between packing treatments. Values in parentheses indicate arc sine transformations for per cent values. NS = Non significant]

Table 3 — Effect of duration of low temperature storage on maximum number of florets open at one time and total water absorbed/spike (mL) of gladiolus (Two way ANOVA followed by comparison of means with LSD)

Storage duration (days, S)	Maximum number of florets open at one time [Packing (P)]			Total water absorbed/spike (mL) [Packing (P)]		
	Unpacked	Packed	Mean	Unpacked	Packed	Mean
6	#4.77±0.68	5.58±0.53	5.17[b]	38.25±4.46	43.99±3.78	41.12[b]
9	4.11±0.73	5.14±0.68	4.62[b]	35.20±4.88	40.81±5.18	38.00[b]
12	1.90±0.25	3.03±0.52	2.46[a]	26.46±2.29	29.42±1.70	29.06[a]
Mean	4.58[b]	3.59[a]		33.30[a]	38.82[b]	
	Control (0 day storage) = 6.32±0.53			Control (0 day storage) = 49.16±4.10		
LSD	S=0.62; P=0.50 ; S×P=NS			S=4.13; P=3.37 ; S×P=NS		

[# a ± b; where a = mean of replicates of four cultivars and b = Standard Deviation of mean. # Different lower case letters in the vertical column represent significant differences between storage durations and in the horizontal row represent significant differences between packing treatments. NS = Non significant]

Table 4 — Effect of duration of low temperature storage on membrane stability index and relative water content in tepals of gladiolus spikes (Two way ANOVA followed by comparison of means with LSD)

Storage duration (days, S)	Membrane Stability Index [Packing (P)]			Relative water content [Packing (P)]		
	Unpacked	Packed	Mean	Unpacked	Packed	Mean
6	#64.42±5.76	68.88±5.14	66.62	64.42±2.81	70.45±3.23	67.44[c]
9	62.58±5.73	67.50±5.30	65.04	60.84±2.94	66.38±4.18	63.61[b]
12	58.36±5.95	64.07±5.00	61.22	54.53±4.47	61.10±3.89	57.81[a]
Mean	61.78[a]	66.82[b]		59.93[a]	65.98[b]	61.78[a]
	Control (0 day storage) =71.46±5.10			Control (0 day storage) = 75.8±3.13		
LSD	S= NS; P=4.71 ; S×P=NS			S=3.80; P=3.12 ; S×P=NS		

[# a ± b; where a = mean of replicates of four cultivars and b = Standard Deviation of mean. # Different lower case letters in the vertical column represent significant differences between storage durations and in the horizontal row represent significant differences between packing treatments. NS = Non significant]

Table 5 — Effect of duration of low temperature storage on catalase activity (mmol H_2O_2 hydrolyzed $min^{-1}g^{-1}$ FW) and Peroxidase activity (ΔA $min^{-1}g^{-1}$ FW) in tepals of gladiolus spikes

Storage duration (days, S)	Catalase activity (mmol H_2O_2 hydrolyzed $min^{-1}g^{-1}$ FW) [Packing (P)]			Peroxidase activity (ΔA $min^{-1}g^{-1}$ FW) [Packing (P)]		
	Unpacked	Packed	Mean	Unpacked	Packed	Mean
6	#1.34±0.11	1.09±0.07	1.21[a]	6.22±0.19	5.37±0.28	5.80[a]
9	1.65±0.20	1.24±0.09	1.44[b]	7.55±0.12	6.71±0.13	7.13[b]
12	1.91±0.08	1.50±0.05	1.71[c]	8.67±0.29	7.71±0.16	8.19[c]
Mean	1.63[b]	1.28[a]		7.48[b]	6.60[a]	
	Control (0 day storage) = 0.66±0.06			Control (0 day storage) = 4.25±0.06		
LSD	S= 0.11; P=0.09; S×P=NS			S=0.22; P=0.18; S×P=NS		

[# a ± b; where a = mean of replicates of four cultivars and b = Standard Deviation of mean. # Different lower case letters in the vertical column represent significant differences between storage durations and in the horizontal row represent significant differences between packing treatments. NS = Non significant]

packed spikes was 66.82 that declined significantly to 61.78 for tepals from unpacked spikes.

The relative water content (RWC) assesses the water deficit stress. Like MSI, the relative water content was high in tepals of freshly harvested spikes (Table 4). The RWC declined significantly with increase in storage duration. Among different storage durations, a significant decline in RWC of tepals after 12 days of storage was recorded whereas RWC after 6 and 9 days were at par. The RWC of tepals after 12 days of storage declined by 24% as compared to control. The tepals excised from packed spikes had significantly higher RWC (9%) as compared to unpack.

Catalase (CAT) is an antioxidant enzyme whose activity indicates the ameliorative effect on oxidative stress. The catalase activity revealed a steady increase from 0 to 12 days of storage in both packed and unpacked spikes (Table 5). The fresh spikes had least of CAT activity of 0.66 mmol H_2O_2 hydrolyzed min^{-1} g^{-1} FW that significantly increased to 1.21, 1.44 and 1.71 mmol H_2O_2 hydrolyzed $min^{-1}g^{-1}$ FWafter 6, 9 and 12 days of storage, respectively. Further, packaging significantly influenced CAT activity as it was recorded to be significantly higher (27%) in tepals of unpacked spikes than packed spikes.

The peroxidase (POX) activity was low in the tepals of freshly harvested spikes. However, the activity increased significantly with increase in storage duration (Table 5). The POX activity of tepals excised from spikes after 12 days of storage was 8.19 $\Delta A\ min^{-1}g^{-1}$ FW in comparison to 4.25 $\Delta A\ min^{-1}g^{-1}$ FW of fresh tepals. The tepals of unpacked spikes exhibited 13% higher POX activity than packed spikes irrespective of storage durations.

Discussion

The appropriate post harvest management that involves packaging and storage of gladiolus spikes help in regulating the marketing of cut flowers during glut i.e. when production exceeds the demand. Further, low temperature during storage reduces both plant metabolic processes and microbial growth rate[21]. Appropriate packaging of cut flowers for optimum storage duration offers advantage of extending vase life and maintaining flower quality. The gladiolus spikes packed in PP sleeves offered modified atmospheric (MA) storage that delayed the opening of basal florets during storage and decreased the days to opening of basal florets after storage (Table 1). The vase life of a spike initiates with opening of basal floret. Significant delay in opening may lead to failure in opening of buds and too early opening may shorten the vase life due to early senescence. Hence, opening of basal floret at appropriate time adds to the vase life of spikes. The florets exhibited decreased metabolic activity during MA storage which did not enable the florets to expand[22]. The delayed floret opening during MA storage is advantageous because spikes with unopened florets can be easily transported as such buds are less prone to damage during transport.

Increase in storage duration leads to decline in the ability of the flower buds to open and decline in vase life (Table 1). The precise mechanism for storage-induced decline in vase life is not yet fully understood but increased sensitivity to ethylene and loss of membrane permeability after storage could be some of the causes which have been reported to shorten post storage vase life of flowers[23]. The decline in vase life of different cut flowers viz. tulip[24], lilies[25] and nine specialty cut flower species[26] has been reported earlier.

After storage the flowers buds lose the ability to open and the effect increases with increase in the duration of storage[27]. This was concomitant with our results as the per cent of floret opening and floret size decreased with increase in storage duration (Table 2). This could be accounted to high level of starch and low levels of soluble sugars in the spikes at tight bud stage due to which upper florets fail to expand or completely expand leading to low percentage of floret opening[28]. The reduction in floral bud opening and floret size might be due to decline in content of soluble sugars, increased sensitivity to ethylene and production of toxic metabolites by various metabolic processes that continue during storage and contribute to poor post storage opening of the buds[29].

Freshly harvested spikes absorbed maximum water whereas significant decline in amount of water absorbed was recorded with increase in storage duration (Table 3). This decrease has been ascribed to microbial growth in vase water or on stem surface or air embolism of xylem tissues[30]. The membrane deterioration continues during storage and decrease becomes more pronounced with increase in duration of storage as indicated by decrease in MSI during storage from 6 to 12 days (Table 5). The loss of membrane integrity during storage supports decreased ability of florets to open, floret size and vase life as recorded in our results. The young and expanding tepals have greater capacity to retain water which accounts for their high relative water content[31]. As with increase in storage duration, the amount of water retained decline and there is loss of membrane integrity also as reported in our results, a steady decline was observed in RWC.

The eventual ion leakage due to loss of membrane permeability can be used to determine the extent of tissue damage[32]. This tissue damage involves free radicals and activated oxygen species which up regulate the antioxidant defence system. The antioxidant enzymes such as CAT and POX are considered as an adaptive response to defend cells against oxidative stress[33]. The increased activity of both enzymes with increase in storage duration in our study explains the higher extent of oxidative stress leading to tissue damage or senescence that leads to decline in post harvest quality of spikes with increase in storage.

The improvement in quality of spikes packed in PP sleeves in terms of different quality parameters *viz*., vase life, days to opening of basal florets, floret size, per cent opened florets, maximum number of florets open at one time after all storage durations was observed in comparison to spikes stored unpacked.

Further, various physiological and biochemical attributes *viz*., membrane stability index, relative water content, catalase and peroxidase activities and total water absorbed also supported the above results as there was decreased MSI, RWC and total water absorbed with increase in storage duration. Further, increased activity of antioxidant enzymes with increase in storage duration supported decreased MSI and RWC.

The peroxidase enzyme play a key role in scavenging of reactive oxygen species (ROS) by regulating the levels of peroxide hydrogen (H_2O_2) produced in plant cells thereby, preventing its contact with superoxide and formation of hydroxyl radicals[34]. The improved quality of packed spikes in different polymeric sleeves has also earlier been reported for gladiolus[13] and gerbera and liliums[35], etc. The enhanced bud opening in cut flowers is associated with high cell turgidity[36] and upregulation of optimum metabolic activities with high petal sugar status[37]. The higher number of floret opening in packed spikes could be attributed to turgidity of the spikes on account of higher water uptake and optimum cell metabolism with sustainable levels of carbohydrates in florets.

The improvement in quality after packaging in polymeric sleeves might be due to the modified internal atmosphere with high CO_2, low O_2 and high relative humidity within the package due to respiration of spikes and low permeability of sleeves to gas[38,39]. The packaging also minimizes respirational loss of carbohydrates and transpirational loss of water that reduces depletion of stored food and supplies adequate energy to the florets for successful opening and to be larger in diameter[40]. This is in concomitant with our findings where florets packed in sleeves have higher per cent of floret opening and diameter than unpacked spikes (Table 2). Similar effects of improved bud opening with modified atmosphere packaging have been reported by Meir *et al*.[41] in gladiolus. The more stored food and higher moisture retention in the packed spikes during storage helps to maintain turgidity of spikes that extends its vase life. The results are in alignment with earlier reports in chrysanthemum[42] and gladiolus[13].

Conclusion

The physiological and biochemical aspects influenced the post harvest quality of flowers during packaging and storage. The quality of spikes stored in Polypropylene (PP) sleeves was better than the spikes kept unpacked for all storage durations and increase in storage duration decreased the post harvest quality, physiological and biochemical parameters in both, the packed and unpacked spikes. The vase life of packed spikes as well as other quality parameters *viz*. per cent floret opening, floret size, maximum number of florets opened at one time and amount of water absorbed were at par after 6 and 9 days of storage. The spikes after 12 days of storage were found to be unacceptable whereas spikes after 6 and 9 had comparable quality to fresh spikes. Although vase life and other quality parameters of freshly harvested spikes were higher than stored and packed spikes but storage of spikes for 9 days gave an additional benefit to growers for management of spikes. Thus, the minor loss in quality of spikes as compared to fresh spikes during storage up to 9 days in PP sleeves is better than the complete loss of produce during transportation and gluts. So, the spikes of gladiolus could be stored dry at 4±0.5°C in PP sleeves for 9 days without much influence on its post harvest quality (Fig. 2).

Conflicts of interest

Authors declare no competing interests.

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