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INFLUENCE OF GROWTH TEMPERATURE ON KEEPING QUALITY TRAITS OF ROSE (*ROSA HYBRIDA* L.) CUT FLOWERS GROWN UNDER CONTINUOUS CO_2 ENRICHMENT

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SUMMARY

An attempt was made to find out if there is any effect of higher than optimum growth temperature along with continuous CO_2 enrichment on the keeping quality traits of Rose (*Rosa hybrida* L.) cut flowers at harvest. Five rose cultivars, *viz.* 'First Red', 'Arjun', 'Raktima', 'Raktagandha' and 'Pusa Pitamber' were grown in phytotron and exposed to high (35/25°C, T1) or optimum (28/18°C, T0) temperature with enriched CO_2 (1000 μmol mol^{-1}) until flowering. Cultivar means at T1 showed significant reduction in keeping quality parameters of flowering shoots in terms of number of days required from flower bud appearance to harvest (34%), stalk length (5%), number of petals (16%), flower diameter (24%), and fresh (17%) and dry (14%) weight of flowers compared to plants grown at T0. However, the vase life of cut flower was not affected by the pre-harvest growing conditions but there was significant cultivar difference. Among the cultivars, except Arjun, all other showed significantly higher number of stomata per cut flower at higher temperature. Days to harvest were significantly correlated with stalk length (0.472), flower diameter (0.588**) and dry matter accumulation (0.52**) in flowers while it was negatively associated with the number of stomata per cut flower (-0.381*). This study indicates that CO_2 enrichment does not mitigate the effect of high temperature during growth of Rose plants and thus, does not improve the keeping quality traits of cut flowers at harvest. Hence, CO_2 enrichment in greenhouses during summers will not yield in good quality cut flowers.**

Keywords: **CO_2 enrichment, cut flowers, keeping quality traits, Rose cultivars, temperature**

INTRODUCTION

The value of cut flower and consumer acceptance is mainly determined by post-harvest longevity or vase life. The keeping quality of cut flower is affected by various pre- and post-harvest factors. The post-harvest factors include water relations, carbohydrate status of cut flower, type of holding solution, hormonal balance and environmental conditions. The pre-harvest factors attributing to keeping quality of cut flowers mainly includes growing conditions of light, temperature, carbon dioxide (CO_2) concentration, humidity and nutrition (Halevy and Mayak 1979, In *et al*. 2007). Reports on pre-harvest growing conditions suggests that cut roses when grown at high humidity (RH>70%) showed no difference in flower opening or on vase life (Urban *et al*. 1995) whereas in another experiment, shorter vase life was reported when roses were grown at elevated RH (90%) (Mortensen and Fjeld 1998). In *et al.* (2007) suggested that humidity is the key pre-harvest

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environmental factor affecting vase life of rose cut flowers 'Asami Red'. Roses raised at high humidity (85%) produced larger size stomata and consequently reduced vase life while those grown under relatively dry condition had functional stomata which regulated water relations adequately after harvest and resulted in longer vase life. Infact, it is the vapour pressure deficit (VPD) which determines the aboveground water relations in flower stems of roses (Liu *et al*. 2007).

The vase life of cut flowers is determined by a balance between transpiration and water uptake. Transpiration depends upon plant as well as environmental factors such as cuticle layer, boundary layer, stomata, temperature, air movement and humidity. Loss of water by transpiration occurs mainly through the stomata, thus, the degree and duration of stomatal opening are of great significance. Schroeder and Stimart (2005) evaluated the leaf stomatal density and post-harvest water loss in *Antirrhinum majus* cut flowers. They reported that cut flowers with 9 days longer vase life had 53% less stomata. Less number of stomata per cut flower, low stomatal transpiration and control of stomatal water loss were major factors determining vase life of *A. majus* cut flowers.

Greenhouses improve environmental conditions for plant growth. In regions with hot and arid climate, high temperature and high vapour pressure deficit (VPD) in greenhouse reduce yield and flower quality. It is reported that CO_2 enrichment mitigates the effect of drought (Rabha and Uprety 1998) but the interactive effect of CO_2 with high temperature needs confirmation (Maherali and DeLucia 2000, Hamilton *et al*. 2008). It was hypothesized that CO_2 enrichment might mitigate the adverse effects of higher temperature on quality traits of cut flowers. An experiment was conducted under controlled environment condition with the aim to study the feasibility of growing rose plants and producing good quality cut flowers during summer months with CO_2 enrichment. For maximum growth and good quality flowers, the rose plants require 1000 µmol mol^{-1} CO_2 and optimum day/night temperature of 28/18°C (Jiao and Grodzinski 1998, Pandey *et al*. 2009).

MATERIALS AND METHODS

Plant material and growth conditions

The buds of four indigenously developed (at Division of Floriculture & Landscaping, Indian Agricultural Research Institute, New Delhi) rose cultivars *viz.* 'Arjun', 'Raktima', 'Raktagandha' and 'Pusa Pitamber' along with an exotic 'First Red' were budded *in situ* on the cuttings of *Rosa indica* L. var. 'Odorata'. The cuttings were planted in coco-peat after dipping them in a solution of indole-3- butyric acid (IBA) (5000 ppm) for 2-3 seconds. The procedure for raising the cuttings were followed as mentioned in Pandey *et al* (2007). Budded plants were pruned to a height of 10-15 cm, leaving five lateral buds on a single stem. Six plants of each cultivar were transferred into two different growth chambers (Conviron, Winnipeg, Canada) at the National Phytotron Facility, Indian Agricultural Research Institute, New Delhi. The pre-harvest environmental conditions maintained throughout the plant growth were identical in all the growth chambers except for temperature. Temperatures were set at 28°/18°C (T0, optimum) and 35°C/25°C (T1, high), while CO_2 concentration was 1000 µmol mol^{-1} in both the chambers. The optimum temperature (data unpublished) and CO_2 concentration (Pandey *et al*. 2009) were determined in our previous studies for these rose cultivars. A 13 h photoperiod was maintained at a photosynthetic photon flux density of 650 µmol m^{-2} s^{-1} and the relative humidity (RH) was 60 ± 5%. Plants were grown for 50 days or until they produced sufficient number of leaves and flower buds.

Post-harvest handling and measurements

The flowering shoots were harvested at tight bud stage. Single stems were placed in plain tap water within minutes of cutting, after re-cutting the basal 5 cm in air. Leaves from the basal 10 cm of the cane were removed. The flowering shoots were kept at room temperature (25ºC), with a photon flux density of 15 µmol m^{-2} s^{-1} (cool white fluorescent light) for 12 h each day and RH at 60%. The stalk was trimmed by one cm and water was changed daily.

Before harvesting, the cane length was measured. Total number of days taken from flower bud appearance till harvest was noted. Flower diameter was measured at the petals fully reflexed stage, i.e. flower unfolding ability. Vase life was calculated from the time the flowers were placed in vase immediately after harvest until 50% of the open florets wilted. The total number of petals of withered flower was counted after termination of the vase life. Ten flowering stalk of each cultivar was used for vase life study. In another set, 5 flowers from each cultivar were harvested and fresh weight (without pedicel or stalk) was recorded immediately. The flowers were then dried in hot air oven at 65°C to a constant weight and the percent water content was derived.

Stomatal measurements

The pre-harvest stomatal count was made by non-destructive sampling on the shoot (before harvesting) with a visible flower bud. A fully expanded fourth leaf from the apex from each plant was sampled for making stomatal counts. The terminal leaflet of the tri- or penta-foliate leaf was used for all the observations. For stomatal and epidermal counts, the detailed protocol was followed as mentioned in Pandey *et al.* (2007). The number of stomata and the number of epidermal cells were counted from five fields of view (area: 0.02979 mm^2) at 400x magnification. The number of stomata per field was converted to number of stomata mm^{-2}. To calculate the average number of stomata per cut flower, the average leaf area for each cut flower was multiplied by their respective stomatal density. Statistical analysis was done following standard methods.

RESULTS AND DISCUSSION

Keeping quality traits of cut flowers influenced by different growth temperature

Earlier reports suggest that the keeping qualities of cut flowers are influenced by the pre-harvest environmental conditions (Bredmose and Nielsen 2004, Pettersen *et al.* 2007) but the effect of higher than optimum temperature along with continuous CO_2 enrichment on keeping quality of rose cut flower is meager. The rose cultivars grown under constant CO_2 enrichment with different temperature regimes showed significant variation for quality traits of cut flowers (Table 1). The number of days required from flower bud appearance to harvest was reduced at T1 by 6.4 d (treatment mean) compared to T0. In all the cultivars, except Pusa Pitamber, a marked reduction in the number of days to harvest was noticed at T1. In Arjun, days to harvest were drastically reduced by 2.1 fold in plants grow at T1 compared to T0. Similarly, all cultivars except Raktima, produced small size stalks at T1 compared to T0. Raktima produced significantly longer stalks at T1 compared to T0, the percent increase being 44.9%. The maximum reduction (23.7%) in stalk length was observed in First Red at T1 over T0 grown plants.

In rose, higher temperature promotes plant growth resulting in a shorter growth period until bud break and smaller size of shoots (Marcelis-van Acker 1995). In this study, except temperature, all other factors were similar in both the treatments. This indicates that the reduction in the number of days from flower bud appearance to harvest and stalk length is decided by the growth temperature. He *et al.* (2005) reported an advancement of timing of flowering in *Phytolacca americana* L. under elevated CO_2 and increased air temperature. They suggested that elevated CO_2 and increased temperatures elicit different responses at the physiological and whole-plant levels with little interaction between CO_2 and temperature effects. The length of stalk is dependent on the number of nodes formed by the apical meristem in an axillary bud and by elongation of the internodes during growth and development. In turn, the number and length of cells formed is closely related to the meristem temperature. In terms of stalk length, cultivar difference could not be ignored as out of five, two cultivars, Raktima and Raktagandha, produced significantly longer stalks at higher growth temperature.

The numbers of petals were reduced significantly in all the cultivars except Arjun, which showed a 1.6-fold increase in petals at T1 over T0 (Table 1). The over all reduction in petal number at T1 was 16%. Raktima produced least number of petals while Raktagandha did not show any marked effect of high temperature on petal numbers. Similarly, the flower diameter was also reduced in all the cultivars at T1 over T0 raised flowers. The percent reduction in flower size due to high temperature

Table 1. Keeping quality traits of cut flowers of five Rose (*Rosa hybrida* L.) cultivars grown under different temperature (T) regimes with CO_2 enrichment (1000 µmol mol^{-1}). T0: 28/18°C (optimum); T1: 35/25°C (high)

Quality traits	Treatment	Cultivars					Mean	CD (*P* = 1%**, 5%*)		
		First Red	Arjun	Raktima	Rakta gandha	Pusa Pitamber		Treatment	Cultivar	Cv. x treatment
Days to harvest (d)	T0	18.5	34.1	13.7	15.3	11.3	18.6	0.76**	1.20**	1.69**
	T1	11.1	15.9	11.0	11.3	11.7	12.2	0.56*	0.88*	1.24*
Stalk length (cm)	T0	43.4	46.2	33.2	40.3	31.2	38.9	0.89**	1.41**	1.99**
	T1	33.1	37.1	48.1	42.7	24.7	37.1	0.65*	1.03*	1.99*
No. of petals (per flower)	T0	50.0	47.3	44.0	82.2	112.3	67.1	3.53**	5.58**	7.89**
	T1	23.8	73.8	17.3	83.3	83.3	56.3	2.59*	4.09*	5.79*
Flower diameter (cm)	T0	7.1	7.8	7.9	7.3	5.5	7.1	0.32**	0.51**	NS
	T1	5.2	5.7	5.3	6.2	4.6	5.4	0.24*	0.37*	0.53*
Flower Fresh wt (g/flower)	T0	10.8	9.9	5.5	5.9	6.7	7.8	0.68**	1.07**	1.51**
	T1	3.0	16.5	2.5	3.8	2.3	6.5	0.49*	0.78*	1.11*
Flower Dry wt (g/flower)	T0	1.45	1.36	0.92	0.93	1.02	1.14	0.14**	0.22**	0.31**
	T1	0.48	2.06	0.48	0.73	0.44	0.98	0.10*	0.16*	0.23*
Water content (%)	T0	86.6	86.3	83.1	84.2	84.8	85.0	NS	2.79**	NS
	T1	83.6	87.5	81.1	80.5	80.8	83.2	1.29*	2.05*	NS
Vase life (d)	T0	7.3	6.0	4.9	3.4	5.0	5.3	NS	1.09**	1.55**
	T1	11.0	4.3	3.2	5.3	2.3	5.2	NS	0.82*	1.13*
Stomata/cut flower ($x10^3$)	T0	104.0	103.9	57.0	57.5	39.7	72.4	3.34**	1.80**	4.46**
	T1	132.4	79.5	115.1	94.5	47.1	93.7	1.65*	1.05*	2.59*

NS = not significant

was 24.0 (cultivar mean). In spite of having significantly higher number of petals in Arjun, small sized flowers were produced at T1. Marcelis-van Acker (1995) found that the size of reflexed sepals decreased slightly with increasing pre-treatment temperature, but effects were larger for isolated buds than for buds attached to the parent shoot. The numbers of petals are determined in the floral primordia before opening of the flower bud which is again dependent on the plant growing condition. This suggests that the higher temperature treatment during plant growth adversely affected the petal numbers. Also, the reduced flower diameter at higher than optimum temperature can be attributed to small size of petals which was evident in Arjun.

Fresh and dry weights of harvested flowers were markedly reduced at T1 in all the cultivars, except Arjun (Table 1). Increase in flower fresh and dry weight in Arjun at T1 might be due to higher number of petals produced at T1 over T0. Among other cultivars, Raktagandha showed less than 2-fold reduction in fresh and dry weight while it was more than 2-fold in First Red, Pusa Pitamber and Raktima. Further, the water content of flowers grown at T1 (83.2%) was less as compared to T0 (85.0%), the treatment difference being significant only at $P = 0.05$. Among cultivars, Arjun and First Red retained maximum water content, 87.5% and 83.6% respectively, in flowers grown at T1 compared to T0. Accumulation of flower biomass is directly dependent on the duration from flower bud formation until harvest, since the developing flower bud acts as a strong sink. This is evident from a positive correlation obtained between numbers of days from flower bud appearance until harvest (Table 2). The pre-harvest temperature treatment had no significant effect on the vase life of cut flowers. In fact, the vase life of flowers was reduced due to higher number of petals which is also evident from a negative correlation (Table 2). This is true in case of Arjun which produced higher petals with relatively less vase life.

Cultivar differences and temperature x cultivar interaction were found significant in terms of vase life, whereas temperature treatments had no significant effect on vase life. Among cultivars, vase life was maximum for First Red followed by Arjun while flowers of Pusa Pitamber withered after 2.3 d. This experiment suggests that the temperature treatment during pre-harvest growth conditions had no direct effect on the vase life of cut flowers. In fact, the vase life of flowers was reduced due to higher number of petals which is also evident from a negative correlation (Table 2). This is evident in Arjun which produced maximum petals and had relatively less vase life. In the growth chamber with higher temperature, RH was maintained at 60% which means the higher temperature was combined with dryer air resulting in increased evaporation demand. The flower shoots adapt to high VPD by decreasing the leaf area for maintaining high sap flow rate per unit area. Liu *et al*. (2007) found that the leaf area of rose flower stems enhanced by low VPD causes a decrease in transpiration per unit leaf area. In the present experiment, we did not measure the water uptake as it is a well known fact that the rate of transpiration of cut shoot adversely influences the vase life of flowers. These rose cultivars (except Raktima) were reported to produce less leaf area at higher than optimum growth temperature (Pandey *et al.* 2007). A possible reason for higher vase life of First Red may be a significant reduction in the size of stomates, guard cell length and width, stoma length and width compared to other cultivars as evident from our previous work (Pandey *et al.* 2007). Analysis of stomatal data further confirmed that Raktima (statistically at par with Pusa Pitambar) had minimum vase life which might be associated with higher stomatal density, increased stomatal size, guard cell and stoma width. These are important stomatal parameters which control the amount of water lost from the leaves and a close relationship has been reported between reduction in vase life and rate of water loss of detached leaves in 14 rose cultivars (Mortensen and Gislerod 1999).

The number of stomata per cut flower is an important factor in terms of keeping quality of cut flowers as it might affect the rate of transpiration from the cut shoot. The number of stomata per cut flower averaged over temperature treatments was higher at T1 (93.7×10^3) over T0 (72.4×10^3) grown plants (Table 1). In Raktima, the increase in stomata per cut flower was more than 2-fold while First Red, Raktagandha and Pusa Pitambar recorded less than 2-fold increase in the number of stomata per cut flower in plants grown at T1

Table 2. Correlation matrix for quality traits of cut flowers of five rose (*Rosa hybrida* L.) cultivars grown under different temperature (T) regimes with CO_2 enrichment (1000 μmol mol^{-1}). T0: 28/18°C (optimum); T1: 35/25°C (high)

Quality traits	Days to harvest	Stalk length	Flower diameter	Petal number	Vase life	Flower fresh wt	Flower dry wt	Moisture content
Stalk Length	0.472**							
Flower diameter	0.588**	0.395*						
Petal No.	-0.146	-0.481**	-0.064					
Vase life	0.144	0.013	0.062	-0.415*				
Flower fresh wt	0.522**	0.206	0.308	0.183	0.074			
Flower dry wt	0.529**	0.235	0.378*	0.204	0.059	0.992**		
Moisture content	0.502**	0.157	0.379*	-0.007	0.418*	0.782**	0.780**	
Stomata/cut flower	-0.381*	0.443	-0.408*	-0.320	0.188	-0.371	-0.373*	-0.265

*Significant at 0.05; ** significant at 0.01: NS = not significant: $n = 30$

compared to T0. Arjun recorded a marked reduction in the number of stomata per cut flower at T1 compared to T0 plants which may be due to small size of leaves on the flowering shoot resulting in less leaf area. Schroeder and Stimart (2005) reported increased post-harvest longevity with decreasing number of stomata per cut flower in *A. majus*. However, other studies have suggested that stomatal closing behaviour is more important than stomatal size and the stomata closing is mostly affected by VPD (Nejad and Van Meteren 2008). Therefore, in our study the value of $r < 50$ suggests that the 50% of correlation could be due to factors other than temperature, possibly VPD, which might have influenced the keeping quality of cut shoot.

Correlation between quality traits of cut flowers under different growth temperature

From the correlation data (Table 2) between quality traits of cut flowers and different temperature regimes, it was seen that longer the duration to harvest, greater the stalk length (r= 0.472**) which might be possibly due to higher accumulation of assimilates. Number of days to harvest was also associated to flower diameter and flower fresh and dry weight. Stalk length was positively associated with flower diameter (r = 0.395*) while petal numbers (r = -0.481**) were negatively affected by stalk length. Higher number of petals were significantly associated with reduced vase life (r = -0.415*). The obvious reason being more exposed surface area for the loss of water as vase life depends on turgidity or moisture content of petals (r = 0.418*) besides reserved carbohydrates. The number of stomata per cut flower also affected adversely the fresh (r = -0.371*) and dry weight (r = -0.373*) of cut flowers. Further, higher number of stomata per cut flower were found to delay the flower buds to reach the harvestable stage (r = -0.381*) and also resulted in significant reduction in flower diameter (r = -0.408*).

This study provides valuable information on the interactive effect of pre-harvest growth temperature and CO_2 enrichment on the keeping quality traits of rose cut flowers. Among the quality traits, it was seen that the flower biomass and flower diameter (size) were significantly influenced by pre-harvest growth temperature. Thus, from the present study it could be concluded that the cultivar differences in keeping quality traits of cut flowers are influenced by growth temperature and also has an association with stomatal density.

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