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Low temperature stress induced changes in the seedling growth and nutrient content of papaya genotypes

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ABSTRACT

The major problem of subtropical papaya cultivation is its susceptibility to low temperature stress. The present study was conducted to investigate the effect of different low temperature regimes on nutrient content and growth parameters in five papaya genotypes namely, Pusa Nanha, Red Lady, P-7-2, P-7-9, P-7-14 and one wild cold tolerant relative, *i.e.* genus *Vasconcellea cundinamarcensis*. It was observed that there was a higher reduction in plant height, stem diameter, leaf fresh and dry weight at all the low temperature regimes. The genotype *V. cundinamarcensis* had higher (5.42%) leaf potassium (K) content followed by P-7-9 (5.28%). The genotype *V. cundinamarcensis* also showed the highest mean calcium (Ca) level in both leaf (3.82%) and root (3.92%) tissues. However, genotype P-7-9 had the highest Mg content in both the tissues, *i.e.* leaf (0.97%) as well as root (0.90%). Low temperature stress, in most of the cases, significantly affected the leaf and root nutrient contents, although the degree of change in nutrient content was genotype specific.

Key words: *Carica papaya*, plant height, root dry weight, low temperature stress, leaf calcium content.

INTRODUCTION

Papaya (*Carica papaya* L.) is one of the most important cultivated species which is widely cultivated for consumption as fresh fruit. It is also consumed as processed products like drinks, jams, candies, dried and crystallized fruits (Villegas, 10). In India, it is cultivated over an area of about 0.139 million ha with a production of 5.83 million tonnes having productivity of 41.94 tonnes/ha (Anonymous, 1). Commercial papaya cultivation is restricted to tropical and sub-tropical areas as it requires warm and humid climate. The optimum temperature for growing papaya is reported to be 21° to 33°C (Knight *et al.*, 6). Night temperature below 12° to 14ºC for several hours, *i.e.* during the winter season detrimentally affects the plant growth and fruit production. Almost all the commercial *C. papaya* varieties are highly sensitive to low temperature. Though, the distant relatives of cultivated papaya, *viz. Vasconcellea cundinamarcensis*, *V. pennata* and *V. pentagona* are resistant to frost, but none have been evaluated systematically for their physiological responses under the low temperature stress conditions (Ram, 9). Various nutrients (mostly potassium and calcium) also play an important role for imparting low temperature stress tolerance in plants (Waraich *et al.*, 11). A better understanding of genotypic responses to specific environmental factors contributes towards efficient utilization of genotypes in papaya breeding programme. Very limited efforts have been made to understand the morphological and vegetatively growth related changes occurring in papaya under low temperature stress. Hence, the present investigation was conducted to study the morphological changes and nutrient acquisition in papaya genotypes under low temperature stress and to identify the cold tolerance papaya genotype based on their performance.

MATERIALS AND METHODS

Plant material for the experiment included five *Carica papaya* L. genotypes (Pusa Nanha, Red Lady, P-7-2, P-7-9 and P-7-14) and one cold tolerant wild genus (*Vasconcellea cundinamarcensis*). Evaluation for low temperature stress was undertaken under controlled environment conditions at the National Phytotron Facility, ICAR-Indian Agricultural Research Institute, New Delhi during 2017-18. The seeds of the above genotypes were sown in the trays containing the growing medium (perlite: vermiculite: cocopeat: vermicompost; 1:1:1:1), and transplanted 8 weeks after sowing into plastic pots filled with same potting medium under the temperature controlled glasshouse. The transplanted plants were irrigated at every three days interval with tap water. The recommended standard operations were performed at appropriate stages. After the proper establishment of the transplanted seedlings, low temperature stress treatments were induced by sequentially lowering the

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temperature in the growth chamber @ 2°C per two day from 28°/18°C (day/night) to 16°/6°C (day/night) (Table 1). Same set of plants were used for individual treatments. Control plants (T_0) of each genotype were maintained at 28°/18°C (day/night) regime, in different growth chambers. All other environmental parameters were maintained at optimum level (photoperiod of 12 h 30 min; relative humidity of 70 ± 5 % (day) and 85-90 % (night); irradiance of 700-800 μmol $m^{-2}s^{-1}$ at leaf level) under growth chamber for both control and low temperature treatments. A set of plants from each genotypes were directly exposed to 18°/8°C (day/night) temperature regime for one week. These plants were designated as acclimatized ones, and were considered as one treatment for statistical analysis. The experiment was laid out in CRBD and replicated thrice comprising of nine plants per replication per genotype under both control and low temperature stress conditions.

Parameters like plant height (cm), of papaya plants was measured from the collar region to the base of the last fully opened leaf on the main stem with the help of measuring scale and stem diameter (mm) were measured at the base of the stem with Digimatic Vernier calipers. Both these observations were recorded one day before treatment (internal control) and twelve days after T_6 treatment. Control plants were grown at 28°/18°C without exposing them to cold stress throughout the experiment. The percent change in final observation over the initial value was calculated for both control and treated plants. Tissue (both leaf and root) nutrient analysis was done at the end of experimentation. Total potassium (K) and sodium (Na) contents were estimated from using a microprocessor based flame photometer, while Calcium (Ca) and magnesium (Mg) contents were ascertained using atomic absorption spectrophotometer (Jackson, 5). The statistical analysis of the data was performed using software, SAS package (9.3 SAS Institute Inc, USA). P values ≤ 0.05 were considered as significant.

Table 1. Details of controlled temperature regimes maintained under growth chambers.

Treatment	Day temp. (°C)	Night temp. (°C)
T_0 (control)	28± 0.1	18 ± 0.1
T_1	26± 0.1	16 ± 0.1
T_2	24± 0.1	14 ± 0.1
T_3	22± 0.1	12 ± 0.1
T_4	20 ± 0.1	10 ± 0.1
T_5	18 ± 0.1	08 ± 0.1
T_6	16 ± 0.1	06 ± 0.1
Acclimatization	18 ± 0.1	08 ± 0.1

RESULTS AND DISCUSSION

The plant height was significantly influenced by low temperature regime, genotype and their interaction (Fig. 1a-b). Irrespective of genotypes, per cent change in plant height was higher in control plants than the low temperature treated stress plants. Amongst the genotypes, the highest per cent change for both control (T_0) (13.24 %) and treated (T_6) plants (12.55 %) was observed in *V. cundinamarcensis*. In acclimatized plants, the highest per cent change was noted in *V. cundinamarcensis* (5.70 %), while it was lowest (2.38 %) in P-7-9. The effect of temperature on the stem diameter was statistically non-significant (Fig. 2a-b). Amongst the G × T interaction treatments *V. cundinamarcensis* × T_6 recorded the thickest stem (16.63 mm). The highest per cent increase in stem diameter was observed in control (T_0) plants of P-7-9 (2.13 %), while for treated P-7-2 plants at was 1.75 %. Both plant height and stem diameter were found to decrease in the acclimatized plants as compared to the control. Earlier, Barros *et al.* (2) also reported decline in the vegetative growth of *Coffea arabica* L. under the low temperature regimes during winter. Similarly life cycle of rice both at vegetative and reproductive phases was found to be affected due to the low temperature stress (Nishiyama, 7). Earlier, Pradhan *et al.* (8) reported the decline in the vegetative growth in terms of plant height and stem diameter in papaya genotypes under controlled low temperature stress conditions. Amongst the genotypes, *V. cundinamarcensis* maintained the highest mean leaf fresh weight (Fig. 3). Amongst the G × T interactions, *V. cundinamarcensis* × T_0 (897.41 mg) was observed to have higher leaf fresh weight followed by P-7-9 × T_0 (616.38 mg). The highest per cent decline was observed in the genotype Red Lady (28.04 %), while it was lowest in the genotype *V. cundinamarcensis* (8.85 %). In the acclimatized plants, the highest per cent decrease was observed in the genotype P-7-14 (27.74 %), while it was lowest in *V. cundinamarcensis* (11.19 %). Leaf dry weight was significantly influenced by low temperature regimes, papaya genotype and their interaction (Fig. 4). With the decreasing temperatures, the leaf dry weight was observed to decrease. Amongst the low temperature regimes, the mean leaf dry weight was observed to be the highest in control (T_0) plants (61.78 mg), while it was lowest in T_6 plants (42.89 mg). Amongst the G × T interactions, *V. cundinamarcensis* × T_0 (99.65 mg) was observed to have the highest mean leaf dry weight. The highest and lowest decline was observed in the genotype P-7-2 (40.13 %) and *V. cundinamarcensis* (18.83 %), respectively. Root fresh weight was significantly influenced by exposure of

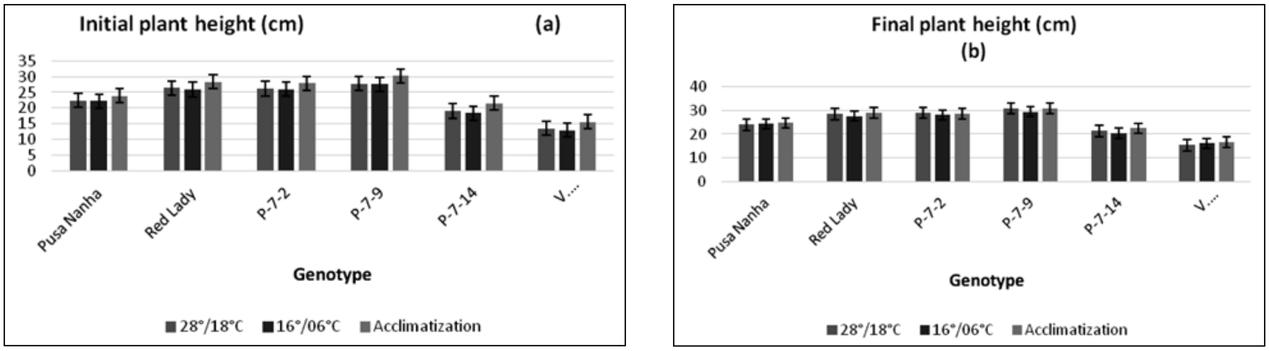

Fig. 1 (a) and (b) Influence of different temperature regimes on plant height (cm) of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

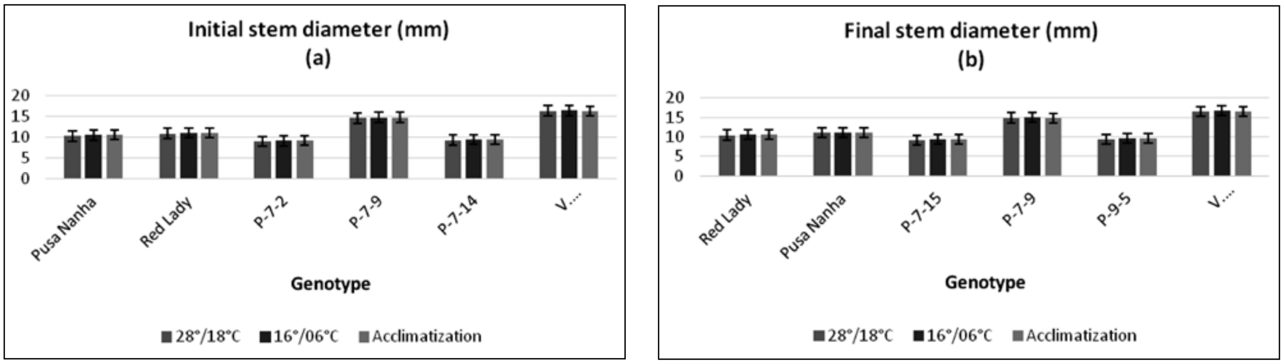

Fig. 2. (a) and (b) Effect of different temperature regimes on per cent change in stem diameter of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

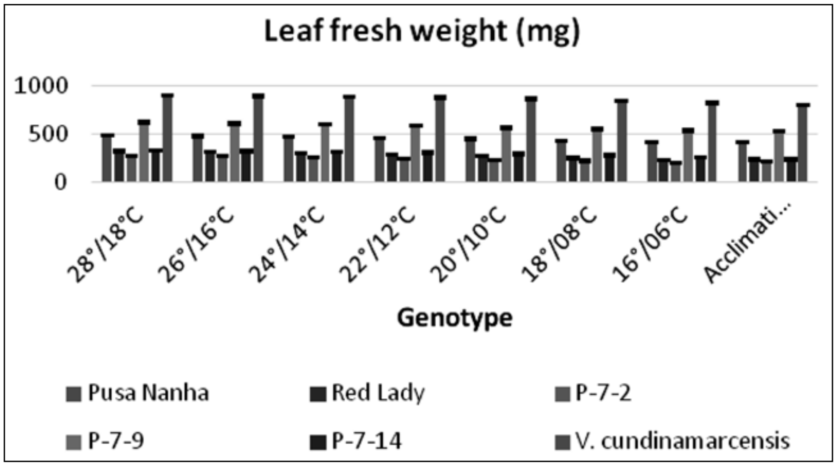

Fig. 3. Influence of different temperature regimes on leaf fresh weight (mg) of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

papaya seedlings to low temperatures with regard to genotype and their interaction (Fig. 5). Amongst the genotypes, *V. cundinamarcensis* had significantly higher fresh weight (7.68 g) than other genotypes. The genotype *V. cundinamarcensis* had the higher root dry weight (Fig. 6) in both control (T_0) (0.55 g) and treated T_6 plants (0.61 g). Both the fresh and dry weights of root and leaf indicated higher dry matter accumulation in the genotype *V. cundinamarcensis* at the low temperature regimes.

Low temperature stress significantly affected the leaf and root nutrient contents, although the

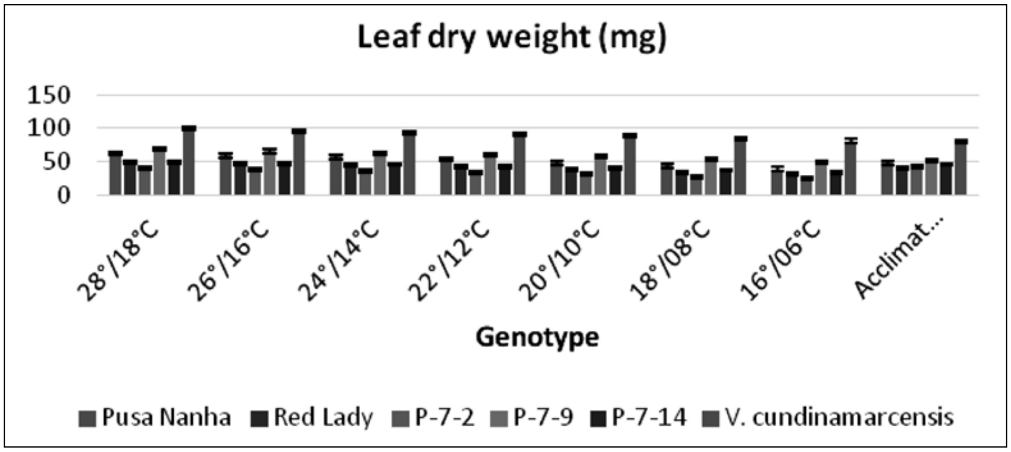

Fig. 4. Influence of different temperature regimes on leaf dry weight (mg) of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

degree of change in nutrient content was genotype-specific. Potassium content showed the increasing trend after exposure to low temperature regimes (Table 2). The genotype *V. cundinamarcensis* had higher leaf K content (5.42 %) followed by P-7-9 (5.28 %). Amongst the G × T interactions, the higher accumulation of leaf K was noted in the plants of *V. cundinamarcensis* × T_6 (6.18 %). The data indicated that there was a slight increase in leaf Ca levels in the T_6 treated plants (2.94 %), compared to control (T_0) plants (2.51 %). Leaf Ca content was observed to be maximum in the genotype *V. cundinamarcensis* (3.82 %) (Table 2). The effect of low temperature stress and papaya genotypes were significantly different for leaf magnesium (Mg) content (Table 3), which decreased significantly following low temperature treatment (0.67 %). Amongst the genotypes, P-7-9 was found to have the highest leaf Mg (0.97 %) content followed by *V. cundinamarcensis* (0.85 %). Amongst the G × T interactions, the leaf Mg content in P-7-9 × T_0 (1.16 %) and *V. cundinamarcensis* × T_0 (0.96 %) was found higher than others. The maximum decrease of leaf Mg content was observed in the genotype Pusa Nanha (33.33 %) and minimum decrease was found in *V. cundinamarcensis* (17.70 %). In acclimatized plants the minimum decrease in leaf Mg content was observed in genotypes *V. cundinamarcensis* (16.66 %). The effect of low temperature on the Na content was statistically non-significant (Table 3). Leaf Na content was observed highest in genotype Pusa Nanha (0.43 %). Amongst the six genotypes, root K content was observed highest in the genotype P-7-9 (6.24 %) followed by *V. cundinamarcensis* (5.91 %) (Table 4). In the G × T interactions, the highest root K content was noted in P-7-9 × T_0 (6.77 %) followed by *V. cundinamarcensis* × T_0 (6.16 %). The

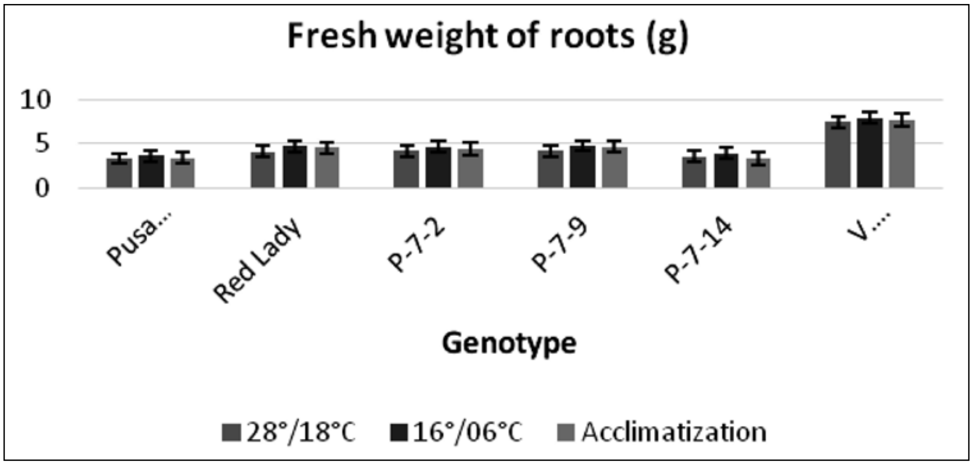

Fig. 5. Effect of different temperature regime on root fresh weight (g) of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

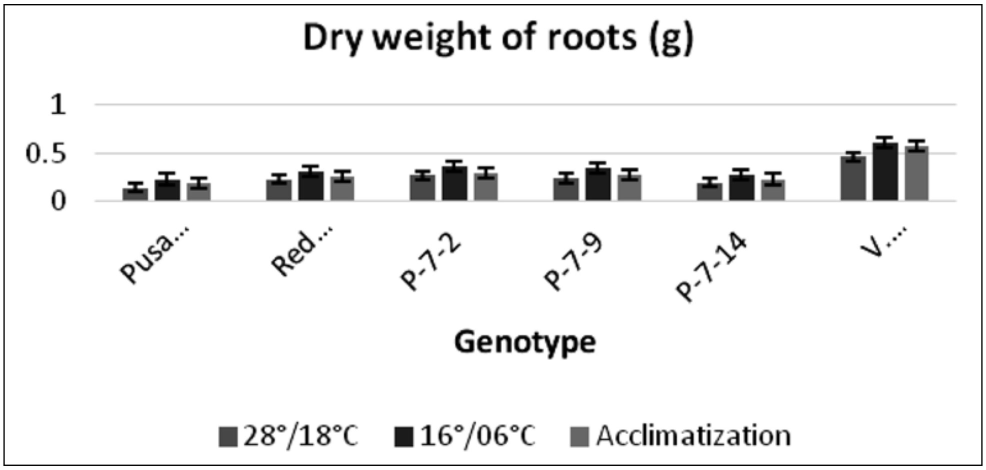

Fig. 6. Effect of different temperature regimes on root dry weight (g) of papaya genotypes grown under phytotron conditions, vertical bars indicate ± SE mean.

data related to root calcium content was influenced significantly by low temperature regimes, papaya genotypes and their interaction. It decreased in the low temperature treated plants (2.82 %) in comparison to control (3.08 %) (Table 4). Root of *V. cundinamarcensis* exhibited statistically higher mean accumulation of Ca (3.92 %). Root of P-7-9 (0.90 %) and *V. cundinamarcensis* (0.89 %) exhibited higher mean accumulation of Mg (Table 5). Plants of P-7-9 × T_0 (1.06 %) followed by *V. cundinamarcensis* × T_0 (1.01 %) were observed to have higher root Mg content. Root of *V. cundinamarcensis* (1.88 %) and P-7-9 (1.86 %) exhibited statistically similar mean accumulation of Na (Table 5). Amongst the G × T interaction, the genotypes P-7-9 × T_0 (2.07 %) were observed to be higher in root Na content. Waraich *et al.* (11) reported that among the nutrients, potassium (K) and calcium (Ca) played a major role in protecting the plants from chilling injury.

Potassium can provide protection against oxidative damage caused by chilling or frost, thus reducing the formation of reactive oxygen species. K also playes significant role in stomata closure and thus reduction of transpiration loss under the cold stress (Wilkinson *et al*., 13). In the present study also, increase in K content was observed. In potato plants, the effect of chilling temperature could be alleviated by application of K fertilizer (Grewal and Singh, 3, Hakerlerler *et al*., 4). Calcium has essential requirement for chilling induced stomata closure in tolerant genotypes. It is also believed that ABA induced stomatal closure is partially mediated by Ca^+ released from internal guard cell stores or the apoplast (Wilkinson *et al*., 13). Calcium also plays role as calmodulin, which controls the plant metabolic activities and enhances the plant growth under low temperature stress conditions Waraich *et al.* (12). In the present study, amongst the six genotypes evaluated, *V. cundinamarcensis* showed the highest mean Ca accumulation in both leaf (3.82%) and root (3.92%). The Mg content in post exposure to low temperature treatment was found to get reduced in both root and leaf tissues. However, genotype P-7-9 was observed to have the highest Mg content in both the tissues, leaf (0.97%) and root (0.90%). It is a well-known fact that Mg is an essential part of leaf chlorophyll. The higher leaf chlorophyll content of genotype P-7-9 can be correlated to the minimum reduction in foliar Mg content under the exposure to low temperature regimes.

It can be concluded from the present study that low temperature exposure of seedlings of six papaya genotypes showed distinct changes in morphological and nutrient acquisition. Amongst the papaya genotypes screened, P-7-9 was found to be tolerant to low temperature stress as noted in cold tolerant genotype *Vasconcellea cundinamarcensis.*

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Table 2. Effect of different temperature regimes on leaf potassium (K %) and calcium (Ca %) contents of papaya genotypes.

Genotype	Leaf potassium (K %)						Leaf calcium (Ca %)					
Temp. regime	Control	Treatment	Accli.	Mean	% Change in treatment	% Change in Accli.	Control	Treatment	Accli.	Mean	% Change in treatment	% Change in Accli.
Pusa Nanha	4.59^{egdf}	5.54^{bac}	4.03^{gfh}	4.72^{bc}	-17.15	-27.26	1.62^{i}	2.05^{fgh}	1.59^{i}	1.75^{e}	26.54	-22.44
Red Lady	4.82^{edfc}	5.55^{bac}	4.90^{ebdfc}	5.09^{ba}	-13.15	-11.71	1.89^{igh}	2.39^{fe}	1.80^{ih}	2.03^{d}	26.46	-24.69
P-7-2	4.16^{egfh}	4.79^{edfc}	3.88^{gh}	4.28^{dc}	-13.15	-19.00	2.28^{fg}	2.69^{de}	2.14^{fgh}	2.37^{c}	17.98	-20.45
P-7-9	5.07^{bdac}	5.84^{a}	4.94^{ebdac}	5.28^{a}	-13.18	-15.41	3.13^{c}	3.55^{b}	3.01^{dc}	3.23^{b}	13.42	-15.21
P-7-14	3.44^{h}	4.55^{egdf}	3.37^{h}	3.79^{d}	-24.40	-25.93	2.38^{fe}	2.84^{dc}	2.30^{fe}	2.51^{c}	19.33	-19.01
V. cund.	5.08^{bdac}	5.78b^{a}	5.01^{ebdac}	5.29^{a}	-12.11	-13.32	3.74^{ba}	4.09^{a}	3.64^{b}	3.82^{a}	9.36	-11.00
Mean	4.53^{b}	5.34^{a}	4.36^{b}				2.51^{b}	2.94^{a}	2.41^{b}			
LSD ($P \leq 0.05$)												
Genotype (G)						0.36						0.16
Temperature (T)						0.51						0.23
G × T						0.89						0.40

Table 3. Effect of different temperature regimes on leaf magnesium (Mg %) and sodium (Na %) content of papaya genotypes.

Genotype	Leaf magnesium (Mg %)						Leaf sodium (Na %)					
Temp. regime	Control	Treatment	Accli.	Mean	% Change in treatment	% Change in Accli.	Control	Treatment	Accli.	Mean	% Change in Treatment	% Change in Accli.
Pusa Nanha	0.78^{becd}	0.52^{gf}	0.57^{gfe}	0.62^{cb}	-33.33	-26.92	0.43^{a}	0.25^{ba}	0.32^{ba}	0.33^{a}	-41.86	-25.58
Red Lady	0.81^{bcd}	0.61^{gfe}	0.57^{gfe}	0.66^{cb}	-24.69	-29.62	0.21^{ba}	0.16^{ba}	0.13^{b}	0.17^{a}	-23.80	-38.09
P-7-2	0.76^{becd}	0.51^{gf}	0.44^{g}	0.57^{c}	-32.89	-42.10	0.26^{ba}	0.19^{ba}	0.17^{ba}	0.21^{a}	-26.92	-34.61
P-7-9	1.16^{a}	0.93^{b}	0.81^{bcd}	0.97^{a}	-19.82	-30.17	0.28^{ba}	0.22^{ba}	0.19^{ba}	0.23^{a}	-21.42	-32.14
P-7-14	0.83^{bc}	0.66^{fecd}	0.65^{gfecd}	0.71^{b}	-20.48	-21.68	0.18^{a}	0.39^{ba}	0.33^{ba}	0.30^{a}	116.66	83.33
V. cund.	0.96^{ba}	0.79^{bcd}	0.80^{bcd}	0.85^{a}	-17.70	-16.66	0.24^{ba}	0.18^{ba}	0.15^{ba}	0.19^{a}	-25.00	-37.50
Mean	0.88^{a}	0.67^{b}	0.64^{b}				0.27^{a}	0.23^{a}	0.22^{a}			
LSD ($P \leq 0.05$)												
Genotype (G)						0.08						NS
Temperature (T)						0.21						NS
G × T						0.36						0.28

Table 4. Effect of different temperature regimes on root potassium (K %) and calcium (Ca %) content of papaya genotypes.

Genotype	Root potassium (K %)						Root calcium (Ca %)					
Temp. regime	Control	Treatment	Accli.	Mean	% Change in Treatment	% Change in Accli.	Control	Treatment	Accli.	Mean	% Change in Treatment	% Change in Accli.
Pusa Nanha	5.74^{bdec}	5.33^{fbdec}	4.99^{fdec}	5.35^{bc}	-7.14	-13.06	2.38^{de}	2.09^{e}	2.08^{e}	2.18^{d}	-12.18	-12.60
Red Lady	6.04^{ba}	5.19^{fbdec}	4.96^{fdec}	5.40^{bc}	-14.07	-17.88	2.64^{de}	2.38^{de}	2.25^{de}	2.42^{dc}	-9.84	-14.77
P-7-2	5.73^{bdec}	4.93^{fdec}	4.86^{fde}	5.17^{c}	-13.96	-15.18	2.74^{dc}	2.48^{de}	2.40^{de}	2.54^{c}	-9.48	-12.40
P-7-9	6.77^{a}	5.92^{bac}	6.04^{ba}	6.24^{a}	-12.56	-10.78	3.77^{ba}	3.57^{ba}	3.28^{bc}	3.54^{b}	-5.30	-12.99
P-7-14	5.35^{fbdec}	4.74^{fe}	4.69^{f}	4.93^{c}	-11.40	-12.33	2.77^{dc}	2.59^{de}	2.51^{de}	2.62^{c}	-6.49	-9.38
V. cund.	6.16^{ba}	5.77^{bdac}	5.80^{bdac}	5.91^{ba}	-6.33	-5.84	4.16^{a}	3.80^{ba}	3.79^{ba}	3.92^{a}	-8.65	-8.89
Mean	5.97^{a}	5.31^{b}	5.22^{b}				3.08^{a}	2.82^{b}	2.72^{b}			
LSD ($P \leq 0.05$)												
Genotype (G)						0.41						0.24
Temperature (T)						0.28						0.34
G × T						1.01						0.60

Table 5. Effect of different temperature regimes on root magnesium (Mg %) and sodium (Na %) content of papaya genotypes.

Genotype	Root magnesium (Mg %)						Root sodium (Na %)					
Temp. regime	Control	Treatment	Accli.	Mean	% Change in Treatment	% Change in Accli.	Control	Treatment	Accli.	Mean	% Change in Treatment	% Change in Accli.
Pusa Nanha	0.80^{ebdac}	0.63^{edgcf}	0.56^{edgf}	0.66^{b}	-21.25	-30.00	1.54^{ebdcf}	1.18^{ehgf}	1.06^{hgf}	1.26^{b}	-23.37	-31.16
Red Lady	0.68^{edgcf}	0.52^{gf}	0.49^{g}	0.56^{b}	-23.52	-27.94	1.57^{ebdacf}	1.33^{ehdgf}	1.26^{ehdgf}	1.39^{b}	-15.28	-19.74
P-7-2	0.75^{ebdgcf}	0.59^{edgcf}	0.53^{egf}	0.62^{b}	-21.33	-29.33	1.65^{ebdac}	1.43^{edcf}	1.40^{edgcf}	1.49^{b}	-13.33	-15.15
P-7-9	1.06^{a}	0.83^{bdac}	0.80^{ebdac}	0.90^{a}	-21.69	-24.52	2.07^{a}	1.74^{bdac}	1.76^{bdac}	1.86^{a}	-15.94	-14.97
P-7-14	0.73^{ebdgcf}	0.59^{edgcf}	0.58^{edgcf}	0.63^{b}	-19.17	-20.54	1.07^{hgf}	0.90^{hg}	0.87^{h}	0.95^{c}	-15.88	-18.69
V. cund.	1.01^{ba}	0.81^{bdac}	0.85^{bac}	0.89^{a}	-19.80	-15.84	2.03^{ba}	1.75^{bdac}	1.85^{bac}	1.88^{a}	-13.79	-8.86
Mean	0.84^{a}	0.66^{b}	0.64^{b}				1.66^{a}	1.39^{b}	1.37^{b}			
LSD ($P \leq 0.05$)												
Genotype (G)						0.11						0.21
Temperature (T)						0.16						0.92
G × T						0.28						0.51

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