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Influence of Scion/Rootstock reciprocal effects on post-harvest and metabolomics regulation in stored peaches



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ABSTRACT

Peach is an important stone fruit crop cultivated at commercial scale in Pakistan. While, appropriate selection of rootstock has significant impact on the quality of peach fruit. Therefore, in the current study the influence of three rootstocks viz. 'GF-677', 'Peshawar Local' and 'Swat Local' were evaluated on the quality of 'Flordaking' peaches following cold storage during two consecutive years. The fruit from these rootstocks were kept at 0 °C for five weeks were studied for various fruit physical (weight loss, colour, firmness) and biochemical (pH, soluble solids content (SSC), titrateable acidity (TA), SSC:TA ratio, fruit juice pH, sugars (total, reducing and non-reducing sugars), ascorbic acid (vitamin C) and free radicals scavenging activities) were evaluated. During both years, fruit harvested from trees grafted on 'GF-677' exhibited reduced fruit weight loss, changes in Chroma (C*) and highest fruit firmness, Lightness (L*), ascorbic acid contents and radical scavenging activities as compared to fruit harvested from tree grafted on other rootstocks. In conclusion, the post-harvest quality of scion 'Flordaking' peach fruit was significantly influenced and best quality can be obtained when it is grafted on 'GF-677' rootstock.

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1. Introduction

Rootstock as mainstay for cultivar tree is not only responsible for scion vigor but increases nutrient uptake, yield efficiency, fruit quality and post-harvest life. Quality parameters like sugars content, firmness, total antioxidants and taste are of greater importance for the consumer acceptance of this fruit. The rootstocks influence on tree vigor, mortality rate yield or fruit weight is well established for the rootstocks which are generally used in the peach production (Forcada et al., 2014). These quality parameters

cannot be improved after harvest therefore, proper rootstock selection along with other pre-harvest measures can help to obtain premium quality peach fruit because rootstock and scion interaction manipulates water relations, gaseous exchange, minerals uptake, plant size, blossoming, fruit set time, fruit quality and yield efficiency (Schmitt et al. 1989; Nielsen and Kappel, 1996; Goncalves et al. 2003). After obtaining substantial yield, proper post-harvest storage of peach fruit is necessary to increase the storage life for extended/distant market availability. The findings of other researchers (Tepe and Koyuncu, 2020) also support the contention regarding great influence of rootstocks on scion cultivar for storage and quality parameters. Reig et al. (2020) also reported that appropriate rootstock selection is very important for establishment of an orchard.

In Pakistan, Peach (*Prunus persica*) is second most important stone fruit, after plums. Peaches are highly perishable and need to reduce deterioration and delay softening to ensure the supply of valued fruits to consumers. Additionally, the maintenance of

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highest possible standards of fruit quality is essential for commercial expansion of peach fruit production (Giorgi et al. 2005).

The economic life of peach orchards is 7 to 10 years (Anonymous, 2013) and the most important factors responsible for this decline have been identified as the use of inappropriate rootstock and calcium induced iron chlorosis. A major problem with wild peach rootstock is its genetic variability. Grierson (2002) has highlighted the importance of pre-harvest factors related to post-harvest disorders. Among other pre-harvest factors, one of the most important pre-harvest factors that may affect post-harvest behavior is rootstock. In addition to the effects on tree vigor, pest resistance and yield, rootstocks have significant effects on fruit quality (Castle et al. 1993). Though, little information is available on the effects of rootstock on post-harvest quality of peach fruit during storage and as it is reported that fruit quality has been found to be related to rootstock and cultivar performance. The current study was designed to assess the suitability of three different rootstocks widely available in Pakistan in terms of production and post-harvest storage capability of peach fruit cv. 'Flordaking' grown in the Potohar area.

2. Materials AND METHODS

Three rootstocks GF-677, Peshawar Local and Swat Local were evaluated in this study at Research Farm of Horticulture Research Institute, National Agriculture Research Center, Islamabad, (latitude 33° 37'S; longitude 73° 06'E) Pakistan. Total 27 peach (*Prunus persica* L. Batsch cv. 'Flordaking') trees; five years of age were selected for this study. The cv. 'Flordaking' was grafted on different rootstocks (GF-677, Peshawar Local and Swat Local) planted in East West direction in rectangular layout system having plant to plant (6 m × 6 m) and row to row (7 m × 7 m) distance. All the selected trees were of uniform size, pests and diseases free and subjected to similar cultural practices. Fruit were thinned at full bloom stage, leaving each fruit approximately 14 cm apart.

For post-harvest evaluation, laboratory and cold storage facility of Department of Horticulture, PMAS-Arid Agriculture University Rawalpindi was utilized. Peach fruits were harvested at commercially mature stage, decided on the basis of firmness, total soluble solids and days from full bloom. From each treatment, 243 fruits free from any disease, disorder, pollutants and of almost uniform in size and color were selected for the experiment. After this fruits were immediately transported to the post-harvest laboratory. Then the fruits were washed with distilled water and spread out on the paper to dry at room temperature (21 °C). After drying, fruits were divided into two main groups. Group one was consisted of 216 fruits while group two was consisted of 27 fruits. Fruit of the each treatment were divided in same manner. Thus, in total fruits for the entire treatments (GF-677, Peshawar Local and Swat Local) were 729. After recording data of different parameters at week 0, fruits of group one of each treatment were separately packed in corrugated carton boxes in three replicates (each replicate consisted of 12 fruits) touching each other. All the carton boxes were marked treatment wise. Then these fruits were stored in a cold store at 0 ± 0.3 °C, 90 ± 4 % relative humidity for five weeks. Twelve fruits were randomly sampled from each replication of every treatment at each sampling week (0 to 5th week) during the entire storage time. These peach fruits were used to evaluate parameters like fruit skin color, weight losses, fruit firmness, SSC, pH, titratable acidity, SSC:TA ratio, sugars (reducing, total and non-reducing), and ascorbic acid content of fruit were done by separating sample portions then immediately used for analysis and data were noted to determine the effect of different rootstocks on fruit quality of peach cv. "Flordaking" during five week storage time. Apart from this a composite sample (5 g) of randomly selected five fruits were

wrapped in aluminum foil then dipped in liquid nitrogen. The same were stored in Ultra Low at –70 °C for further analysis of radical scavenging activity.

Fruits of group two of each treatment were placed in separate carton boxes and kept them in the same cold store after marking the boxes treatment wise. Fruits of this group were used for the determination of weight loss and skin color. Each replicate having nine fruits were numbered (1–9) and kept intact throughout the experiment with other groups in the same cold store.

2.1. Fruit physical properties

2.1.1. Fruit weight loss

Fresh weight of peach fruit was recorded soon after harvest. Separately kept fruits of all three rootstocks were used for evaluation of percent weight loss until end of the trial. Fruit weight loss (%) was recorded at each sampling week and computed by the following formula:

$$\text{Weight loss (\%)} = [(A - B) / A] \times 100$$

Whereas;

A = First day weight

B = Subsequent weight taken

2.1.2. Fruit firmness

Peach fruit flesh firmness was recorded using a penetrometer (Wagner Fruit Firmness Tester model FT-327). After removing the epidermis at two equatorial sites an 8 mm plunger tip was used to measure the fruit firmness. Data was recorded on day 0 and subsequently at weekly intervals till the end of experiment. Readings were expressed in newton (N).

2.1.3. Fruit skin color

In order to assess how the rootstocks and cold storage period effect changes in peach fruit skin/peel color. In this regard data was recorded using a chromameter (CR-400 Konica Minolta Sensing, Inc., Japan). Separately kept fruits of three rootstocks were used for the measurement of skin color. Fruit skin color parameters including L^* (higher positive values indicate more lightness while negative readings indicate darkness), a^* (greenish is indicated by negative readings while redness is indicated by positive values) and b^* (negative readings are indicative of blueness and higher positive readings are indicative of yellowness) were measured during storage period at weekly intervals from two opposite sides of each fruit. C^* (saturation or intensity of color) and hue angle (h°) were computed as mentioned by Mcguire (1992).

2.2. Fruit chemical properties

2.2.1. Soluble solids content

The soluble solids content was determined with a refractometer (Atago-Palette PR 101; Atago Co., Itabashi-Ku, Tokyo, Japan). Wedge shaped pieces and homogeneous in size from five peach fruit were selected randomly from all treatments per replication. A composite sample was made by homogenizing with high speed juicer machine. Soluble solids content data was calculated from the homogenized juice.

2.2.2. Titratable acidity

Juice was extracted by filtration of 10 g peach fruit pulp blended with 40 mL distilled water from each treatment. Titration method was used to ascertain the titratable acidity in peach fruit. The obtained peach fruit juice was titrated against 0.1 NaOH (sodium hydroxide). The titration of juice was done till pH of the juice stabilized at 8.2 then reading was noted. The data was recorded from

all the three replications of each treatment. The results were expressed as percent mallic acid with the help of following formula:

$$\% \text{ TA} = (\text{mL NaOH used}) \times (\text{Normality of NaOH}) \times (\text{Equi. weight of mallic acid}) / (\text{Weight of sample}) \times (\text{Volume of aliquot taken})$$

2.2.3. Soluble solids content and titratable acidity ratio (SSC:TA)

The calculations for Soluble Solids Content and Titratable Acidity Ratio (SSC:TA) were done by dividing soluble solids content by the corresponding titratable acidity value.

2.2.4. pH of fruit

Hydrogen-ion concentration of peach fruits was determined with the help of a pH meter from the homogenized juice as prepared earlier.

2.2.5. Sugars

Fruits used for firmness and SSC were used for juice extraction for the analysis of sugars.

2.2.6. Reducing sugars

Peach fruit juice was used for the determination of reducing sugars according to the method described by Horwitz (1960). Sample juice taken in 250 mL volumetric flask was 10 mL then 100 mL H₂O (distilled) was added followed by adding lead acetate solution (25 mL) and potassium oxalate (10 mL). Then volume was made up with distilled water and filtered. Thereafter prepared sample aliquot was poured in the burette. After taking Fehling solution of 100 mL and then was boiled in a conical flask. Then the sample aliquot was allowed to run drop wise from burette to conical flask which was containing the boiling Fehling solution. During the titration of Fehling solution boiling was continued. When brick red color appeared then in conical flask 2–3 drops of methylene blue were added and kept titrating till brick red color appearance was observed again. Used sample aliquot readings were recorded from burette. Percentage of reducing sugars was computed with the help of following formula:

$$\text{Reducing sugars (\%)} = 6.25 (X / Y)$$

Whereas;

X = mL of standard sugar solution used against 10 mL Fehling solution.

Y = mL of sample aliquot used against 10 mL Fehling solution.

2.2.7. Total sugars

Peach fruit juice was used for the determination of total sugars according to Horwitz (1960). An aliquot of 25 mL was poured in a flask of 100 mL from the previously prepared aliquot for reducing sugars. Then 20 mL H₂O (distilled) and 5 mL concentrated hydrochloric acid was poured in the flask for conversion of non-reducing sugars into reducing sugars. The solution was kept for 24 hrs. (at room temperature) for complete hydrolysis. Next day the same was neutralized by adding 1 N NaOH solution and phenolphthalein was used as an indicator. Then volume was made up with 100 mL H₂O (distilled). For total sugars estimation, rest of the procedure was followed as per procedure of reducing sugars. Total sugars were computed by using following formula:

$$\text{Total sugars (\%)} = 25 \times (X / Y)$$

Whereas;

X = mL of standard sugar solution used against 10 mL Fehling solution.

Y = mL of sample aliquot used against 10 mL Fehling solution.

2.2.8. Non-reducing sugars

Calculation of non-reducing sugars was done by the following formula:

$$\text{Non-reducing sugars (\%)} = \text{Total sugars (\%)} - [\text{Reducing sugars (\%)} \times 0.95]$$

2.3. Fruit antioxidant properties

2.3.1. Ascorbic acid content

Peach fruit ascorbic acid content was evaluated according to Hans (1992). Peach pulp (5 g) was randomly collected from ten fruits, were blended with (5 mL) 1.0% Hydrochloric acid (w/v) then centrifuged at 10,000×g for 10 min. Taken supernatant was ascorbic acid extract. Then the absorbance (at 243 nm) of the same was recorded by using a spectrophotometer. Prior to recording of readings spectrophotometer was calibrated by preparing standard solutions of ascorbic acid in same manner. The content of vitamin C (ascorbic acid) was computed as mg/100 g edible portion.

2.3.2. Radical scavenging activity of DPPH

The radical scavenging activity was assayed by following the method of Brand-Williams et al. (1995). For the purpose free radical 2, 2-diphenyl-2-picrylhydrazyl hydrate (DPPH) prepared in a methanol (MeOH) solution was used. Five grams of ground frozen tissues of peach fruit were blended and extracted in 10 mL methanol for 2 hrs. Then the same extract was used for assay of radical scavenging activity against stable DPPH prepared in methanol. Already prepared extract (100 μL), 3.9 mL of 6×10^{-5} mol/L of DPPH solution was kept for incubation for 30 min. Then absorbance (A) (at 515 nm) was noted at 0 and 30 min. DPPH is reduced when it reacts with an antioxidant compound that changes deep violet color to light yellow. Radical scavenging activity was computed as percent inhibition of DPPH with the help of following formula:

$$\text{Inhibition (\%)} = [(A_B - A_A) / A_B] \times 100$$

Whereas:

A_B = absorption of blank sample (t = 0 min.)

A_A = absorbance of tested extract solution (t = 30 min.)

2.4. Statistical analysis

Randomized complete block design (RCBD) was used as statistical design with two factor factorial arrangement having three replicates. Data were statistically analyzed by using analysis of variances (ANOVA) techniques for the validity of analysis and the means were separated using Duncan's multiple range test (Chase and Bown, 1997). Statistical analysis was done with the help of MSTAT-C software (Michigan State University, 1991). For least significant difference, a probability (p) of <0.05 levels was considered.

3. Results

3.1. Fruit physical properties

3.1.1. Fruit weight loss

Results pertaining to influence of rootstocks on percent weight loss of peach fruit cv. 'Flordaking' was recorded significantly different among the treatments for the 1st year (Fig. 1). Fruit of trees grafted on GF-677 rootstock was observed with least weight loss (11.47%) followed by Peshawar Local (PL) rootstock. Maximum weight loss (14.79%) was found in fruits of Swat Local (SL) rootstock. The interaction between treatments and storage period was statistically significant. A continuous decrease for weight loss was noted among all the treatment during storage period. Highest

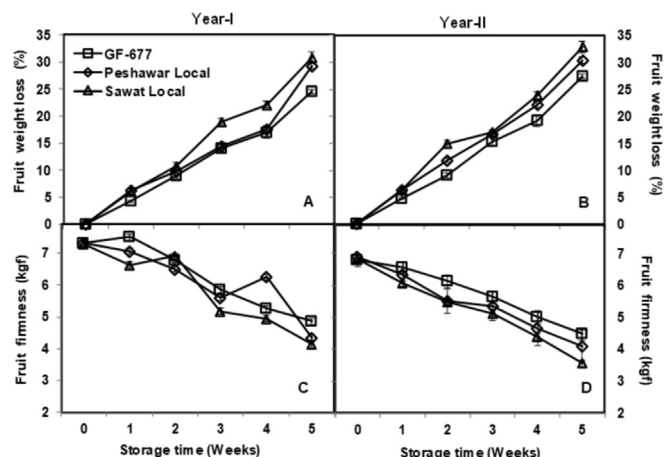


Fig. 1. Effect of rootstocks on the changes in fruit weight loss (A and B) and fruit firmness (C and D) of 'Flordaking' fruit during cold storage. Vertical bars represent ± SE of means. n = 30 (10 fruit × 3 replicates).

fruit weight losses were recorded during fourth week of storage. The 2nd year data show minimum fruit weight loss (12.63%) in fruit of trees grafted on GF-677 rootstock during five week storage. Whereas maximum loss in fruit weight (15.98%) was observed in fruits of trees grafted on SL rootstock followed by PL rootstock. Means for weekly intervals reveal a decreasing trend for weight loss in all treatments during the entire storage period.

3.1.2. Fruit firmness (N)

Analysis of variance for fruit firmness depicts that fruit of trees grafted on GF-677 rootstock, remained firmer (61.52 N) than the rest of treatments for the 1st year (Fig. 1). Least fruit firmness (56.37 N) was recorded in fruit of trees grafted on SL rootstock during five week storage period. Rootstocks GF-677 and PL showed no significant difference ($p < 0.05$) among them for firmness. The interaction between rootstocks and storage period was significantly different. Mean values for week wise data showed a steady decrease in fruit firmness which reached to a minimum level during week five. Maximum fruit firmness (56.56 N) was observed in fruit of trees grafted on GF-677 rootstock followed by PL rootstock for the 2nd year. On other hand minimum firmness (51.45 N) was found in fruit of trees grafted on SL rootstock during storage period. Means for storage period indicate significant increase in fruit softness with progress in storage period and firmness of all treatments reached to its lowest level at the end of storage period.

3.1.3. Fruit skin lightness (L^*) values

The treatments means for fruit skin lightness (L^*) indicate highly significant differences among the treatments for the 1st year (Fig. 2). Fruits of trees grafted on GF-677 rootstock showed increased L^* values (33.18) with significance as compared with SL rootstock having values of L^* (25.12) during five week storage period. The interaction between treatments and storage period was significantly different. All three rootstocks were observed with highly significant difference for fruit skin L^* of peach cv. 'Flordaking' for the 2nd year. Highest values for L^* (33.54) were recorded in the skin of fruit of trees grafted on GF-677 rootstock followed by PL rootstock during storage period. Whereas lowest values for L^* (29.83) were noted in fruits of trees grafted on SL rootstock. The mean values during five week storage period for both years showed decreasing trend in fruit skin L^* .

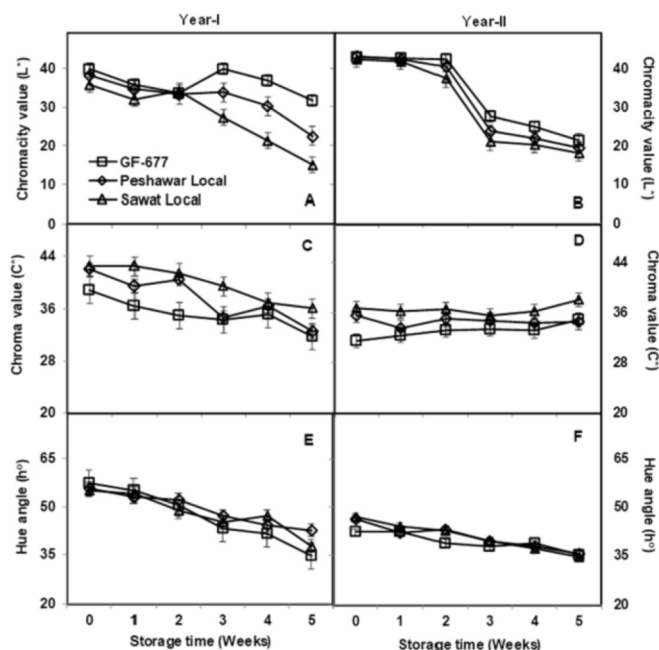


Fig. 2. Effect of rootstocks on the changes in chromacity value L^* (A and B), chroma value (C and D) and hue angle (E and F) of 'Flordaking' fruit during cold storage. Vertical bars represent ± SE of means. n = 30 (10 fruit × 3 replicates).

3.1.4. Fruit skin color chroma (C^*) values

Treatment means indicate highly significant effects on the chroma (C^*) in fruit skin of peach cv. 'Flordaking' for the 1st year (Fig. 2). Least changes in C^* (35.20) were found in fruit skin of trees grafted on GF-677 rootstock followed by PL rootstock during five week storage period. In contrast, maximum changes in skin color for C^* (39.78) was registered by fruit of trees grafted on SL rootstock. Weekly means taken from values of data showed that there was consistent decrease in chroma of peach fruit skin during storage. GF-677 rootstock significantly lowered down (33.03) C^* in the skin of peach fruit 'Flordaking' followed by PL rootstock for the 2nd year. Whereas, highest C^* values (35.51) were found in fruit of trees grafted on SL rootstock during five week storage period. Means for storage intervals reveal a fluttered trend during the entire storage period.

3.1.5. Fruit skin color hue angle (h°) values

Results pertaining to hue angle (h°) showed that fruit of trees grafted on GF-677 rootstock had decreased h° (47.00) as compared to rest of treatments for the 1st year (Fig. 2). While, highest h° (49.15) was observed in fruit of trees grafted on PL rootstock followed by SL rootstock during storage period. The interaction between treatments and storage period was found statistically significant. Means for storage period show that h° in general, decreased consistently during the entire storage period. Maximum h° (40.85) was recorded in fruits of trees grafted on SL rootstock for the 2nd year. Whereas, least changes in h° (39.25) was noted in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during five week storage period. Mean values for weekly intervals indicate that h° decreased consistently throughout storage period of the experiment.

3.2. Fruit chemical properties

3.2.1. Soluble solids content

Soluble solids content (SSC) (% °Brix) differed significantly among the treatments for the 1st year (Fig. 3). Decreased levels

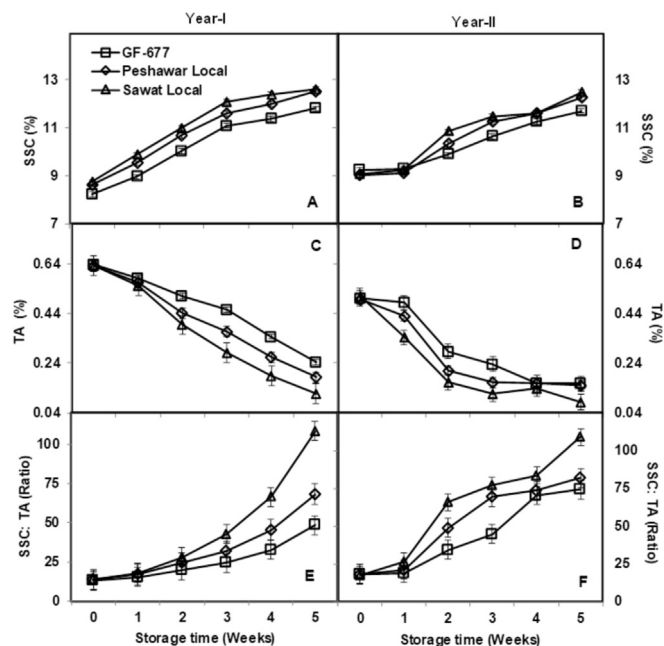


Fig. 3. Effect of rootstocks on the changes in SSC (A and B), TA (C and D) and SSC:TA ratio (E and F) of 'Flordaking' fruit during cold storage. Vertical bars represent ± SE of means. n = 3 replicates.

of SSC (10.23 % °Brix) was noted in fruits of trees grafted on GF-677 rootstock followed by PL rootstock while, increased SSC levels (11.10 % °Brix) were recorded in fruit of trees grafted on SL rootstock. The interaction between rootstocks and storage period was noted with significance during both years. Results of weekly intervals revealed an increasing trend in SSC of peach fruits during the entire storage period. The obtained results showed that minimum levels of SSC (10.31 % °Brix) was recorded in fruit of trees grafted on GF-677 rootstock during five week storage period for the 2nd year. Highest soluble solids content (10.76 % °Brix) was observed in fruit of trees grafted on SL rootstock followed by PL rootstock. However, these both rootstocks revealed non-significant difference ($p < 0.05$) between them. Means regarding storage period indicated that SSC generally, increased with passage of storage period. There was stability in SS content at the beginning of storage period then the same increased during second week thereafter it remained constant during third and fourth week and for a second time it increased during the fifth week of experiment.

3.2.2. Titratable acidity

Treatment means of rootstocks influence on titratable acidity (TA) of peach fruit cv. 'Flordaking' reveal significant differences among the treatments for the 1st year (Fig. 3). Least losses in TA (0.46) were recorded in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during five week storage period. Whereas, fruit of trees grafted on SL rootstock showed greater loss in TA (0.36) compared with GF-677 rootstock. The interaction between rootstocks and storage period was recorded with significance ($p < 0.05$) for both years. The graphical presentation for TA in peach fruit show linear decrease during storage period. Data pertaining to effect of rootstocks on TA of peach fruit indicate that minimum TA loss (0.30) was found in fruit of trees grafted on GF-677 followed by PL rootstock during the 2nd year. Minimum values of TA (0.22) was observed in fruit of trees grafted on SL compared with GF-677 during storage period. Data recorded at weekly intervals showed that TA decreased in peach fruit as the storage period progressed.

3.2.3. Soluble solids content and titratable acidity ratio (SSC:TA)

Concerning results for SSC:TA ratio reveal that fruit of trees grafted on GF-677 rootstock had lower SSC:TA ratio (25.64) followed by PL rootstock during storage period for the 1st and 2nd year (Fig. 3). Maximum SSC:TA ratio was found in fruit of trees grafted on SL rootstock. The interaction between treatments and weekly intervals was significant for both years. SSC:TA ratio showed steady increase. For the 1st year, all the rootstocks were statistically different from each other. Minimum SSC:TA ratio (43.80) was recorded in fruit of trees grafted on GF-677 rootstock compared with SL rootstock during storage period. Highest SSC:TA ratio (73.73) was noted in fruit of trees grafted on SL rootstock followed by PL rootstock. Means for weekly intervals show that SSC:TA ratio had increasing trend during storage for both years.

3.2.4. Total sugars (%)

Fruit of trees grafted on GF-677 had minimum content of total sugars (5.85%) for the 1st year (Fig. 4). By contrast, maximum total sugars content (6.14%) was noted in fruit of trees grafted on SL rootstock followed by PL rootstock. The interaction between treatments and storage period was recorded statistically significant for both years. Means for storage period indicate increasing trend for total sugars content in peach fruit during storage period (Fig. 4). Lower content of total sugars was found in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during the 2nd year. However, these rootstocks showed no significant difference ($p < 0.05$) between them. Results for weekly intervals showed increased total sugars content in general, in all treatments as storage period progressed (Fig. 4).

3.2.5. Reducing sugars (%)

The reducing sugars content of peach fruit cv. 'Flordaking' was significantly affected by different rootstocks for the 1st year (Fig. 4). Lowest reducing sugars content (2.10%) was noted in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during five week storage period. Whereas, fruit of trees grafted on SL rootstock showed highest content of reducing sugars (2.46%). Means for weekly intervals reveal that reducing sugars content increased

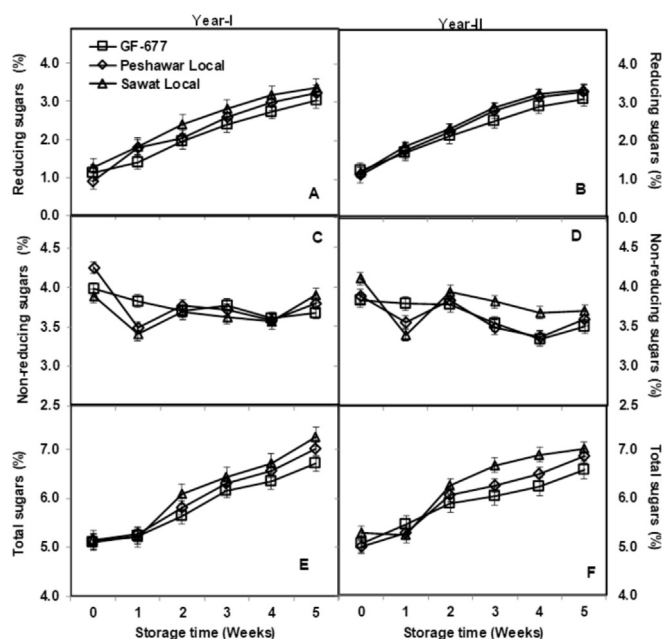


Fig. 4. Effect of rootstocks on the changes in reducing (A and B), non-reducing (C and D) and total sugar (E and F) contents of 'Flordaking' fruit during cold storage. Vertical bars represent ± SE of means. n = 3 replicates.

in all treatments during the whole storage period (Fig. 4). Results pertaining to the effects of different rootstocks on reducing sugars show highest reducing sugars content in fruit of trees grafted on SL rootstock followed by PL rootstock during the 2nd year. However, non-significant difference ($p < 0.05$) has been observed between these two rootstocks. While, least changes for reducing sugars content was found in fruit of trees grafted on GF-677 rootstock compared with SL rootstock. The interaction between treatments and weekly intervals was found significant for both years. Mean values for weekly intervals indicate that reducing sugars content increased in peach fruits of all treatments during the entire storage period (Fig. 4).

3.2.6. Non reducing sugars

Although there were no significant differences among the treatments for non-reducing sugars however, peach fruit cv. 'Flordaking' grafted on PL rootstock had higher non reducing sugars content followed by GF-677 rootstock for the 1st year. Whereas least content of non-reducing sugars was observed in fruit of trees grafted on SL rootstock. Means for storage period reveal non reducing sugars content level remained inconsistent during the entire storage period (Fig. 4). No significant differences for non-reducing sugars were recorded among the treatments during five week storage period for the 2nd year. However, fruit of trees grafted on PL rootstock registered lowest content of non-reducing sugars compared with GF-677 and SL rootstocks. The interaction between rootstocks and weekly intervals also remained non-significant indicating no effects of storage period on non-reducing sugars (Fig. 4).

Reducing sugars content was significantly affected by rootstocks in the fruit of peach cv. 'Flordaking' during both years of storage period experiments. Fruits of trees on GF-677 had significantly lower contents of reducing sugars than that of SL rootstock. Decreased levels of reducing sugars may be due to slower conversion of starch into sugars; less conversion of polysaccharides to monosaccharaides. The interaction means were recorded with significant changes and show increase in reducing sugars content in all treatments as the storage period advanced. Non reducing sugars were noted non-significant among the treatments for both years. However, fruits of trees on PL and SL rootstocks were found higher in non-reducing sugars content during the 1st and 2nd years respectively. This may be because of higher concentration of sucrose and that is sign of relatively lower quality of the fruit than that of lower sucrose concentration. The interaction between rootstocks and weekly intervals show non reducing sugars content fluctured trend during the 1st year and no significant effect during the 2nd year of the experiment.

3.2.7. Fruit pH

Average treatment means of peach fruit cv. 'Flordaking' reveal that fruit of trees grafted on GF-677 rootstock had low pH level (4.34) followed by PL rootstock during storage period for the 1st year (Fig. 5). However, rootstocks did not show statistical ($p < 0.05$) difference for pH. Results for weekly intervals indicate surging trend in pH of peach fruit from the start of storage period and this trend remained increasing to the fifth week of experiment. Treatment means regarding fruit pH parameter presented in (Fig. 5) indicate minimum levels of pH (4.53) in fruit of trees grafted on GF-677 for the 2nd year. Maximum level of fruit pH was found in fruit of trees grafted on SL rootstock followed by PL rootstock during five week storage period. The interaction between rootstocks and storage period was significant for both years. The means values reveal a continual increase in fruit pH during the entire storage period.

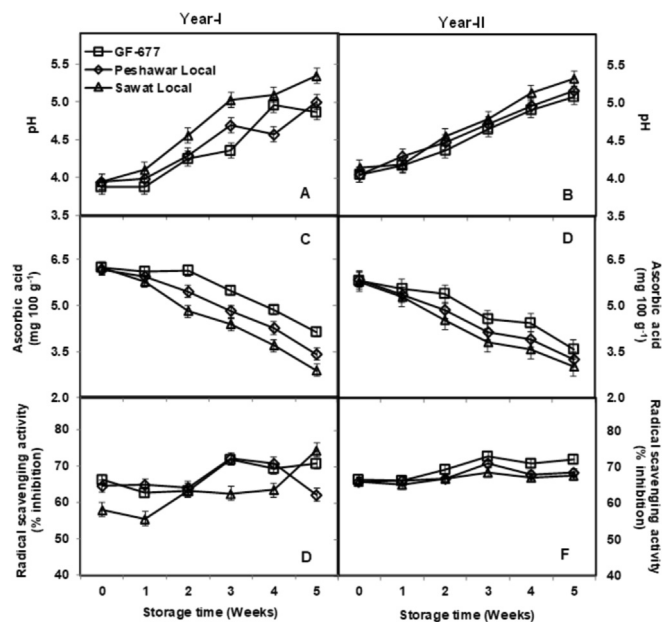


Fig. 5. Effect of rootstocks on the changes in pH (A and B), ascorbic acid (C and D) and radical scavenging activity (E and F) of 'Flordaking' fruit during cold storage. Vertical bars represent \pm SE of means. $n = 3$ replicates.

3.3. Fruit antioxidant properties

3.3.1. Ascorbic acid

Influence of rootstocks on ascorbic acid (AA) of peach fruit cv. 'Flordaking' was recorded with highly significant differences among the treatments for the 1st year (Fig. 5). Maximum ascorbic acid content (5.47 mg/100 g FW) was noted in fruit of trees grafted on GF-677 rootstock. Minimum AA (4.62 mg/100 g FW) was observed in fruit of trees grafted on SL rootstock followed by PL rootstock. The interaction between treatments and storage period was significant for both years. The AA content of peach fruit in general, decreased as the storage period advanced (Fig. 5). Highest AA content (4.87 mg/100 g FW) has been observed in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during storage period for the 2nd year. Whereas, lowest content of AA (4.32 mg/100 g FW) was found in peach fruit of trees grafted on SL rootstock. Mean values for weekly intervals reveal a linear decrease for AA content in all treatments during the entire storage period (Fig. 5).

3.3.2. Free radical scavenging activity

Free radical scavenging activity (FRSA) of DPPH (67.24) was significantly high in peach fruit cv. 'Flordaking' of trees grafted on GF-677 rootstock followed by PL rootstock compared with SL rootstock for the 1st year (Fig. 5) while, minimum FRSA (62.83) was recorded in fruit of trees grafted on SL rootstock. The interaction between treatments and weekly intervals has been found significant ($p < 0.05$). However, means for weekly intervals show fluctuation in FRSA during first two weeks thereafter it relatively remained consistent till the end of experiment. Treatments means for FRSA show significant differences among the treatments for the 2nd year. Highest RSA (69.64) was recorded in fruit of trees grafted on GF-677 rootstock followed by PL rootstock during storage period. Least FRSA (66.81) was noted in fruit of trees grafted on SL rootstock. Weekly intervals means indicate that FRSA increased during first three weeks then it decreased during last two weeks of storage period (Fig. 5).

4. Discussion

Water losses through skin evapotranspiration are the main cause of fruit weight loss and to some extent respiration also contribute in water loss. It is an established aspect that stored fruit lose weight as storage period prolongs. Low temperature storage may enhance storage life but cannot completely inhibit water losses from fruit (Ding et al. 1998). The fruit of peach cv. 'Flordaking' grafted on GF-677 rootstock showed significantly lowest percent water loss compared with SL and PL rootstocks for both years. The interaction between rootstocks and storage period was significant which also indicate consistent decrease in weight losses in all treatments during both years. The most frequent effect of any rootstock on fruit quality is differences in fruit firmness, organic acid levels and contents of sugars (Westwood et al. 1973). Fruit firmness is a major consideration of consumers (HoeHN et al. 2003; Lu, 2004). Well systematic agronomical attributes (including selection of right rootstock and scion) lead to high flesh firmness which guarantees prolonged storage life of peaches with intact quality. The results for peach fruit firmness showed significant influence of rootstocks peach cv. UFSun (Shahkoomahally et al. 2020). Sams (1999) stated that fruit size was negatively correlated to firmness, because of increased cell wall material in small sized fruits. Peach fruit due to its' high perishable nature, subjected to quick softening after harvest. Fruit softening can be slowed down by lowering the metabolism which in return can inhibit deterioration of fruit tissues (Gonzalez et al. 2004).

This study revealed that with regard to fruit firmness, trees of GF-677 rootstock had significantly higher fruit firmness when compared with PL and SL rootstocks during five week storage period for both the years. This can be attributed to inhibition of insoluble protopectin into water-soluble pectin by fruits of trees grafted on GF-677 which results in delayed softening of fruits. Small fruits have more percentage of cell wall material therefore; have more firmness than larger fruits. Our findings are backed up by Tsipouridis and Thomidis (2005) who reported that peach cultivar "May Crest" on GF-677 rootstock had highest fruit firmness among other thirteen rootstocks. Cherry fruit firmness has significantly been influenced by scion-rootstock combination (Cantin et al. 2010). The interaction of rootstocks and storage period shows consistent increase in peach fruit softening but this trend was relatively slower in fruits of GF-677 rootstocks.

Fruit color analysis is commonly an important consideration while assessing the efficacy of a variety for postharvest performance (McGuire, 1992). High luminosity (L^*) values depict freshness of the fruit. High luminosity values of fruit skin have great importance which can be correlated with the total pigments present in the fruit skin (Silva et al. 2005). In current experiment, rootstocks showed highly significant effect on L^* in the skin of peach fruit cv. 'Flordaking' during storage period for both years. Fruits of trees on GF-677 rootstock had significantly higher L^* values followed by PL rootstock. While, lowest values i.e., darkest peel color was noted in fruit of trees on SL rootstock. The reason for lower L^* in the skin of peach fruit may be referred to excessive moisture loss from fruit skin. Our outcomes are in line with the findings of Delwiche and Baumgardner (1985) who described moisture loss from the fruit surface resulted in decrease of L^* values. GF-677 rootstock was found to induce lower L^* (less intense color) than 'Adarcias' or 'Adafuel' rootstocks having peach fruit cv. 'Flavortop' (Albas et al. 2004). The L^* values of cherry fruit skin was also significantly influenced by different rootstocks (Cantin et al. 2010). Results for treatments and storage period interaction indicate a declining trend in all treatments till end of the experiment for both years.

Fruit color intensity or saturation can be assessed by chroma (C^*) values. This study indicates that GF-677 rootstock significantly lowered the changes in C^* in the skin of peach fruit cv. 'Flordaking'

compared with other rootstocks during five week storage period for both years. Fruits of trees on SL rootstock had maximum C^* values and exhibited more intense colored fruits during storage period. Increased color (C^*) can be attributed to increased degradation of chlorophyll and biosynthesis of carotenoids. The interaction between treatments and weekly intervals was significant during first year and showed decreasing trend while, second year storage period showed fluctuated trend. The corresponding a^* and b^* readings were employed to compute the hue angle (h°) in the fruit skin (McGuire, 1992). Hue angle was recorded higher in fruit of trees on PL rootstock as compared with other rootstocks. In contrast, GF-677 rootstock showed least h° values during storage period for the 1st year. SL rootstock showed intermediate response for h° during storage period. No significant effect of rootstocks was observed for h° during second year of experiment. The interaction between treatments and storage period was significant and had declining tendency irrespective of treatments.

Soluble solids content is one of the main quality attributes which contributes towards fruit acceptability. It is well known that SS content of fruit increases during storage due to insoluble starch conversion into soluble solids. In other words, SS content changes are directly correlated with hydrolytic changes in the starch concentration in harvested fruits and these changes cause starch conversion into sugars, which are vital index for ripening process (Kays, 1991). Soluble solid content increased in 'Flordaking' peaches when compared with the day of harvest while 'Dixiland' peaches showed opposite behavior during 28 days of cold storage at 0 °C (Murray and Valentini, 1998). Jimenez et al. (2004) have described in their report that cherry fruits SS content was influenced with significance by different rootstocks. Peach fruit quality is a multifaceted and reckons with cultural conditions (Crisosto et al. 1997; DeJong et al. 2002). The study under discussion indicates increasing SS content in all treatments with increase in storage period. However, fruit of trees on GF-677 rootstock have significantly lowered the SS content as compared with fruits of rest of rootstocks during storage period for both years. The higher level of SS content may be correlated to hydrolysis of polysaccharides which leads to higher concentration of SS content in juice due to increased fruit weight loss. GF-677 rootstock reduced SS content levels in fruits of different peach genotypes (Drogoudi and Tsipouridis, 2007). Higher concentration of SS content in SL rootstock may be due to low yield (less number of fruit on a tree) than higher yielding rootstocks. Cantin et al. (2010) have also ascribed high SS content concentration to low yield induced by rootstock. The interaction between rootstocks and storage period was found with significance. This interaction was also observed with increasing trend in SS content with increase in storage period. Plum fruits grafted on two different rootstocks have been reported with increasing SS content levels during cold storage (Rato et al. 2008). Generally, increasing soluble solids content enhances the stone fruit eating quality, which should have minimum standard of 11% SS content in yellow fleshed peaches (Mcglasson, 2001; Kader, 2002).

Higher titratable acidity levels depict increased life and intact quality of fruit during storage. Soluble sugar content, TA and aroma volatile composition are all together result in a flavor and are used frequently for fruit quality measurement (Ferguson and Boyd, 2002). Ripened fruit retains flavor for longer when acidity levels are higher (Ulrich, 1970). The study under discussion indicates maximum TA was found in fruit of trees on GF-677 rootstock during storage for both years. While, minimum TA was recorded in fruit of trees on SL rootstock. Fruits with higher levels of TA showed better performance in terms of intact quality. This can be because of decreased transformation of insoluble starch into soluble solids. Our findings are verified by the results of Albas et al. (2004) who have reported that TA in peach fruit was substantially

affected by rootstocks. The interaction between treatments and storage period showed a linear decrease in TA in peach fruits for all treatments as the storage period progressed. SSC:TA ratio is one of quality attributes which determines fruit maintenance status during storage. It is based on the concentrations of both organic acids and sugars or soluble solids. This study shows substantial effect of rootstocks on SSC:TA ratio during five week storage period for both years. SSC:TA ratio was found remarkably lowered down in fruits of trees grafted on GF-677 rootstock when compared with SL rootstock which had highest ratio for both years. The increase in SSC:TA ratio can be attributed to higher soluble solids and lower titratable acidity contents in SL and PL rootstocks fruits. [Cantin et al. \(2010\)](#) reported that SSC:TA ratio increased with increase in fruit size and their findings are in conformity with our results that SL rootstock attributed increased peach fruit size and higher SSC:TA ratio as well. SSC:TA ratio increased in all treatments with increase in storage period for both years.

The ratio of sugars and organic acids are main determinants which directly relate to the attributions of fruit taste. Non reducing sugars (sucrose) are less reactive molecules as compared to reducing sugars (fructose and glucose). Normally, non-reducing sugars is brought into cells, secluded (sequestered) in vacuoles and consumed during respiration; nevertheless, rest of the sugars are shifted as well ([Mir and Beaudry, 2002](#)). Non reducing sugars significantly contribute to flavor due to its sweetness characteristic. This research work revealed that minimum content of total sugars was observed in fruits of trees on GF-677 rootstock followed by PL rootstock during storage period for both years. Maximum levels of total sugars were recorded in fruits of trees on SL rootstock for both years. Highest content of total sugars in fruits of trees on SL rootstock may be attributed to increased conversion of starch into total sugars due to increase in softening and water losses. In contrast to our results [Albas et al. \(2004\)](#) reported that GF-677 rootstock trees performed intermediate role in lowering sugars content of peach fruits. The interaction between treatments and storage period was noted with significance and had general increasing trend for total sugars content during the entire storage period. The measurement of hydrogen ion concentration (pH) in fruit juice is another parameter to determine the fruit quality. Lower levels of pH in fruit enhance its defensive mechanism against microbial attack during storage. In this study, pH in peach fruit of trees cv. 'Flordaking' on GF-677 rootstock was significantly maintained at lower level than fruits of the rest of rootstocks during five week storage period for both years. Highest level of pH was observed in fruits of trees on SL rootstocks. In contrary to the findings of [Albas et al. \(2004\)](#), this study reveals significant effect of rootstocks on pH of fruits grafted on them. Means for weekly intervals of both years indicate a consistent increase in fruit pH of all treatments during storage period.

Ascorbic acid (vitamin C) is a vital nutrient in fruits and vegetables in general while in peaches in particular. It is subjected to quick degradation as compare to other nutrients during different foods processing and storage ([Akhtar, 2010](#)). If levels of AA are retained during storage then it is believed that rest of the nutrients would remain stable as well ([Fennema, 1996; Ozkan et al. 2004; Rueda, 2005](#)). The AA content tends to decline throughout the processing and storage period ([Veltman et al. 2000](#)) and it has been reported that decrease in AA leads to senescence and deteriorated quality ([Watada et al. 1987](#)). Because AA content tends to decrease in fruits during storage because of consumption of organic acids during respiration or its conversion to sugars ([Kader, 2002](#)). This study indicates significant effect of rootstocks on AA content of fruits of peach cv. 'Flordaking' during five week storage period for both years. Fruits of trees on GF-677 rootstocks showed remarkably highest AA content followed by PL rootstock as compared with SL rootstock. Decreased content of AA may be attrib-

ted to increased respiration rate and senescence in fruits of different treatments with lowered AA content. Thus, the results of our study verify that GF-677 rootstock has previously been documented as relatively better rootstocks for good fruit quality ([Tsipouridis and Thomidis, 2005; Drogoudi and Tsipouridis, 2007](#)).

Besides other quality attributes FRSA is also another authentic stick yard to measure fruit quality. In another words fruit antioxidant capability depicts a good measurement of fruit dietary worth ([Wang et al. 1996](#)). Antioxidants are believed to scavenge free radicals produced during reactive oxygen species (ROS) activity. Fruits contain increased FRSA because of their affluence in antioxidants which includes polyphenolic and vitamins and these are involved in free radical scavenging activities. However, the antioxidant activity may differ cultivar to cultivar and species to species ([Award et al. 2001; Kondo et al. 2005](#)). The results of our study indicated peach fruit of trees grafted on GF-677 rootstocks had significantly highest FRSA values compared with SL rootstock during five week storage period for both years. Thus, we find significant effects of rootstocks on the FRSA of peach fruit cv. 'Flordaking'. The interaction between rootstocks and storage period showed significant effects on FRSA of all rootstocks during both years. Harvested fruits from GF-677 rootstock had high antioxidant activity ([Giorgi et al. 2005](#)). In agreement to our findings some other researchers have also stated that peach fruit antioxidant activity was dependent on rootstock type and cultivar, fruit maturity stage and postharvest storage conditions, mineral contents, sugars and organic acids ([Di Vaio et al. 2001; Kubota et al. 2001; Forlani et al. 2003; Scalzo et al. 2005; Giorgi et al. 2005](#)).

5. Conclusion

During storage of peach fruit from all three rootstocks, the fruit on trees of rootstock GF-677 showed highest L^* and lowest a^* values for skin, less weight loss, higher firmness, decreased SSC and higher TA. Free radicals scavenging activity and ascorbic acid content were also found higher in fruits of GF-677 rootstock compared with PL and SL rootstocks during five week storage intervals. It is understood that the influence of rootstocks on scion is much complicated than some measured variables. However, the selection of right combination of scion and rootstock is important for obtaining the desired physical, chemical and other quality characteristics of peach cultivars.

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Data Availability

Data presented in this study are available on fair request to the corresponding author.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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