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Effect of Hydro and Cold Room Pre-cooling on Cooling Kinetics and Post-harvest Quality of Amla

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Pre-cooling is an important step in the post-harvest management of fresh produces. This study was initiated to evaluate the effect of hydro and cold room pre-cooling on cooling kinetics and post-harvest quality parameters for amla. Amla fruits were hydro cooled using immersion method in chlorinated water (200 ppm) at 3, 5, and 8°C temperatures, while Cold Room (CR) pre-cooling was done in a display-type refrigerator at 6°C. Comparative cooling kinetics showed the highest cooling rate of 1.83 for 3°C water temperature among all cooling treatments. In addition, cooling kinetics represents that 3°C water temperature exhibited the lowest cooling time with maximum cooling coefficient. Analysis of post-harvest quality was done at 3°C Hydro Cooling (HC) water temperature. Amla fruits of HC at 3°C and CR cooled at 6°C were stored at 6 ± 1°C temperature and 90–95% Relative humidity for 15 days. During the storage study analysis, the HC process of amla fruits showed significantly lower weight loss, higher firmness, and less ascorbic acid degradation. An insignificant effect of HC and CR cooling process were observed for total soluble solid and titrable acidity during the storage. Therefore, HC process can be possibly used for pre-cooling amla fruits, significantly reducing the cooling time and contributing to better post-harvest qualities than CR cooling.

Keywords: Ascorbic acid, Firmness, Fruit, Hydro cooling, Principle component analysis

Introduction

Amla (*Emblica officinalis* L.), commonly known as Indian gooseberry, is an indigenous fruit, widely cultivated throughout the Indian subcontinent. It is the seasonal winter fruit crop, harvested between October and February month in India. The total production of amla was 1206,170 Metric tons in 2021–22, with the first rank in the world (Agricultural and Processed Food Products Export Development AuthorityAgri Exchange 2022). It comes under the minor and underutilized fruit category and is recognized for various nutritive, health benefits, and medicinal compounds such as minerals, vitamins, phenols, tannin, and other phytochemical compounds at a low price.[1] It has the richest source of ascorbic acid, which depends on the variety and ranges from 500 to 1,500 mg/100g. In India, commonly, amla is consumed after processing and value addition in the form of juice, candy, jam, pickle, murabbah, dried powder, and sauce. The higher perishability and strong astringency of fresh amla, restrict its application in consumption.[2] Amla has a short shelf life of five to six days at ambient temperature conditions (20ºC).[1] Delay in cooling and storage of fresh amla fruit leads to the quality deterioration.[3]

Removal of internal heat and storage at low temperatures immediately after harvesting is a fundamental and necessary step for fruit and vegetable preservation.[4] Rapid pre-cooling of fresh fruit and vegetables retards the physiological disorder, and metabolic rate, resulting in the prevention of quality deterioration during refrigerated storage.[5] Therefore, pre-cooling is the crucial method for extending the shelf life of fresh commodities. Pre-cooling of fruits and vegetables is possibly done by methods such as hydro, room, ice, vacuum, and forced air cooling.[6] The efficiency of pre-cooling process depends on different factor such as cooling rate, chilling sensitivity, water tolerance, etc.[7,8] Hydro cooling is the simple, inexpensive, and rapid pre-cooling technique in which the fruits and vegetables are exposed to cold water by soaking and spraying. It offers a faster heat transfer rate and a shorter chilling period. Additionally, it removes the dirt and lessens the microbial load from the product surface. It is three times faster than forced air cooling or ten times compared to a cold room or conventional cooling.[9]

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Some research have already been carried out on hydro cooling (HC) process and its effect on parsley leave[10], strawberry[11], litchi[6], tomato, carrot, eggplant[12], rock melon[13], and cashew apple.[8] Some fruits and vegetables are sensitive to wetting, and it can negatively impact the quality of fresh produces. However, no research has been found regarding comparision of HC and CR cooling kinetics for amla fruit and its effect on quality characteristics during storage. This research aimed to conduct the cooling modelling for amla fruits and the effect of the cold room and hydro-cooling process on the post-harvest quality of amla fruits during refrigerated storage.

Materials and Methods

Sample and Cooling Treatments

Fully mature fresh amla samples (Chakaiya cultivar) were collected near Rourkela at the same harvesting time and maturity. Amla fruits were selected based on uniformity in weight, size, color, and free from damage. The weight and geometric characteristics of the chosen amla fruit were 20 ± 1 g, major diameter of 34.3 ± 0.36 mm, and minor diameter of 28.60 ± 0.71 mm measured as per the method described by Tomar and Pradhan.[14] Fresh amla fruits were analyzed with maturity indices, including moisture content: 85.9 ± 0.35% (w.b.), TSS: 7.9 ± 0.21%, TA: 5.54 ± 0.6%, and ascorbic acid: 643 ± 27.42 mg/100 g were found. Amla fruits were divided into four groups (0.250 kg/ treatment); three for hydro-cooling and one for cold room cooling. All experiments were conducted in triplicate. Hydro-cooling of fresh amla fruits was carried out by immersion cooling method. Cold water at three different temperatures, 3ºC (HC_3), 5ºC (HC_5), and 8ºC (HC_8) were selected for cooling kinetics of samples. The water's temperature was continuously measured using a digital thermometer and maintained constant by circulating the chilled water at the outerperiphery of the hydro-cooling container. A copper container of 2 L capacity was used for the hydro-cooling process. The temperature of amla fruits core before initiating the pre-cooling treatment was 29±1ºC, and it was continuously measured at an interval of 30 seconds with a digital probe-type thermometer (Cason digital food thermometer, 0.1ºC resolution) during the cooling process inserted into the fruit pulp. Cold room cooling experiments were conducted in a display-type refrigerator (Elanpro, India). Amla fruits were arranged in a single layer on the plastic tray for effective cooling of samples.

Research experiments were divided and conducted into two parts. First, the effect of different hydro-cooling (3,5, and 8ºC) and cold room cooling (6ºC) treatments on the cooling kinetic of amla fruits, and the second experiment was conducted to analyze the effect of HC and CR cooling on the post-harvest qualities of amla fruits. After cooling, amla fruits were kept in unperforated LDPE bags for carrying out a comparative storage study at 6 ± 1ºC and 90–95% RH.

Cooling Kinetics

The cooling times, cooling rate (ºC/min), cooling coefficient, half cooling time ($T_{1/2}$), and seven-eighths cooling time ($T_{7/8}$) are the important characterization parameters for the cooling process.[3,8] Half cooling time ($T_{1/2}$) and seven-eighths cooling time ($T_{7/8}$) were defined as the time required to reduce the temperature difference between amla pulp and cooling medium (water and air)by 0.5 (1/2) and 0.875 (7/8).

Fractional unaccomplished temperature difference or dimensionless temperature rate (Y) for amla fruit was calculated using Eq. (1).[(8,13)]

$$Y = \frac{T_t - T_m}{T_i - T_m} \quad \dots (1)$$

where, T_t= Temperature of amla core pulp at t time, ºC, T_m= Temperature of cooling medium, ºC, and
T_i = Initial amla pulp core temperature, ºC

The cooling rate is the decreased rate of pulp temperature with respect to time. It was calculated by dividing each temperature data point by its corresponding time point, using Eq. (2).[(3)]

$$\dot{T} = \frac{T_{pi} - T_{pf}}{\Delta t} \quad \dots (2)$$

where $\dot{T}$ is the cooling rate expressed in ºC/min, T_{pi} and T_{pf} are the initial and final core temperature of amla fruit, and Δt is the time taken in cooling.

The cooling coefficient is the rate at which the temperature of the fruit changes for each unit change in the temperature differential between the product and the medium, which is equal to minus the slope of the ln Y vs time cooling curve. The cooling coefficient (C) is expressed in Eq. (3). It serves as a standard reference point for evaluating the various precooling techniques employed.[15]

$$c = \frac{lnY}{\theta} \quad \dots (3)$$

where, c = Cooling coefficient, (min^{-1}) and θ = time taken during the cooling, min

Quality Analysis

Weight Loss

A digital weighing balance (Model CY 224, Aczet) with the least count (0.1mg) was used to measure the weight loss of hydro and cold room-cooled amla fruit at regular intervals of storage study. The weight of 20 fruit from both cooling methods was measured. It is expressed in the weight loss percentage concerning the initial weight of fruits. Weight loss was calculated using Eq. (4).[16]

$$Weight\ loss\ (\%) = \frac{W_i - W_t}{W_i} \times 100 \qquad \dots (4)$$

where, W_i =Initial weight of amla fruit (g) and W_t=Weight of amla fruit at storage study analysis time (5 days' interval) (g).

Firmness

Texture Analyzer (CT3, Brookfield, USA) with 10 kg load cell was used to analyze the firmness of fresh and stored samples. All sample analyses were conducted using stainless steel cylindrical texture analyzer probes with a 4 mm diameter and a testing speed of 1 mm/s. The maximum force required to penetrate inside the 7 mm amla pulp was determined, and measured results are represented in Newton. The test was conducted with five replications for hydro and cold room-cooled samples.

Total Soluble Solid (TSS)

TSS content of the amla sample was measured using a benchtop digital refractometer (RFM 700 model, Bellingham and Stanley, UK) described by Subrahmanyam *et al.*[17] Amla fruits were cut into small pieces for measuring TSS content and ground in a mixer grinder for 120 sec. The ground mixture was pressed and filtered to release the juice using a muslin cloth. A few drops of amla juice were spotted on the prism of the refractometer. Before measuring the TSS of amla juice, the refractometer is calibrated using double distilled water. The measured TSS content of the sample was expressed in º brix.

Titratable Acidity (TA)

Three grams of ground amla pulp samples were boiled in 50 mL of distilled water for 60 min on a heating plate. After boiling, evaporated water volume was makeup, and samples were cooled to room temperature and filtered using the Whatman filter paper (Whatman filter no. 41). The filtrate samples of 5 mL were transferred into the 100 mL conical flask then added a few drops of 1% phenolphthalein indicator. Samples were titrated against 0.1N sodium hydroxide solution till the light pink color as the end point persisted for more than 30 sec. Measured the titre value required for titration of samples. Titratable acidity was calculated with standard formula in terms of the percentage of ascorbic acid (% of ascorbic acid).

$$\%\ Titrable\ acidity = \frac{titre\ value \times N \times V_1 \times Eqw \times 100}{V_2 \times W \times 1000} \qquad \dots (5)$$

where, N= Normality of alkaline solution, V_1= Volume made up for analysis (mL), Eqw = Equivalent weight of acid (ascorbic acid), V_2= Volume taken for titration (mL), and W= Weight of the sample taken for preparation (g).

Ascorbic Acid (AA)

The ascorbic acid content of fresh and stored amla fruits was extracted and determined using the 2, 6di-nitro indophenol titration method with some modifications described by Zainal *et al.*[13] For the extraction, 5 g of diced amla was blended with 3% meta-phosphoric acid (HPO_3) solution in a mixer blender at full speed. Blended slurry mixtures were kept in an incubator shaker at 25ºC and then filtered using the muslin cloth. Samples volume was made up to 100 mL using HPO_3 solution. A 10 mL volume of diluted HPO_3 sample extract was taken into a 50 mL conical flask and titrated with a standardized dye solution filled into a 50 mL burette. Titration was carried out till the pink color formation as the end point at least persisted for 15 sec. Ascorbic acid was calculated as per the standard Eq. (6)and expressed in mg of ascorbic acid per 100 g of fruit samples.

$$Ascorbic\ acid = \frac{titre\ value \times Dye\ factor \times Volume\ made\ up\ (ml) \times 100}{Aliquoat\ sample\ taken\ for\ titration (ml) \times weight\ of\ sample (g)} \qquad \dots (6)$$

Statistical Analysis

All performed parameter results were presented in mean ± standard deviation. One-way Analysis Of Variance (ANOVA) and significant differences between the means were performed (p <0.05) by independent sample t-test using IBM SPSS Statistics 26 (Chicago, IL, USA). Principal component analysis was carried out to analyze the comparative effectiveness of the cooling methods (hydro and cold room cooling) and storage time on post-harvest quality using the Minitab software 2022.

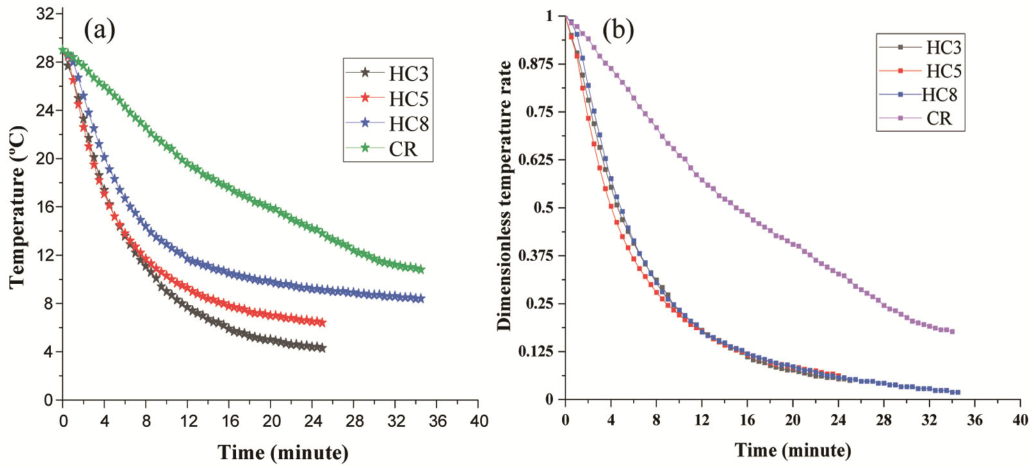

Fig. 1 — (a) Effect of hydro and cold room cooling on temperature profile changes and (b) dimensionless temperature rate of amla pulp

Result and Discussion

Cooling Kinetics

The data obtained from HC_3/HC_5/HC_8/CR cooling were analyzed to evaluate the effect of the cooling process on cooling kinetics and its evaluation parameters. The average initial temperature of amla fruit pulp was 29ºC. The temperature profile changes of amla fruit pulp with respect to cooling time is shown in Fig. 1(a). The hydro-cooling process was carried out with chilled water at different temperatures of water 3, 5, and 8ºC. After 30 min, amla pulp attained the temperature of 4, 5.9, and 8.8ºC, respectively. Similarly, the cold room-cooling experiment was done at 6 ± 1ºC refrigeration temperature, and it took 54 min to reach 8ºC pulp temperature. The dimensionless temperature rate (DTR) versus cooling time relationship for the hydro and cold room cooling is presented in Fig. 1 (b).

Half cooling time ($T_{1/2}$) and Seven-Eights cooling times ($T_{7/8}$) were also calculated to characterize the efficiency of the hydro and cold room cooling process. The time required to achieve the $T_{1/2}$ and $T_{7/8}$ cooling was 4.5, 5, and 5.5 min for HC_3, HC_5, and HC_8, respectively. For cold room cooling, both cooling time, $T_{1/2}$ and $T_{7/8,}$ was found to be 16.5 and 38 min, respectively. However, cold room cooling had substantially higher values for these cooling process-determining parameters than all hydro-cooling treatment techniques. Results indicated that hydro cooling of amla fruit decreased the cooling time. A similar trend was also observed for the cooling rate. The cooling rate is the primary factor in evaluating the cooling process. The hydro-cooling process presented a higher cooling rate. However, the lowest cooling rate was observed for the cold room cooling method. The HC_3 process was shown to have the highest cooling rate (°C/min) among all hydro and cold room cooling processes. It was found 1.35, 3.15, and 3.9 times faster than the HC_5, $HC_{8,}$ and CR, as represented in Table 1. The faster cooling rate for the hydro-cooling process was due to the higher heat transfer coefficient of the cooling medium (water) than the cold room cooling (air). Direct contact between the fruit surface and cold water quickly dispersed the heat into the water, enabling the heat removal process faster.[6]

Table 1 — Obtained value of cooling parameters for amla fruit

Cooling parameters	HC_3	HC_5	HC_8	CR
Initial Temperature	29	29	29	29
Cooling rate (ºC/min)	1.83	1.35	0.58	0.47
Cooling coefficient (min^{-1})	0.122	0.113	0.118	0.049
R^2	0.998	0.977	0.983	0.993
Half cooling time (min)	4.5	5	5.5	16.5
Seven- Eight cooling time (min)	15.5	15	16.5	38

The rate of cooling can also be analyzed by the cooling coefficient. Cooling coefficient of the hydro and cold room cooling process for the amla fruit are shown in Table 1. The higher the value of the cooling coefficient faster the cooling process and less required cooling time. The highest and lowest value of 0.122 and 0.049 cooling coefficient was observed in HC_3 and CR cooling process, respectively. The higher cooling rate is due to the higher heat transfer coefficient of water with respect to air convection cooling.[6]

Firmness

The firmness of fruits is the most crucial attribute that directly dictates the commercial worth and shelf life of fresh produce. The firmness value of the fresh amla sample was 44.01 ± 0.62N found during this study. Throughout the storage study, a decreasing trend of firmness (N) was observed for both cooling techniques, and variations in the firmness are tabulated in Table 2. In addition, hydro cooled sample showed a significantly higher firmness than the cold room-cooled sample. The firmness (N) degradation rate for the hydro cooled was much less (9.35%) as compared to cold room cooled (19.11%) at the end of the 15th day of storage. This can be due to a significant difference in weight loss of hydro and cold room-cooled fruit, in which cold room-cooled fruits become more flaccid and show less resistance to trigger force.[18] During storage, weight and water losses decay the fruit's texture by damaging the cell microstructure. This high firmness retention in hydro-cooled fruit demonstrated that hydro-cooling effectively prevents cell wall deterioration and preserves the fruit quality. Similar findings for hydro cooled samples were also reported for strawberry and cashew apple Jacomino *et al*. and de Oliveira Alves Sena *et al*.[8,11]

Weight Loss

Weight loss of fresh commodities is another major parameter for assessing the shelf life and commercial value of fruits and vegetables. During this analysis, results findings revealed that the rate of weight loss in the cold room-cooled amla sample was significantly higher than in the hydro-cooled samples. This significant difference (P <0.01) was observed during the entire storage duration analysis. The overall weight loss of amla fruit during the storage is presented in Table 2. It revealed that the weight loss of amla fruits were significantly (P <0.05) increase as days of storage increasese. Although, highest amount of weight loss of 1.24% and 0.22% for CR and HC, respectively, was recorded after the 5th day of storage, while the lowest loss was observed between the 10th and 15th-day storage interval. At the end of storage, hydro-cooled amla fruit showed 0.51% weight loss, significantly (P <0.01) lesser than the cold room cooled 2.03% loss. Results findings indicated that the hydro-cooling process reduced the weight loss of amla fruits during storage.

Ascorbic Acid (AA)

The ascorbic acid content of amla fruit was measured at zero and regular intervals of 5 days during the storage study. It is the important bioorganic molecule responsible for the antioxidant activity of amla fruit and helps in protecting and maintaining the cells healthy. The ascorbic acid concentration of amla fruit reduced significantly (P <0.05) for hydro and cold room-cooled amla fruit during the entire storage period, as shown in Table 2. However, the rate of decrease in ascorbic content of hydro-cooled samples was substantially slower than cold room-cooled samples during the all-storage analysis study. This delay in AA content may be due to the higher concentration of organic acids, which may have performed a protective effect against the ascorbic acid oxidation to dehydroascorbic acid throughout the prolonged storage period.[8,19] These findings are in accordance with the result of Sena *et al.*[8], who reported a significant difference in hydro and cold room-cooled cashew apple fruit during storage.

Total Soluble Solid

The average TSS content of fresh amla was 7.9% found during this study. It varied a little during the storage period (Table 2). Storage analyses of amla fruit showed an increasing trend of TSS for both cooling methods. This increased trend of TSS may be caused by the water loss or solubilization of cellular compounds into cell walls.[20] Hydro-cooled amla fruit showed a higher TSS content during storage analyses.

Table 2 — Post-harvest quality of amla fruit subjected to hydro and cooling stored at 6ºC

Parameters	Days	0	5	10	15
Firmness (N)	HC	44 ±0 .62^a	42.14 ± 0.57^a	40.64 ± 0.70^a	38.47 ±0.49^a
	CR	44 ± 0.62^a	39.99 ± 0.71^b	37.72 ± 1.18^b	34.89 ± 0.69^b
Weight loss (%)	HR	NA	0.26 ± 0.05^a	0.44 ± 0.02^a	0.54 ± 0.03^a
	CR	NA	1.2 5± 0.11^b	1.89 ± 0.05^b	2.01 ± 0.08^b
TSS (%)	HR	7.9 ± 0.21^a	8.5 ± 0.08^a	8.73 ± 0.12^a	10.4 ± 0.19^a
	CR	7.9 ± 0.21^a	8.3 ± 0.07^b	8.5 ± 0.13^a	10.1 ± 0.22^a
Acidity (%)	HR	5.94 ± 0.6^a	6.73 ± 0.12^a	7.74 ± 0.12^a	8.04 ± 0.18^a
	CR	5.94 ± 0.6^a	6.3 ± 0.16^b	7.01 ± 0.14^b	7.65 ± 0.12^a
Ascorbic acid	HR	649 ± 27.42^a	616.83 ± 24.56^a	577.16 ± 25.42^a	532 ± 34.76^a
(mg/100g)	CR	649 ± 27.42^a	582.83 ± 35.91^a	543.33 ± 25.46^b	501.5 ± 27.47^b

Values are represented as mean ± standard deviation. Different lowercase letters indicate significant differences between treatments for the same storage period (P <0.05).

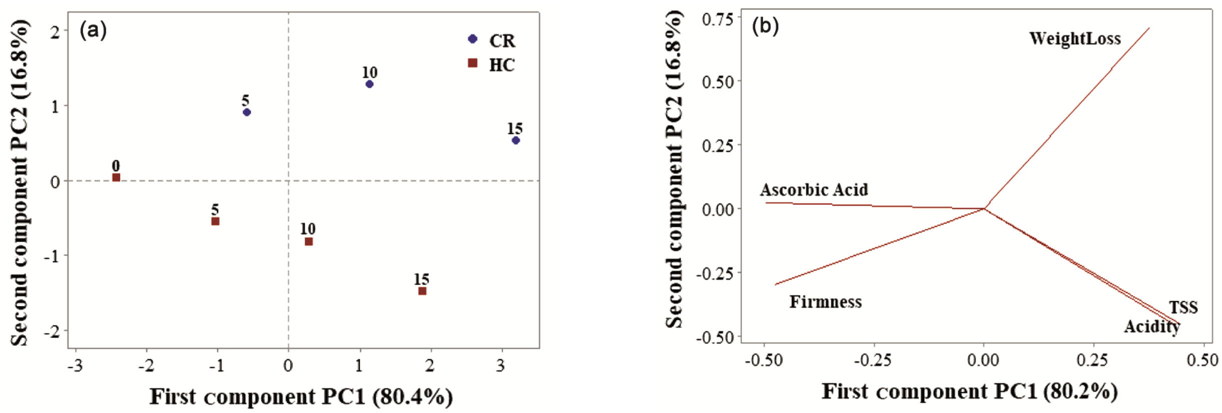

Fig. 2 — Principal component analysis of amla fruit subjected hydro and cold room cooling depicting (a) the score plot, (b) loading rotated bi-plot between the PC1 and PC2

But, there was no significant difference (P <0.05) between the hydro and cold room-cooled amla fruits during the entire storage study. These results are in accordance with the finding of de Oliveira Alves Sena *et al.*[8] in the hydro-cooling of the cashew apple.

Titrable Acidity (TA)

The titrable acidity of HC and CR-cooled amla fruit was increased with respect to storage time. Variations in TA of amla fruits are shown in Table 2. During the 5th and 10th day storage analysis, a significant difference (P <0.05) was observed between the HC and CR samples, while there was no significant difference found between HC and CR samples on the 15th day. HC samples displayed a higher TA concentration during the entire storage period analysis. This higher concentration of TA in HC samples may be due to higher ascorbic acid content in respective samples. Similar trends were also found in the case of the cashew HC and CR cooling study.[8]

Principle Component Analysis (PCA)

Principle Component Analysis (PCA) is the multivariate statistical technique that summarizes the content of the entire datasheet in some principal components. These principal components represent the most variation in the dataset without eliminating any variable characteristics but instead reduces the enormous number of dimension by creating the principal component.[21] PCA was used to discriminate the hydro and cold room amla fruit samples based on post-harvest quality characteristics during the storage time; its output concerning the score plot and rotated loading bi-plot were presented in Fig. 2 (a & b). The total cumulative variance of the first two principal components was 97.4%, with the highest ability to distinguish the treatments' overall data point. The individual contribution of the first component (PC1) and the second component (PC2) was 83.3% and 14.1 % of the overall variation, respectively. PC1 was positively associated with firmness, TSS, and TA of amla fruit, which showed an increasing trend during the storage study, while ascorbic acid and firmness were negatively associated with PC2, presented in Fig. 2(b). The score plot graph showed the relationship between the cooling method. The entire storage point of hydro and cold room cooling between PC1 and PC2 were not interactive with each other and results are revealed in Fig. 2 (a). Qualitative properties of hydro-cooled amla fruit stored for 5, 10, and 15 days seem to differ from those of cold room-cooled fruit. The output of PCA analysis suggested that post-harvest qualitative parameters of the hydro and cooled room differed from each other during the storage period.

Conclusions

In the present work, the amla fruits were pre-cooled using hydro and cold room cooling methods. The cooling process of the hydro pre-cooling method is significantly affected by water temperature. A low water temperature showed a higher cooling rate resulting in faster heat removal. The cooling rate of the HC_3 treatment was 3.9 faster than CR cooling. The finding of cooling kinetics suggests that hydro-cooling could be a better option to remove the heat rapidly than cold room cooling. The effect of a faster cooling process is reflected in weight loss reduction, firmness conservation, and higher ascorbic acid and titratable acidity during storage. Hydro-cooled amla fruits showed 10.26% higher firmness, 8% higher AA content, and 1.47% less weight loss at the end of the 15th day of storage. The result suggested that hydro-cooling could be utilized for faster removal of field heat and to maintain the post-harvest qualities of fruits and vegetables at the industry or agriculture field level. However, more studies should be conducted on the suitability of different disinfectant agents for fulfilling the criteria of the hydro-cooling process.

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Conflicts of interest

No conflict of interest among the authors.

Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors.

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