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Research Article

Influence of Precooling Systems on Postharvest Quality and Shelf Life of Dragon Fruits (*Hylocereus polyrhizus*)

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ABSTRACT

Postharvest loss management has attained the main concern in the current world for the growing population and to ensure global food security. As a non-climacteric fruit, proper postharvest management is vital for dragon fruits in the context of decreasing postharvest losses and extending shelf life. A factorial experiment consisting of three locations (Tala, Dumuria, Keshobpur), and three precooling systems (without cooling, hydro cooling, CoolBot-AC cooling) was conducted to evaluate physico-chemical quality attributes of dragon fruits. The results showed that physico-chemical quality attributes were significantly influenced by precooling systems in which the CoolBot-AC cooling system significantly reduced weight loss by more than 9 % and extended shelf life by more than 2.5 days. Of the three-precooling systems, the CoolBot-AC system performed significantly better resulting in higher flesh weight, flesh and pericarp ratio, edible portion, moisture, and dry matter content over other precooling systems. Similarly, CoolBot-AC precooling system performed pointedly better than other precooling systems and retained acceptable skin colour, firmness, high levels of TSS content, 12.03 % more anthocyanins, 30.73 % more flavonoid, 32.55 % more total phenols, 24.22 % more carotenoid, and high levels of ascorbic acid content. No statistical variation was documented among locations with a few exceptions. Therefore, the results indicated that CoolBot-AC precooling system could be an effective postharvest management strategy for prolonging shelf life and reducing postharvest losses of dragon fruit.

Introduction

Dragon fruit (*Hylocereus polyrhizus*) is an exotic fruit known as pitaya, pitahaya, strawberry pear, and thang loy fruit (Khalili et al., 2009; Lobo et al., 2013). The flesh is sweet, delicate, white, or red-purple, and contains numerous tiny black seeds. It has the ability to control obesity, cancer, diabetes, high cholesterol as well as high blood pressure (Blancke, 2016). High antioxidant levels in the fruit prevent free radicals from attacking the body. Dragon fruit may help to maintain eye health as well (Luu et al., 2021).

Postharvest loss management is a key concern worldwide due to the growing population and shrinking resources. Cultivation of dragon fruit in Bangladesh has expanded greatly, but postharvest management strategies are not developed due to a lack of research and education on the postharvest system. A huge number of fruits were lost due to faulty postharvest management systems (Rahim et al., 2008). In peak season, due to improper handling, packaging problems, transportation difficulties, unavailability of precooling facilities, and marketing problems, around 16-36 % of fruit spoils in general (Kader, 2002, Erkan, 2012). Researchers have claimed that in India every 1% reduction in loss will save 5 million tons of fruits per year (Saraswathy et al., 2018).

The soil, in which a fruit grew, has always been an important component that shapes its nutritional value. Even the way it's preserved or transported can have an effect on its nutrients, making it poorer to consumers than it would be if the fruits were consumed where it was produced. The major sources of dragon fruits in Khulna city are Tala, Dumuria, and Keshobpur Upazila. As a result, it is assumed that these locations may play an important role in the different nutritional compositions of dragon fruits available in Khulna city. Limited published works of literature evaluating the location effect on physico-chemical attributes of dragon fruits were explored. Also, interactive functions of

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locations and precooling systems are very much limited that presently forcing to get attention to a holistic perception in the postharvest management sectors.

Precooling slows the ripening process, respiration rate, senescence, and water loss from the harvested fruit, which helps to retain overall fruit quality and extend shelf life (Workneh, 2010). Since the dragon fruit metabolism rate is so fast, and precooling slows it down, precooling is so important to maintain postharvest fruit quality (Kitinoja and Thompson, 2010). Kuchi and Sharavani (2019) stated that proper temperature management is vital, and it all begins with proper precooling. Precooling is virtually non-existent in Bangladesh because of high refrigeration costs and a lack of knowledge about the benefits of precooling. However, cold storage facilities and continuing cold chains help to gain more revenue by keeping the products for a longer period with maintaining acceptable quality (Erkan, 2013). Now-a-days low-cost cold storage facilities viz. evaporative cooling, CoolBot-AC cooling is becoming popular and obtainable for low-income growers (Saran et al., 2010, Kitinoja and Al Hassan, 2012).

Deficit knowledge about the necessity of precooling dragon fruit hinders the farmers from maximum benefit. Being able to extend shelf life and save dragon fruits from spoilage using CoolBot-AC technology might be helpful in overcoming existing postharvest management challenges in sub-tropical conditions. Research in precooling systems for dragon fruits to extend shelf life is meager in subtropical conditions. Therefore, the present research work was undertaken to evaluate the influence of precooling systems on postharvest quality and shelf life of dragon fruits collected from different locations.

Materials and Methods

Description of the experiment

The experiment was carried out at the Horticulture Laboratory of the Agrotechnology Discipline of Khulna University, Khulna, Bangladesh in 2021. The two-factor (locations and precooling systems) experiment was laid out in a Completely Randomized Design (CRD) with three replications. Each treatment combination consisted of ten dragon fruits. Tala, Dumuria, and Keshobpur upazilas were used as locations. Alike locations, CoolBot-AC (8±1° C), and hydro cooling (17±1° C) were used as precooling approaches. Also, dragon fruits kept at normal temperature (24±1° C) in open space considered as control. After the collection of dragon fruits, the samples were placed overnight (5.0 p.m. to 8 a.m., 15-h) for precooling according to the treatment for the evaluation of quality parameters. The physico-chemical attributes were determined after 3-day of storage.

The developed CoolBot-AC facility (Store It Cold, USA) took around 95 minutes to reach the lower limit of room temperature (10±1° C). The relative humidity (RH) of the CoolBot-AC room was 90-95 %. The temperature of the hydro cooling installing area was 17±1° C and the relative humidity (RH) of that room was 80-85%. The normal temperature was 24±1° C with relative humidity (RH) of 77-80%.

Physical parameters evaluation of dragon fruits

The weight of dragon fruits was measured by an electric balance. The following equation was used to assess weight loss (Qin et al., 2015):

$$\text{Weight loss}\,(\%) = \frac{M_0 - M_1}{M_0} \times 100 \quad \text{.... (2)}$$

Where, M_0 is the weight of dragon fruit on the first day, and M_1 is the weight on third day of storage.

The pericarp thickness was measured using digital slide calipers immediately after harvesting and three days after storing. By detecting and judging the quality parameters like appearance (color chart), disease incidence (scale rating: 0 means no infection and 5 means more than 50 % area infected), etc., the shelf life of dragon fruit was assessed with respect to storage days. The pericarp weight, the flesh and pericarp ratio and edible portion percentage were also determined accordingly.

Fifty grams (50 g) of fresh fruit sample from each treatment was taken and cut into small pieces on an aluminium foil and oven dried at 70°C until the constant weight was attained. Percent moisture content was calculated according to the following formula:

$$\text{Moisture content}\,(\%) = \frac{\text{Fresh weight of sample (g)} - \text{Dry weight of sample (g)}}{\text{Fresh weight of sample (g)}} \times 100 \cdots (3)$$

Dry matter content (%) was calculated as
100 - moisture content (%) ...... (4)

Color and firmness assessment of dragon fruits

The surface colour of the dragon fruit was determined using a colorimeter (CR-410, Konica Minolta, USA). The readings were obtained at the basal portion of the pericarp and expressed as L*, a*, b*, chroma (C). A texture analyzer (Shimadzu EZ-SX, USA) was used to determine the firmness of treated dragon fruit equipped with a cylindrical probe (2 mm diameter). The penetration depth of the probe was 5 mm and the crosshead speed of the texture analyzer was 2 mm/s. The maximum force firmness was stated in N.cm^{-2} from the force vs time curve.

Determination of pH, total soluble solids and titratable acidity

The pH of dragon fruit pulp was determined using a Benchtop pH meter (HI2210, Hanna Instrument, USA, 0.01 pH resolutions) following the procedure described by Mazumdar and Majumdar (2001) and Saini et al. (2006). The percentage of total soluble solids (TSS) was evaluated from the reading of the digital Brix meter (Digital/Brix/RI-Check Reichert Technologies, USA). Similarly, dragon fruit Titratbel acidity (TA) was assessed using the procedure described by Mazumdar and Majumdar (2001) and Saini et al. (2006).

Determination of anthocyanin

Anthocyanin was extracted with ethanolic-hydrochloride. Color intensity was measured calorimetrically. From the reading, the amount of the pigment present was determined. The following calculation was used to assess the anthocyanin content of dragon fruit pulp (Mazumdar and Majumda, 2001, Saini et al., 2006).

Total absorbance

$$\left(\frac{mg}{100g}\,sample\right) = \frac{e \times b \times c}{d \times a} \times 100 \;.....\;(5)$$

a = sample weight, b = volume constructed for color determination c = total volume, d = aliquot volume taken for assessment, and e = 535 nm volume

$$\text{Anthocyanin}\left(\frac{mg}{100}\,gFW\right) = \frac{Total\,absorbance}{98.2} \;......\;(6)$$

Assessment of total flavonoid

To determine the flavonoid content of dragon fruits, the procedure mentioned by Mazumdar and Majumdar (2001) and Saini et al. (2006) was followed. Ten grams (10 g) of the sample dragon fruits pulp was taken and crushed finely. Then 100 ml of 80 % methanol was added and kept in a water bath for 10 hours at 40°C. The whole solution was filtered through filter paper (Whatman No. 42). After that, the filtrate was transferred to a crucible and then evaporated to dryness over a water bath at room temperature. The final finding was weighed as a flavonoid.

Estimation of total carotenoids

To assess the carotenoid content the following equation was used to determine the carotenoid content according to Mazumdar and Majumdar (2001) and Saini et al. (2006):

$$\text{Carotenoid}\left(\frac{mg}{100}\,gFW\right) =$$

$$\{7.6\,(A\,480) - 1.49(A\,510)\} \times \frac{V}{1000 \times W} \;.......\;(7)$$

A = Absorbance of the specific wavelength, V = Final volume of the carotenoid in 80 % acetone, W = Fresh weight of the tissue extract

Assessment of total phenolic compounds

Total phenolic compounds of dragon fruit samples were extracted and determined according to the methods described by Toor and Savage (2005). The extracts were appropriately diluted and then oxidized with 2.5 ml of freshly diluted 0.2 M Folin-Ciocalteau reagent. This reaction was neutralized by adding 2.0 ml of 7.5% w/v sodium carbonate, and the samples were vortexed for 20 sec. The samples were then incubated at 45° C for 15 min and the absorbance of the resulting blue color was measured at 765 nm on a UV–Vis recording spectrophotometer. Gallic acid was used as a standard and the results were expressed as gallic acid equivalents, in mg/100 g fresh weight.

Ascorbic acid evaluation

To determine dragon fruits' ascorbic acid contents, 30 g of fruit pulp was weighed and melded for 3 to 4 minutes with 6 % metaphosphoric acid. Then 15 g of the mixture was combined with 85 g of 3 % metaphosphoric acid in a 100 ml volumetric flask. After that, the mixture was filtrated with a filter paper (Whatman No. 42) and titrated immediately following the procedure stated by Mazumdar and Majumdar (2001) and Saini et al. (2006). The following equation was used to determine the ascorbic acid content:

$$\text{Ascorbic acid}\left(\frac{mg}{100}\,gFW\right) = V \times T \times \frac{100}{W} \;.......\;(8)$$

V = In titration volume of dye used, T = standardized dye value, and W = pulp weight

Postharvest data were subjected to a two-way ANOVA and the data were analyzed using the data analysis and graphical software Origin 2020 and means with a significant difference were identified by the F test and separated by Tukey's HDS test at $p \leq 0.05$ and $p \leq 0.01$ (OriginLab Corporation, Version 9.6.5, USA) wherever applicable. All quality parameters were analyzed using a model that as locations and precooling approaches as the main effects and their-2-ways interactions. The principal component analysis was run using raw data to establish relationships among variables and treatments.

Results

Shelf life

Fruits shelf life for the location treatments was not varied significantly (Figure 1A). The effect of precooling systems on the shelf life of dragon fruits differed significantly from each other ($p \leq 0.01$) (Figure 1B). Fruits precooled to the CoolBot-AC system showed the maximum shelf life (6.44 days), while the fruits without precooling (control) showed the minimum shelf life (3.89 days). Fruits precooled to CoolBot-AC system extended shelf life by more than 2.5 days. Factorial interaction of locations by precooling systems was not significant for the shelf life ($p \leq 0.19$) of dragon fruits.

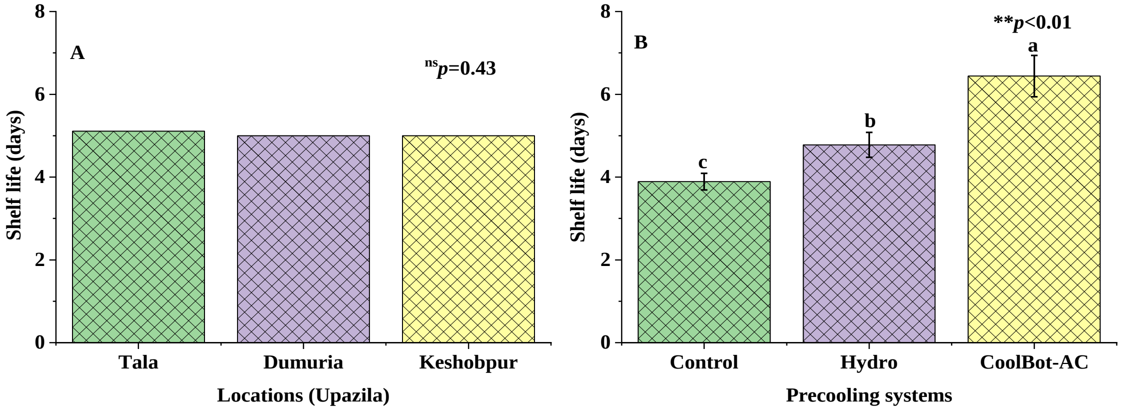


Figure 1. Effect of locations (A) and precooling systems (B) on the shelf life of dragon fruit. Bars that do not contribute to a letter are significantly unique based on Tukey's HDS test and *p*-value indicating the level of significance, vertical bars represent ± standard error.

Weight loss and fresh weight of dragon fruits

Significant ($p \leq 0.05$) variation was observed in weight loss in different locations (Table 1). The dragon fruits collected from Tala gave the maximum weight loss followed by a statistically alike weight loss reading at Dumuria, whereas it was the minimum from Keshobpur. The weight loss varied from 3.73 % to 9.09 % among the locations. The weight loss was markedly affected by precooling systems ($p \leq 0.01$) and the effect was found to the maximum without precooling system over hydro cooling as well as CoolBot-AC cooling system. The weight loss varied from 6.48 % to 15.74 % among the precooling systems. There is no significant variation due to treatments observed in fresh weight. Factorial interaction of locations by precooling systems was not significant for the weight loss ($p \leq 0.49$) and fresh weight ($p \leq 0.73$) of dragon fruits.

Pericarp thickness

The pericarp thickness was significantly ($p \leq 0.05$) impacted by precooling systems (Table 1). The highest pericarp thickness was recoded from CoolBot-AC system followed by hydro cooling system whereas the lowest in without precooling system. There is no significant variation was observed in pericarp thickness for the location differences. Factorial interaction of locations by precooling systems was not significant for the pericarp thickness ($p \leq 0.51$) of dragon fruits.

Pericarp weight

The pericarp weight was significantly ($p \leq 0.01$) affected by locations (Table 1). The dragon fruits collected from Keshobpur gave the maximum pericarp weight whereas the minimum at Tala. Similarly, the pericarp weight was significantly influenced by the precooling systems ($p \leq 0.05$), and the effect was found to be the maximum without precooling followed by the hydro cooling system over the CoolBot-AC system. Factorial interaction of locations by precooling systems was not significant for the pericarp weight ($p \leq 0.29$) of dragon fruits.

Flesh weight

Significant ($p \leq 0.05$) variation was observed in the flesh weight of dragon fruit in different locations (Table 1). The highest flesh weight (163.30 g) was recorded in those fruits collected from Tala whereas the lowest (156.86 g) was in Keshobpur. Similarly, a significant ($p \leq 0.01$) trend was observed for precooling systems. The maximum flesh weight (156.90 g) was noted from the CoolBot-AC system whereas the minimum (152.74 g) was recorded from the hydro cooling system followed by without precooling (153.62 g). Factorial interaction of locations by precooling systems was not significant for the flesh weight ($p \leq 0.25$) of dragon fruits.

Flesh and pericarp ratio

The flesh and pericarp ratio were significantly ($p \leq 0.05$) impacted by locations (Table 1). The dragon fruits collected from Tala gave the maximum flesh and pericarp ratio followed by Dumuria whereas the minimum was documented from Keshobpur. A similar significant ($p \leq 0.01$) trend was noticed for precooling systems. The highest flesh and pericarp ratio were recorded from the CoolBot-AC system whereas the lowest in without precooling followed by the hydro cooling system. Factorial interaction of locations by precooling systems was not significant for the flesh and pericarp ratio ($p \leq 0.84$) of dragon fruits.

Edible portion

Significant ($p \leq 0.05$) variation was observed for the edible portions of dragon fruit in different locations (Table 1). The dragon fruits were collected from Tala gave the maximum edible portion and the minimum was obtained from Keshobpur. Similarly, a significant ($p \leq 0.01$) trend was observed for precooling systems. The maximum edible portion was noted from the CoolBot-AC system whereas the lowest in without precooling followed by the hydro cooling system. Factorial interaction of locations by precooling systems was not significant for the edible portion ($p \leq 0.09$) of dragon fruits.

Moisture

The moisture content was significantly ($p \leq 0.05$) impacted by locations (Table 1). The dragon fruits collected from Tala gave the maximum moisture content followed by Dumuria whereas the minimum was recorded from Keshobpur. A similar significant ($p \leq 0.01$) trend was noticed for precooling systems. The highest moisture was recorded from the CoolBot-AC system whereas the lowest was in without precooling system. Factorial interaction of locations by precooling systems was not significant for the moisture content ($p \leq 0.77$) of dragon fruits.

Dry matter

Significant variation ($p \leq 0.05$) was observed in percent dry matter contents among the locations (Table 1). The dragon fruits collected from Tala gave the highest dry matter content followed by Dumuria whereas the minimum was recorded from Keshobpur. Statistically significant variation ($p \leq 0.05$) was noticed among the precooling system on dry matter contents of dragon fruits. The maximum dry matter content (16.01 %) was found in the CoolBot-AC system and the minimum dry matter content (14.78 %) was found in without precooling system followed by hydro cooling system (14.58 %). Factorial interaction of locations by precooling systems was not significant for the dry matter content ($p \leq 0.58$) of dragon fruits.

Table 1. Effect of locations and precooling systems on fresh weight, weight loss, pericarp thickness, pericarp weight, flesh weight flesh and pericarp ratio, edible portion and moisture of dragon fruit

Treatments	Fresh weight (g)	Weight loss (%)	Initial pericarp thickness (cm)	Pericarp thickness (cm)	Pericarp weight (g)	Flesh weight (g)	Flesh and pericarp ratio	Edible portion (%)	Moisture (%)	Dry matter (%)
Factor A: Locations										
Tala	215.13	14.73 a	0.27	0.24	51.83 c	163.30 a	3.15 a	75.91 a	82.64 a	18.32 a
Dumuria	214.86	14.18 a	0.28	0.23	54.96 b	159.90 b	2.91 a	74.42 ab	82.34 a	17.81 a
Keshobpur	215.10	13.10 b	0.29	0.24	58.24 a	156.86 c	2.69 b	72.92 b	81.12 b	15.62 b
Factor B: Precooling systems										
Without cooling (control)	208.83	15.12 a	0.29	0.17 b	55.21 a	153.62 b	2.78 b	73.56 b	78.71 c	14.78 b
Hydro cooling	207.46	14.14 b	0.28	0.23 ab	54.72 a	152.74 b	2.79 b	73.62 b	81.98 b	14.58 b
CoolBot-AC cooling	209.11	12.74 c	0.27	0.25 a	52.21 b	156.90 a	3.01 a	75.03 a	85.42 a	16.01 a
Level of significance										
A	NS	*	NS	NS	**	*	*	*	*	*
B	NS	**	NS	*	*	**	**	**	**	*
A × B	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	4.25	4.46	3.28	5.76	2.75	5.89	6.97	1.67	1.09	1.52

In a column, the mean followed by the same letters were not significantly different by Tukey's HDS test at $p \leq 0.05$; NS, *, **, not significant or significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, CV= Coefficient of variation

Surface color evaluation

Surface color significantly ($p \leq 0.05$) differed among the precooling systems (Table 2). The peel color remained bright red for fruits precooled with the CoolBot-AC system compared to without precooled. As fruits precooled with the CoolBot-AC system hue color angles (°h) changed and the fruits become completely red and increased the intensity without a cooling system. The lightness (L*) fell from 27.63 to 24.43 as the precooling system differences indicated that the color of the fruits had been darker. The results revealed that the pericarp color green to red (a*) was increased in without precooling compared to the CoolBot-AC cooling system. Regarding the variable b*, which expresses the degree of blue to yellow variation, the without precooling system tends to be more yellow compared to the CoolBot-AC system. The changes in chroma (C) values from 22.60 to 19.10 indicated that color intensity increased in fruits precooled with the CoolBot-AC system compared to those without precooled fruits. There was no variation in surface color was observed due to location differences. Factorial interaction of locations by precooling systems was not significant for the hue angle ($p \leq 0.12$), L* ($p \leq 0.40$), a* ($p \leq 0.39$), b* ($p \leq 0.27$), C ($p \leq 0.82$) of dragon fruits, respectively.

Firmness

As dragon fruits were not precooled, fruits firmness increased significantly ($p \leq 0.05$). Therefore, minimum softening occurred in the outer layers for fruit treated with the CoolBot-AC system whereas the maximum in without precooling system. Factorial interaction of locations by precooling systems was not significant for the firmness ($p \leq 0.22$) of dragon fruits.

Table 2. Effect of locations and precooling systems on hue angle, L*, a*, b*, C and firmness of dragon fruit

Treatments	Hue angle (°h)	L*	a*	b*	C	Firmness (N)
Factor A: Locations						
Tala	3.75	26.22	20.89	1.35	20.93	13.81
Dumuria	4.00	26.16	20.67	1.41	20.73	13.51
Keshobpur	3.68	25.92	20.61	1.32	20.66	13.47
Factor B: Precooling systems						
Without cooling (control)	3.62	24.43 c	22.54 a	1.51a	19.10 c	12.32 c
Hydrocooling	3.87	26.24 b	20.58 b	1.34 a	20.62 b	13.56 b
CoolBot-AC cooling	3.94	27.63 a	19.07 c	1.18 b	22.60 a	14.91 a
Level of significance						
A	NS	NS	NS	NS	NS	NS
B	NS	**	**	**	**	**
A × B	NS	NS	NS	NS	NS	NS
CV (%)	8.64	3.21	3.71	7.73	3.70	2.93

In a column, the mean followed by the same letters were not significantly different by Tukey's HSD test at $p \leq 0.05$; NS, *, **, not significant or significant at $p \leq 0.05$ and $p \leq 0.01$, respectively, CV= Coefficient of variation, L* = lightness, a* = green-red variation, b* = blue-yellow variation, C = Chroma (Color intensity or saturation).

pH of dragon fruit flesh

The effect of precooling systems on fruit pH value was significant ($p \leq 0.05$) (Table 3). The maximum pH value (4.82) was recorded without precooling and the minimum (3.77) was noticed from the CoolBot-AC cooling system. There was no variation in pH observed due to location differences. Factorial interaction of locations by precooling systems was not significant for the pH ($p \leq 0.16$) of dragon fruit flesh.

Total soluble solids (TSS) of dragon fruit flesh

It was observed that the differences in TSS content of dragon fruits were significant ($p \leq 0.01$) due to precooling system differences (Table 3). The highest TSS (13.18 %) was recorded from the CoolBot-AC cooling system while without the cooling system produce the lowest TSS (10.47 %). The total soluble solids content was not varied due to location variation. Factorial interaction of locations by precooling systems was not significant for the TSS ($p \leq 0.77$) of dragon fruit flesh.

Titratable acidity (TA) of dragon fruit flesh

The titratable acid content of fruits precooled with the CoolBot-AC system was significantly higher ($p \leq 0.01$) than that of the without precooled fruits (Table 3). The titratable acidity content of dragon fruit was reduced markedly due to the variation of precooling systems and no significant differences were observed among the locations. Factorial interaction of locations by precooling systems was not significant for the TA ($p \leq 0.46$) of dragon fruit flesh.

Anthocyanin content of dragon fruit flesh

The effect of anthocyanin content on fruit pulp was significantly ($p \leq 0.05$) varied due to precooling system differences as displayed in Table 3. The anthocyanin content of the fruits treated with the CoolBot-AC system was 12.03 % more than the control treatments (without pre-cooling). The fruits precooled with the CoolBot-AC system was the highest anthocyanin content (14.46 mg/100 g FW) and the control was the lowest (12.72 mg/100 g FW). There were no differences in anthocyanin content of fruit pulp noticed due to location variation. Factorial interaction of locations by precooling systems was not significant for the anthocyanin content ($p \leq 0.07$) of dragon fruit flesh.

Flavonoid content of dragon fruit flesh

Significant ($p \leq 0.05$) variation in flavonoid content was found due to precooling system differences (Table 4). The maximum flavonoid content (269.28 mg/100 g FW) was found from the fruits precooled with the CoolBot-AC system whereas the minimum (186.52 mg/100 g FW) was obtained from the control. The flavonoid content of the fruits treated with the CoolBot-AC system was 30.73 % more than the control treatments (without precooling). However, no significant differences regarding flavonoid content were observed among the locations. Factorial interaction of locations by precooling systems was not significant for the flavonoid content ($p \le 0.30$) of dragon fruit flesh.

Total phenols content dragon fruit flesh

Significant ($p \le 0.01$) variation in total phenol content was observed due to the differences in precooling approaches (Table 3). The maximum total phenol content was observed when the fruits were precooled with the CoolBot-AC system whereas the minimum was found in control. Fruits precooled with the CoolBot-AC exhibited 32.55 % more total phenol content than that of control. No significant differences regarding total phenols content were observed among the locations. Factorial interaction of locations by precooling systems was not significant for the total phenols content ($p \le 0.80$) of dragon fruit flesh.

Carotenoid content of dragon fruit flesh

Carotenoid content significantly ($p \le 0.05$) differed among the precooling systems (Table 3). The maximum carotenoid (1.61 mg/100 g FW) was obtained from fruits pre-cooled with a CoolBot-AC system and the minimum (1.22 mg/100 g FW) from without precooling system followed by hydro cooling system (1.30 mg/100 g FW). The carotenoid content of the fruits treated with the CoolBot-AC system was 24.22 % more than the control treatments (without precooling). However, no noticeable differences regarding carotenoid content were observed among the locations. Factorial interaction of locations by precooling systems was not significant for the carotenoid content ($p \le 0.92$) of dragon fruit flesh.

Ascorbic acid content

Significant ($p \le 0.05$) difference in ascorbic acid content was found due to location variation (Table 3). The dragon fruits collected from Tala gave the highest ascorbic acid content than the fruits collected from Keshobpur. Statistically significant variation ($p \le 0.01$) was obtained among the precooling system on ascorbic acid contents of dragon fruits. Ascorbic acid of fruits precooled with the CoolBot-AC system (10.50 mg/100 g FW) was noticeably higher than without precooled fruits (9.26 mg/100 g FW). Factorial interaction of locations by precooling systems was not significant for the ascorbic acid content ($p \le 0.15$) of dragon fruit flesh.

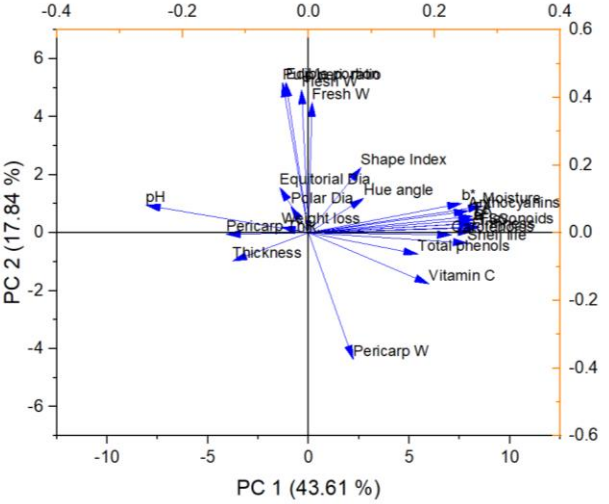
Table 3. Effect of locations and precooling systems on pH, TSS, titratable acid, anthocyanin, flavonoid, carotenoid and ascorbic acid of dragon fruit

Treatments	pH	TSS (%)	Titratable acidity (%)	Anthocyanins (mg/100 g FW)	Flavonoid (mg/100 g FW)	Total phenols (mg/100 g FW)	Carotenoid (mg/100 g FW)	Ascorbic acid (mg/100 g FW)
Factor A: Locations								
Tala	4.38	12.11	5.38	13.83	209.21	6.23	1.38	9.91 a
Dumuria	4.36	11.88	5.03	13.47	206.18	5.69	1.37	9.68 a
Keshobpur	4.32	11.83	5.20	13.43	202.76	5.55	1.38	8.76 b
Factor B: Precooling system								
Without cooling (control)	4.82 a	10.47 c	4.12 c	12.72 c	186.52 c	5.47 c	1.22 b	9.26 c
Hydro cooling	4.33 a	12.14 b	5.07 b	13.58 b	217.34 b	6.78 b	1.30 b	9.51 b
CoolBot-AC cooling	3.77 b	13.18 a	6.43 a	14.46 a	269.28 a	8.11 a	1.61 a	10.50 a
Level of significance								
A	NS	NS	NS	NS	NS	NS	NS	*
B	*	***	***	**	***	**	**	**
A × B	NS	NS	NS	NS	NS	NS	NS	NS
CV (%)	1.53	3.49	8.50	2.84	1.96	2.05	6.86	3.16

In a column, the mean followed by the same letters were not significantly different by Tukey's HSD test at $p \le 0.05$; NS, **, ***, not significant or significant at $p \le 0.01$, and $p \le 0.001$, respectively, CV = Coefficient of variation, TSS = Total soluble solids

Principal component analysis (PCA)

PCA was performed on all 27 studied variables of the experiment to understand the significance of the gross variability and to identify the main variables contributing the most to understanding the experimental variance (Figure 2). Of all the PCAs, the first two elements PCA 1 and PCA 2 accounted for 43.61 % and 17.84 % of the total variation, respectively. The biplot is a good way to visualize the findings from PCA that combines the principal element scores and the loading vectors in a single display. The biplot explained shelf life, shape index, fresh weight, pericarp weight, moisture, hue angle, L*, a*, b*, chroma, firmness, TSS, TA, anthocyanins, flavonoids, total phenols, carotenoids, vitamin C are positively correlated but equatorial diameter, polar diameter, pulp thickness, weight loss, pericarp thickness, flesh weight, pulp and pericarp ratio, edible portion and pH variables are not likely to be linked. According to the findings, all the investigated parameters had a variable effect on understanding the experimental variance, either positive or negative. Among 27 variables in PCA1, moisture (%), flavonoids (mg/100 g FW), TSS (%), L*, chroma (C), a*, TA (%), firmness (N), anthocyanins, shelf life, respectively were identified with more positive loadings on experimental variation while fruit weight (g) had the highest negative loadings on. However, PCA 2 did not explain the experimental variation too much.



Experimental Variables	PC1
Shelf life	0.253
Equitorial diameter	-0.046
Polar diameter	-0.028
Pulp thickness	-0.121
Shape index	0.083
Weight loss	-0.043
Fresh weight	0.006
Pericarp thickness	-0.131
Pericarp weight	0.071
Flesh weight	-0.011
Pulp and pericarp ratio	-0.041
Edible portion	-0.036
Moisture	0.277
Hue angle	0.088
L*	0.264
a*	0.262
b*	0.243
Chroma (C)	0.263
Firmness	0.260
pH	-0.258
TSS	0.271
TA	0.261
Anthocyanins	0.254
Flavonoids	0.273
Total phenols	0.174
Carotenoids	0.228
Vitamin C	0.191
Eigenvalue	11.78
Variation	43.61 %

Figure 2. PCA biplot (Principal component-1 PC1 vs Principal component-2 PC2) visualizing the correlations among the quality parameters affected by the locations and precooling approaches of dragon fruits.

Discussion

The results of this study suggest that precooling dragon fruits quickly to a low temperature is effective at increasing shelf life compared to no precooling treatment. The low-cost cooling facilities (Evaporative cooling, CoolBot-AC cooling) have been shown significant capability to attain the ideal temperature (5-16° C) and RH (85-95 %) for storage (Paull and Duarte, 2012) which are essential to prolonging the shelf life of horticultural commodities (Bill et al., 2014, Barman et al., 2015). Precooling might slow the high metabolic rate of dragon fruits. Also, low temperatures reduce the cell wall softening mechanisms that solubilize and degrade cell wall polyuronides and hemicelluloses (Huber, 1984). The findings of this study are comparable and consistent with the results of Shin et al. (2008) who mentioned that low temperature slows down the cell wall degradation of stored fruits.

Weight loss varied among locations may be the differences in compositions of fruit and their physiological events although the genetic causes were not investigated. Precooled dragon fruits reduced weight loss observed in the present study. Kitinoja and Thompson (2010) reported that loss of weight progressively enhanced over time of storage, and was higher for fully ripe dragon fruits, in support of the latter theory. However, the CoolBot-AC cooling system assists to retain moisture content in the fruits by inhibiting water loss from the surface and slow down the chemical reactions thus increasing the percent moisture content in fruits (Workneh, 2010). The dragon fruits precooled to CoolBot-AC system were better surface color than the fruits without cooling. This is consistent with prior research which found that there is a significant relationship between dragon skin color and environment, which makes dragon fruits sensitive to light intensity and air moisture (Esquivel et al., 2007). However, the results of our study indicated that high temperatures resulted in softening of dragon fruit tissue, with the opposite trend for low temperatures. These findings are consistent with Harivaindaran et al. (2008), who found that increased metabolic activity and loss of water during storage resulted in fruit softening and reduced dragon fruit firmness.

Harivaindaran et al. (2008) reported that fruit pH didn't change dramatically, especially in the ripening stage. These results are consistent with this study's findings. It was mainly citric and malic acid present in the fruits that directly influenced the cell pH, flavor, and color (Costa et al., 2011). Fruits' pH levels tend to rise as ripeness progressed. This happens as the concentration of organic acids in the fruit decreases and the concentration of soluble solids rises as the fruit ripens as indicated by Faridah et al. (2020). Total soluble solids increased over time and increased with precooling treatment compared to without precooling. Fruit maturity triggers the fruit to increase sugar content, resulting in greater TSS (Barbeau, 1993). This may be the hydrolysis of sucrose to invert sugar. The increase in TSS with precooling treatment is that low temperatures slow down respiration, resulting in less use of soluble solids by the dragon fruit. Our results were consistent with the findings of other experiments which showed that the TSS content changed during storage due to inversion of soluble solids, moisture loss by evaporation, and respiration (Resende et al., 2008; Miaruddin et al., 2011).

The low temperatures slow down acid consumption due to respiration, consequently also slowing TA losses within the dragon fruit during storage. Anthocyanin levels within our experiment were consistent which Muche et al. (2018), who found that in grape (cv. Merlot) juice, significantly greater anthocyanin losses occurred when stored at 25-35° C compared to 5° C. The level of flavonoids identified in the present study is corroborated by the earlier study by Moo-Huchin et al. (2014) who reported that the 100 g of fresh dragon fruit contained total flavonoid content of about 255 mg. Also, red dragon fruits contain more phenolic substances compared to the other color fruits (Wu et al., 2006). Ascorbic acid levels due to precooling in our study were consistent with previous research findings that low temperature during storage changes membrane permeability, preventing respiration and slowing down the oxidation of ascorbic acid (Hussain et al., 2012).

Conclusions

Compared to open fruits/without precooling (control), dragon fruits precooled with a CoolBot-AC system could efficiently decrease the weight loss rate, firmness, titratable acidity content, and prolong shelf life during storage. The dragon fruits precooled with the CoolBot-AC system retained acceptable color, high levels of TSS, ascorbic acid, anthocyanin, flavonoids, and total phenols content after three days of storage. However, dragon fruit didn't show any significant differences in physico-chemical quality attributes due to location variations. Therefore, dragon fruits precooled with the CoolBot-AC system could be effective to manage the postharvest quality and the results will create a new window for the postharvest management sector in sub-tropical environments.

Authors contribution

ZK collected the fruits sample, performed the laboratory experiment, contributed to recording the data and writing the initial manuscript. PKD was developed the concept and design the experiment, analysed data statistically, assessed the results and review the manuscript. MAM contributed to revising the manuscript critically for essential intellectual content. The final version of the manuscript has been read and approved for publication by all the named authors.

Competing interests

The authors have confirmed that they have no known competing interest associated with this publication.

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