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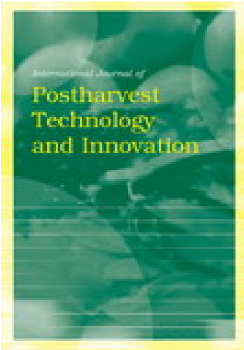

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Optimisation of strawberry precooling temperature using CoolBot: a potential post-harvest management tool pertinent to the subtropical environment

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Abstract: Conventional cold storage is financially impractical for farmers due to limited resources. A potential post-harvest management tool (CoolBot), which is relevant to the subtropical environment was introduced to investigate its applicability for extending the shelf-life of strawberries and controlling their spoilages. Different precooling temperatures [4°C, 8°C, 12°C, control (22°C)] were evaluated as means of post-harvest management of strawberries to determine the optimum precooling temperature during the winter season of 2019–2020. Precooling to 4°C resulted in decreased ascorbic acid and titratable acidity losses. It also delayed the free radicle scavenging activity in strawberries and caused in lowered fruit decay percentage as well as weight loss percentage, and improved firmness, prolonged shelf life by more than three days, and preserved skin colour. The installation cost saving plus less post-harvest losses contributed to net annual profit Tk. 6,777,000. Therefore, the results indicate that CoolBot could be an effective post-harvest tool for precooling strawberries to 4°C in subtropical environments.

Keywords: subtropical; precooling; net profit; CoolBot; shelf life.

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1 Introduction

Post-harvest loss management is a key concern worldwide due to growing population and shrinking resources (e.g. land, water). Cultivation of strawberries in Bangladesh has expanded greatly, but post-harvest management strategies have remained largely the same. 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). Previous researchers have claimed that in India every 1% reduction in loss will save 5 million tons of fruits per year (Saraswathy et al., 2018). Reducing post-harvest losses could also mean a lot for Bangladesh. In Bangladesh, strawberry farmers lack of knowledge regarding good harvesting practices, and the necessity of precooling to extend the shelf life of strawberries.

Precooling slows the ripening process, respiration rate, senescence, and water loss from the harvested fruit, which helps to retain overall fruit quality and prolong shelf life (Workneh, 2010; Kitinoja and Thompson, 2010). Strawberry precooling is essential within the first hour of harvest. Without precooling, marketability decreases rapidly (DeEll, 2005). Since the strawberry metabolism rate is so fast, and precooling slows it down, precooling is very important to maintain post-harvest fruit quality. Therefore, 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. Nevertheless, temperature control alone can extend shelf life by weeks or even months. The most important factors in maintaining good fruit quality are prompt precooling and maintaining an appropriate environment during transportation as well as storage condition (Talbot and Chau, 2002). However, cold storage facilities and continuing cold chains help to gain more revenue by keeping the products for a longer period with maintaining the acceptable quality (Erkan, 2013). Also, fresh fruits and vegetables will be accessible year-round, and it will offer income-generating opportunities for unemployed youths (Sargin and Okudum, 2016). In sub-tropical climate, a low-cost cold storage technology is so vital to small-income farmers and little-scale agro-processors (Kitinoja and AlHasan, 2012; Workneh, 2010). Now-a-days the low-cost cold storage facilities viz. evaporative cooling, and CoolBot cooling is becoming so popular and obtainable for the low-income growers (Saran et al., 2010; Kitinoja and Thompson, 2010; Kitinoja and AlHasan, 2012). Therefore, the researchers are suggested for small-income farmers to use low-cost cooling facilities to prolong the life span of the harvested fruits and vegetables and decrease losses of post-harvest (Roy and Pal, 1994; Saran et al., 2010; Workneh, 2010).

Bangladeshi farmers using CoolBot may prolong strawberry shelf life and save a significant number of fruits from spoilage. Also, farmers can use CoolBot as a cold storage for other seasonal fruits. Being able to extend shelf life and save strawberries from spoilage using CoolBot-AC technology might be helpful in overcoming existing post-harvest management challenges in Bangladesh. Therefore, the aims of the current work were to optimise precooling temperature for strawberries in Bangladeshi conditions using CoolBot facilities while evaluating physicochemical characteristics of stored fruits in order to extend shelf life and reduced strawberries post-harvest losses.

2 Materials and methods

2.1 Location of experiment, design, treatment, materials, environments of CoolBot room

The experiment was carried out at the Horticulture Laboratory, Khulna University, Bangladesh, from December 2019 to June 2020. The experiment consisted of four different precooled temperatures viz. 4°C, 8°C, 12°C, control (22°C) for overnight (7.0 p.m. to 7 a.m.) (12-h) cooling. The experiment was carried out in a completely randomised design (CRD) which was replicated five times. Individual precooling temperature consisted of 50 clam shells containing 400 g strawberry/shell. Thus, each replication consisted of 10 clam shells of strawberries. Mature ripe strawberries (RU-2) were selected as the experimental materials. A CoolBot room was developed following the procedure outlined by the Horticulture Innovation Laboratory, USA. The room was totally concealed and insulated, and the temperature was adjusted by a CoolBot (Store It Cold, USA) panel. The developed CoolBot facility took <2 hours to reach the lower limit of room temperature (4°C). The relative humidity (RH) of the CoolBot room was 90–95%. The different dimensional factors of the CoolBot room are given below.

- cold storage facility outside dimension: 7 ft × 9 ft × 10 ft
- cold storage facility inside dimension: 6 ft × 8 ft × 9 ft

- cold storage facility door dimension: 0.1 ft × 3 ft × 7 ft
- floor area = 48 sq-ft.

2.2 Physicochemical post-harvest quality assessment of strawberry

Strawberry shelf life was assessed at different days of storage by measuring appearance, (colour chart) rotting, firmness, disease incidence (scale rating: 0 means no decay or excellent quality and 4 means >40 % area infected or very poor quality) (Wang et al. 2021), etc. The first measurement was done when the maximum numbers of fruits were marketable. Three clamshells of strawberries were also randomly selected every two days from each treatment and weighed with an electric balance for comparison with the weight of first day, expressed as a percentage. The following equation was followed to assess the weight loss-

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

M_0 is the initial fresh weight of the strawberry, and M_1 is the individual sampling day measured weight (Qin et al., 2015).

A food texture analyser (Shimadzu EZ-SX, USA) was used to determine the firmness of treated strawberries (2 mm diameter). Each fruit was penetrated at four different equilateral locations to assess its firmness. The probe speed was 2 mm/s. and the penetration depth was 5 mm. The maximum force firmness was stated in N/cm^2. Likewise, the surface colour of the strawberry was determined using a chromo meter (CR-410, Konica Minolta, USA) by calculating L*, a*, and b* values, where L* represents brightness, a* means redness, b* means yellowness, and the output was evaluated as hue angle (*h*). The following equation was used to assess the hue angle: $h = \tan^{-1}(b^*/a^*)$. Also, the visual quality losses (fungal decay, brushing, softening, rupturing skin) of stored strawberry fruits were evaluated by visual inspection and disease incidence scale rating, 0 means no decay percentage or excellent quality and 4 means >40 % area infected or very poor quality, etc (Wang et al. 2021) for every two days. The fruits infected with visible fungal mycelia or 1/3 damaged was discarded from the clamshells, and the decay percentage was determined from the total number of strawberries.

The pH of pulp was determined using a benchtop pH meter (HI2210, Hanna Instrument, USA, 0.01 pH resolution) 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, strawberry titratable acidity (TA) was assessed using the following procedure mentioned by Mazumdar and Majumdar (2001) and Saini et al. (2006).

In order to determine strawberry ascorbic acid contents, 30 g of strawberry pulp was weighed and melded for 3 to 4 minutes with 6% meta phosphoric acid. Then 15 g of the mixture was combined with 85 g of 3% meta phosphoric 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 mentioned by Mazumdar and Majumdar (2001) and Saini et al. (2006). Finally, the following equation was used to determine the ascorbic acid content:

$$\text{Ascorbic acid (mg/100 g FW)} = V \times T \times \frac{100}{W}$$

V is the in titration volume of dye used, *T* is the standardised dye value, and *W* is the pulp weight.

Anthocyanins were extracted with ethanolic-hydrochloride. Colour intensity was measured calorimetrically. From the reading, the amount of the pigment present was determined. The total procedure was illustrated by Mazumdar and Majumdar (2001) and Saini et al. (2006). The following calculation was used to assess the anthocyanin content of the strawberry pulp.

$$\text{Total absorbance (/100 g sample)} = \frac{e \times b \times c}{d \times a} \times 100$$

a is the sample weight, *b* is the volume constructed for colour determination *c* is the total volume, *d* is the aliquot volume taken for assessment, and *e* is the 535 nm volume.

$$\text{Anthocyanin (mg/100 g FW)} = \frac{Total\ absorbance}{98.2}$$

The scavenging activity of the free radicle of the strawberry extracts was analysed using 2,2-diphenyl-1-picrylhydrazyl according to Jadid et al. (2015). Methanol was used to prepare 2,2-diphenyl-1-picrylhydrazyl solution and then the solution was added to make different concentrations of the extracts of strawberry. At 517 nm the absorbance changes of each test tube were determined by a UV spectrophotometer. However, a positive control (standard) as ascorbic acid was used. These measurements were presented in blank as well as strawberry extract. The following equation was used to compute the results:

$$\text{Scavenging activity (\%)} = 1 - \frac{Absorbance_{sample}}{Absorbance_{Blank}} \times 100$$

2.3 Economic evaluation of using CoolBot system

Yields (kg year^{-1}) of strawberries were calculated based on BBS (2020) and the average price was computed based on DNCRP (2020). The yearly revenue from strawberries was evaluated using the following equation:

$$\text{Revenue (Tk. Year}^{-1}\text{)} = \text{Total yield (kg year}^{-1}\text{)} \times \text{Price (Tk. kg}^{-1}\text{)}$$

It is assumed that benefit expanded from the CoolBot system was equal to the present losses of strawberries after harvest. The losses for strawberries after harvest were set as 36% in Bangladesh. The following equation was used to compute the benefits of storing strawberries with the CoolBot system.

$$\text{Benefit (Tk. year}^{-1}\text{)} = \text{Revenue-Revenue} \times \text{(100\%-Post-harvest losses of strawberry)}$$

The annual profit was determined using the following formula:

$$\text{Annual Profit (Tk. year}^{-1}\text{)} = Benefit - \frac{Net\ Installation\ Cost}{Lifetime\ of\ the\ project}$$

2.4 Statistical analysis

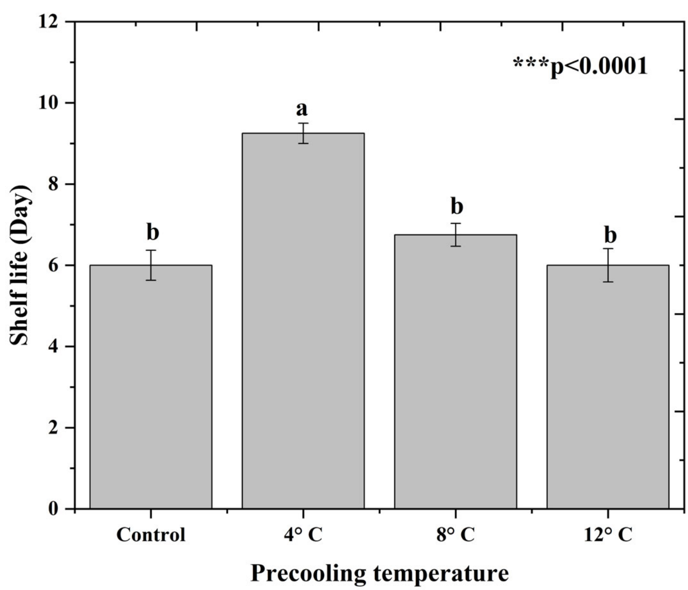
Data were calculated using the analytical software SAS following the procedure of GLIMMIX and Tukey's HSD test was done for mean separation at $p \leq 0.05$ (SAS 9.4, Cary, NC). Also, the graphical software SigmaPlot 10.0 was used for the illustration of the graphs. An economic evaluation was carried out to assess the feasibility of the CooBot system in Bangladesh.

3 Results

3.1 Shelf life

Effects of different precooling temperatures [4°C, 8°C, 12°C, control (22°C)] on the shelf life of strawberries differed significantly from each other (df = 3, f-statistics = 20.73, p-value = 0.0001) as displayed in Table 1. Fruit precooled to 4°C had maximum shelf life (9.25 days), while fruit without precooled (control) had a minimum shelf life (6.00 days) (Figure 1). The results revealed that precooling to 4°C prolongs shelf life (>3 days). Shelf life for the 8°C and 12°C treatments did not vary statistically with the control.

Figure 1 Effect of precooling temperature on strawberry shelf life



Note: Data are shown as mean ± standard error. Bars that do not contribute to a letter are significantly unique based on Tukey's HSD test and p-value indicating level of significance.

Table 1 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on shelf life and weight loss of strawberry

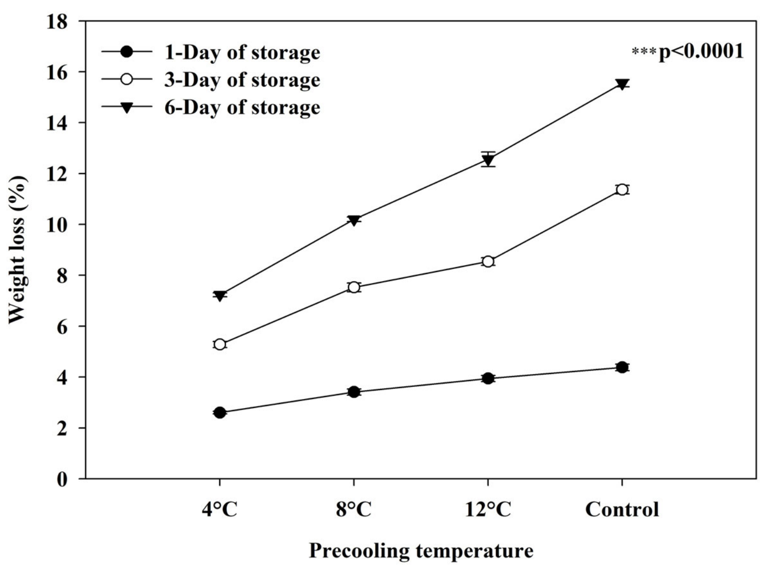
Source	*df*[a]	*Shelf life (day)*		*Weight loss (%)*					
				Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	20.73	0.0001***	49.57	0.0001***	270.23	0.0001***	412.06	0.0001***
Error	12	-		-		-		-	
Total	15	-		-		-		-	
CV (%)		9.67		6.07		3.76		3.06	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***$p < 0.0001$.

3.2 Weight loss

The distinct temperatures for precooled of strawberries was followed a weight loss trend that is shown in Figure 2. The various temperatures for precooling had a significant (df = 3, f-statistics = 412.06, p-value = 0.0001) effect on the weight loss of strawberries that were demonstrated in Table 1. During the storage period, gradually increased of weight loss. At 1 day of storage, precooled strawberries at 4°C and 8°C were significantly (***$p < 0.0001$) lower weight loss than that of without precooling and 12°C. The same trend was observed at 3 and 6 days of storage. The fruits' weight loss was precooled by separate temperatures shown as control > 12°C > 8°C > 4°C. The reference value of weight loss indicated that 7.6 to 13.6 (%) loss of weight after storage of 3 days with 10°C storage temperature.

Figure 2 Effect of precooling temperature on weight loss of strawberry

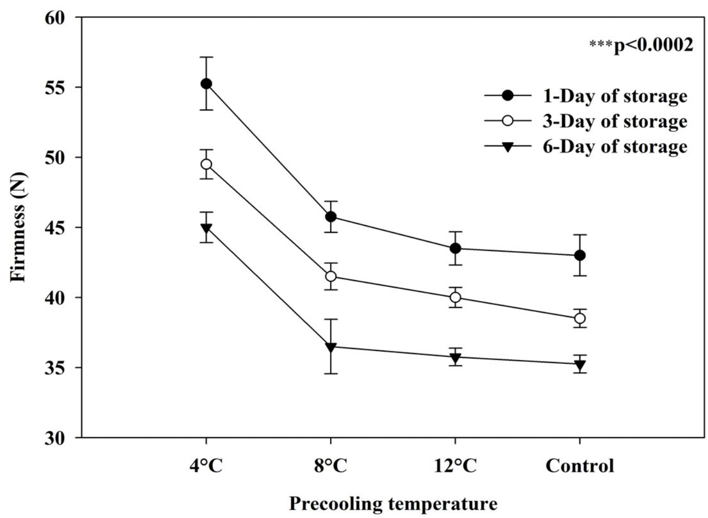


Note: The values are shown as mean ± standard error, and p-value indicates level of significance.

3.3 Firmness

Firmness is a vital strawberry quality indicator. The strawberry tissue firmness trend at different precooled temperatures is presented in Figure 3. After 6 days of storage, the lower precooling temperatures were found to play a key role to reduce the firmness of strawberries wherein 4°C precooling temperature significantly overweighted the firmness level incurred by both 12°C and 8°C temperatures (df = 3, f-statistics = 14.91, p-value = 0.0002) as shown in Table 2. During the storage period, all samples became less firm. After 6 days of storage, the strawberry precooled to 4°C had the maximum firmness value (45.00) and the strawberry without precooled had the minimum firmness value (35.25) followed by 12°C and 8°C. However, the reference value firmness varied from 32.0 to 48.0 (N) which differed due to cultivars, storage condition, temperature within the storage, the composition of the fruits, growing conditions, the temperature within fruits, and metabolic rate within fruits etc.

Figure 3 Effect of precooling temperature on firmness of strawberry



Note: The values are shown as mean ± standard error, and p-value indicates level of significance.

Table 2 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on the firmness of strawberry

Source	*df*[a]	*Firmness (N)*					
		Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	15.57	0.0002***	33.00	0.0001***	14.91	0.0002***
Error	12		-		-		-
Total	15		-		-		-
CV (%)		6.17		4.03		6.27	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***p < 0.0001.

3.4 Surface colour

Strawberry appearance differs by surface colour. Discoloration primarily occurs on the surface of the strawberry during storage, resulting in spoilage. After six days of storage, the various precooling temperatures had a significant (df = 3, f-statistics = 5.99, p-value = 0.0001) effect on changes in the surface colour of strawberries that was illustrated in Table 3. Changes in strawberry surface colour were determined by hue angle. The hue angle of strawberries samples from different precooled temperatures decreased gradually due to the passes of time in storage. The hue angle of the control, 12°C, 8°C, and 4°C treatments decreased by 31.52%, 30.67%, 26.21%, and 18.03%, respectively, when compared with the primary hue angle value after storage of 6 days. The strawberries precooled to 4°C had a higher hue angle than the other treatments, with high statistical significance (**p<0.001). Though the reference value of the hue angle of strawberry differed from 23 to 25 (°h) at 6 days of storage maintaining 10°C storage temperature.

Table 3 Effect of precooling temperature on surface colour (hue angle) and fruit decay of strawberry

Treatments	*Hue angle (°h)*			
	Day 0	*Day 1*	*Day 3*	*Day 6*
Control (22°C)	33.0 ± 0	26.63 ± 0.7 b	24.38 ± 0.8 c	22.60 ± 0.9 b
4°C	33.0 ± 0	30.65 ± 0.7 a	28.95 ± 0.6 a	27.05 ± 0.9 a
8°C	33.0 ± 0	28.63 ± 0.3 ab	26.75 ± 0.4 ab	24.35 ± 0.6 ab
12°C	33.0 ± 0	27.10 ± 0.4 b	25.50 ± 0.4 bc	22.88 ± 0.8 b
f-statistics	0.00	10.37	12.07	5.99
p-value	0.00	0.0012	0.0006	0.001
CV (%)	0.00	3.99	4.28	6.87

	Fruit decay (%)		
	Day 1	*Day 3*	*Day 6*
Control (22°C)	4.39 ± 0.2 a	24.85 ± 0.7 a	57.56 ± 1.1 a
4°C	1.00 ± 0.1 d	10.85 ± 0.6 d	19.80 ± 1.8 d
8°C	2.92 ± 0.1 c	16.35 ± 0.5 c	35.99 ± 1.6 c
12°C	3.60 ± 0.2 b	21.73 ± 0.7 b	46.23 ± 1.7 b
f-statistics	97.61	86.18	988.70
p-value	0.0001	0.0001	0.0001
CV (%)	9.84	7.20	8.09

Notes: Means supported by the matching letters (a, b, c, d) within column do not vary significantly whereas means having different letters vary significantly and for manifold comparison a Tukey's HSD test was done at p < 0.05, ± value indicate standard error, p-value specify level of significance, CV – coefficient of variation.

3.5 Fruit decay

Fungal decay is the primary cause of post-harvest strawberry quality loss. A significant (df = 3, f-statistics = 97.61, p-value = 0.0001) variation in fruit decay percentage was detected between precooling treatments at 1 day of storage (Table 3). At 1 day of storage, the maximum (4.39%) decay occurred without precooling, and the minimum (1.00%) at 4°C, followed by 8°C and 12°C. The same trend was observed during the rest of the experimental period. Fruits decay percentage increased until, by 6 days, no precooling and precooling to 4°C reached 57.56% and 19.80%, respectively. However, the fruit decay percentage ranged from 0 to 100% depending on cultivars, storage condition, and duration of storage.

3.6 pH of strawberry pulp

The strawberry fruit pH increased during storage. At 1 day of storage, the effect of various precooling temperatures on the pH of strawberries differed significantly from each other (df = 3, f-statistics = 20.13, p-value = 0.0001) as displayed in Table 4. The initial pH was 3.0. At 1 Day of storage, the highest pH (3.65) was obtained from 12°C, followed by 8°C, 4°C, and then the control (3.13). The same trend was observed at three and six days of storage. However, the reference pH value of strawberries varied from 3.0 to 3.5.

Table 4 Effect of precooling temperature on pH and TSS of strawberry

Treatments	*pH*			
	Day 0	*Day 1*	*Day 3*	*Day 6*
Control (22°C)	3.0 ± 0	3.13 ± 0.04 b	3.26 ± 0.03 b	3.35 ± 0.01 c
4°C	3.0 ± 0	3.49 ± 0.06 a	3.61 ± 0.01 a	3.68 ± 0.03 b
8°C	3.0 ± 0	3.56 ± 0.02 a	3.64 ± 0.03 a	3.72 ± 0.02 ab
12°C	3.0 ± 0	3.65 ± 0.06 a	3.72 ± 0.05 a	3.83 ± 0.05 a
f-statistics	0.00	20.13	35.37	36.32
p-value	0.00	0.0001	0.0001	0.0001
CV (%)	0.00	2.93	1.92	1.88
	(TSS (%) or °Brix)			
	Day 0	*Day 1*	*Day 3*	*Day 6*
Control (22°C)	6.18 ± 0	6.67 ± 0.15 b	6.92 ± 0.17 b	7.19 ± 1.5 b
4°C	6.18 ± 0	7.56 ± 0.12 a	7.92 ± 0.06 a	8.21 ± 0.08 a
8°C	6.18 ± 0	7.55 ± 0.09 a	7.75 ± 0.07 b	7.93 ± 0.05 a
12°C	6.18 ± 0	7.55 ± 0.07 a	7.73 ± 0.07 b	7.84 ± 0.06 a
f-statistics	0.00	15.08	18.57	20.51
p-value	0.00	0.0002	0.0001	0.0001
CV (%)	0.00	3.10	2.74	2.45

Notes: Means supported by the matching letters (a, b, c, d) within column do not vary significantly whereas means having different letters vary significantly and for manifold comparison a Tukey's HSD test was done at $p < 0.05$, ± value indicate standard error, p-value specify level of significance, CV – Coefficient of variation.

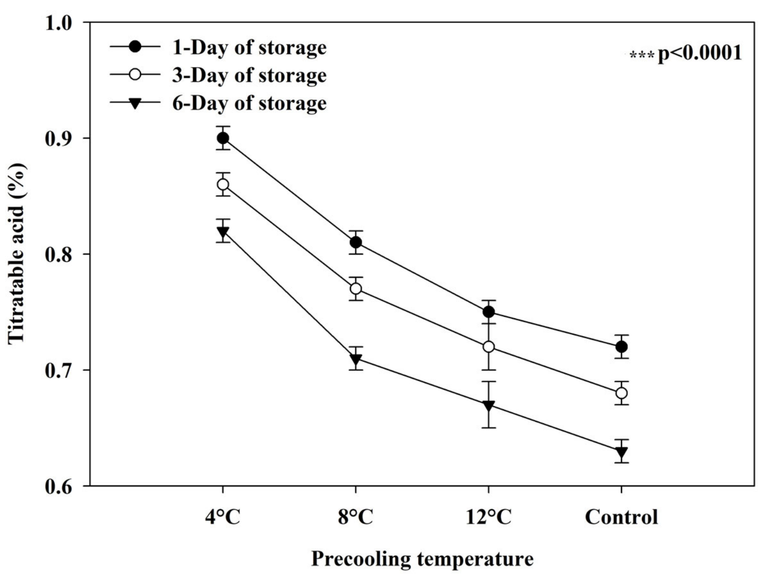
3.7 Total soluble solids

The TSS is a key sign of strawberry sweetness. The trends over time of strawberry TSS precooled in different temperatures are displayed in Table 4. After 6 days of storage, the various precooling temperatures had a significant (df = 3, f-statistics = 20.51, p-value = 0.0001) effect on the TSS levels of strawberries. During the storage, the TSS amount exhibited an upward movement from all samples. The strawberries precooled to 4°C had the highest TSS value (8.21%) followed by 8°C, 12°C, and then the control (7.19%) after storage of 6 days. The reference value of TSS in strawberries differed from 6.0 to 15 (%) which changed due to cultivars, storage conditions, the composition of the fruits, and metabolic rate within fruits etc.

3.8 TA of strawberry pulp

Strawberry flavour depends on the amount of TA present within the strawberry. Strawberry respiratory metabolism rises as TA decreases. At 1 day of storage, the different precooling temperatures had significant (df = 3, f-statistics = 105.42, p-value = 0.0001) effect on the TA of strawberries that was demonstrated in Table 5. In Figure 4, the TA content of all four precooling treatments declined continuously with the addition of storage time. TA declined most in the control (22°C) group, followed by 12°C, 8°C, and then 4°C. The reference value of TA differed from 0.25 to 0.95 (%) based on strawberry cultivars and storage conditions.

Figure 4 Effect of precooling temperature on strawberry TA



Note: The values are shown as mean ± standard error, and p-value indicates level of significance.

Table 5 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on titratable acid of strawberry

Source	*df*[a]	*Titratable acid (%)*					
		Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	105.42	0.0001***	39.30	0.0001***	30.91	0.0001***
Error	12	-		-		-	
Total	15	-		-		-	
CV (%)		1.90		3.17		4.12	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***p < 0.0001.

3.9 Ascorbic acid content

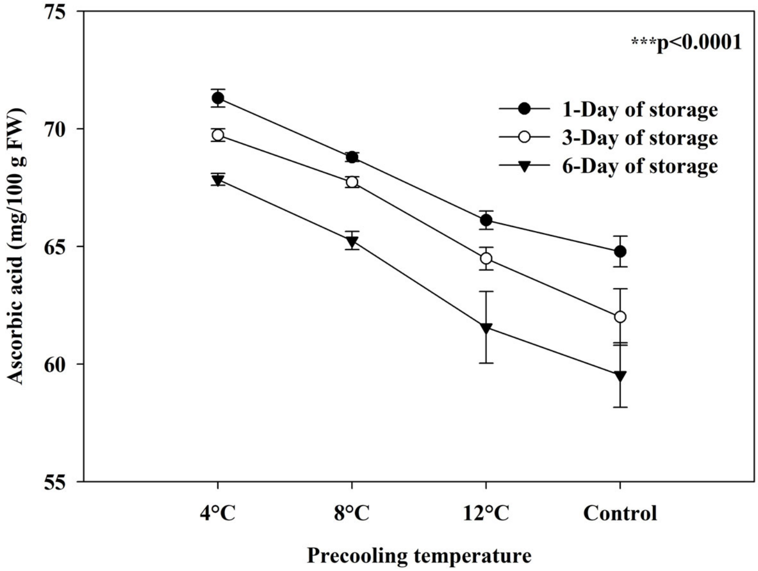
Strawberry ascorbic acid (AA) content decreased for all precooling temperatures with passes of storage time (Figure 5). The lower precooling temperatures were found to play a key role to modulate the ascorbic acid content of strawberries wherein 4°C precooling temperature significantly overweighted the ascorbic acid level incurred by both 12°C and 8°C temperatures (df = 3, f-statistics = 12.53, p-value = 0.0005) as shown in Table 6 after storage of 6 days. Strawberries precooled at 4°C had significantly (***p < 0.0001) more ascorbic acid than the control during the whole experimental period. Ascorbic acid at 4°C was higher than the other precooled treatments over time. The AA content of 4°C, 8°C, 12°C, and control treatments decreased by 7.05%, 10.62%, 15.67% and 18.45%, respectively after storage of 6 days. However, the prior results indicated that the ascorbic acid content of strawberries varied from 58.8 to 75.5 (mg/100 g) which differed due to cultivars and storage conditions variations.

Table 6 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on ascorbic acid of strawberry

Source	*df*[a]	*Ascorbic acid (mg/100 g FW)*					
		Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	44.15	0.0001***	26.08	0.0001***	12.53	0.0005***
Error	12	-		-		-	
Total	15	-		-		-	
CV (%)		1.29		2.03		3.31	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***p < 0.0001.

Figure 5 Effect of precooling temperature on strawberry ascorbic acid



Note: The values are shown as mean ± standard error, and p-value indicates level of significance.

3.10 Anthocyanins content of strawberry pulp

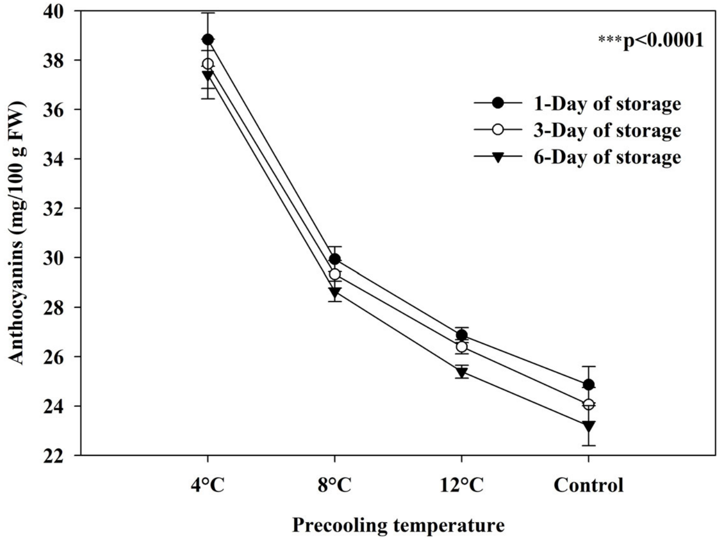
Effect of different precooling temperatures [4°C, 8°C, 12°C, control (22°C)] on anthocyanins content of strawberry varied significantly from each other at 6 days of storage (df = 3, f-statistics = 84.16, p-value = 0.0005) as displayed in table 7. At 6 days of storage, anthocyanin levels for the 4°C precooling treatment were 14% more than the control treatment (Figure 6). Anthocyanin levels for the control were also low compared to the 8°C and 12°C precooling treatments. The fruits precooled at 4°C had the greatest anthocyanin content (37.41 mg 100 g^{-1}) and the control had the lowest (23.20 mg 100 g^{-1}) after storage of 6 days. The reference value of anthocyanins of strawberries varied from 8.5 to 65.9 mg 100 g^{-1} based on the cultivars.

Table 7 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on anthocyanins content of strawberry

Source	*df*[a]	*Anthocyanins content (mg/100 g FW)*					
		Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	73.73	0.0001***	77.15	0.0001***	84.16	0.0005***
Error	12		-		-		-
Total	15		-		-		-
CV (%)		4.77		4.66		4.75	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***p < 0.0001.

Figure 6 Effect of precooling temperature on strawberry anthocyanins



Note: The values are shown as mean ± standard error, and p-value indicates level of significance.

3.11 Radicle scavenging assessment

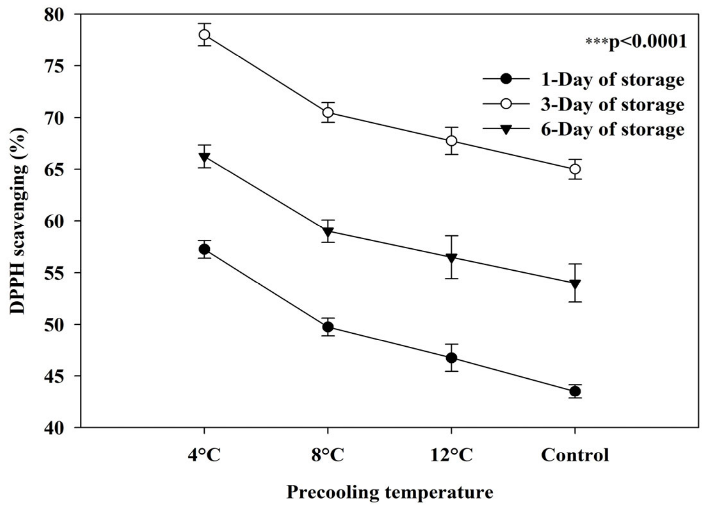
The radicle scavenging using the DPPH procedure for assessing fruit antioxidant capacity was used in this experiment since it is simple, reliable, and the method commonly used. In Figure 7, DPPH free radicle scavenging rates for all precooling treatments expanded first and then dropped. The different precooling temperatures had a significant (df = 3, f-statistics = 25.15, p-value = 0.0001) effect on the free radical scavenging activity of strawberries that was shown in Table 8 after storage of 3 days. On day 3 of storage, DPPH free radicle scavenging rates of all precooling treatments peaked, and on day 6 they declined. DPPH free radicle scavenging rates for the 4°C precooling treatment were significantly greater (***p < 0.0001) than the control. The reference value of DPPH radicle scavenging activity of strawberries varied from 35 to 80 (%) which changed due to cultivars and storage conditions variations.

Table 8 Degree of freedom (df), f-statistics, and p-values (Pr > F) of type III tests of fixed effects of precooling temperature on antioxidant (%) of strawberry

Source	*df*[a]	*Antioxidant (%)*					
		Day 1		*Day 3*		*Day 6*	
		F	*Pr > F*	*F*	*Pr > F*	*F*	*Pr > F*
Treatment	3	38.31	0.0001***	25.15	0.0001***	11.20	0.0009***
Error	12	-		-		-	
Total	15	-		-		-	
CV (%)		3.85		3.17		5.36	

Notes: [a]df: degree of freedom, F – f-statistics, CV – coefficient of variation.
***p < 0.0001.

Figure 7 Effect of precooling temperature on strawberry antioxidant capacity



Notes: The values are shown as mean ± standard error, and p-value indicates level of significance.

3.12 Economic evaluation of using the CoolBot system

Conventional cold storage is financially and practically are unworkable for limited resources farmers. However, the cooling of perishable commodities by the CoolBot system offers growers to store their products on-farm with a minimum cost. The estimated cost of the conventional refrigeration system is Tk. 4,55,000 (approx.) whereas the projected cost for the CoolBot system is about Tk. 135,000 (Table 9). The CoolBot system saves Tk. 320,000 (approx.) (70.33%). The cooler construction costs that are not included in the item list that are assumed to parallel for both methods. Thus, the cooler construction costs are not included in the analysis. Moreover, the final economic evaluation indicated that the farmers could save a significant proportion of strawberries from spoilage as well as boost up their revenues, benefits, and annual profits, respectively which may create a new avenue for the post-harvest section in Bangladesh (Table 10). The installation cost saving plus less post-harvest losses contributed to net annual profit Tk. 6,777,000.

Table 9 Installed cost of conventional refrigeration and CoolBot room system

Sl. #	*Item*	*Conventional refrigeration system estimated cost (Tk.)*	*CoolBot room system estimated cost (Tk.)*
1	Air-cooled condensing unit (1.5 ton)	170,000	-
2	Ceiling mount, 15 $MBtuh^{-1}$, air defrost	285,000	
3	Air conditioner (General Inverter, 1.5 ton, ASGA-18JCCZ)	-	99,000
4	CoolBot controller	-	30,000
5	Insulation and foam		6,000
	Total	455,000	135,000

Table 10 Effect of using CoolBot facilities for storage of strawberries to boost up revenue, annual benefit and profit

Item	*(Tk. year^{-1})*
[a]Revenue	18,900,000
[b]Benefit	6,804,000
[c]Annual profit	6,777,000

Notes: [a]Total yield = 54,000 kg year^{-1} and average price = 350 Tk. kg^{-1};
[b]Post-harvest losses of strawberry = 36%;
[c]Net installation cost = Tk. 135,000 and the lifetime of the project = 5 years.

4 Discussion

The results of this study suggest that precooling strawberries 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 (Thompson, 2003; Nunes, 2008; Paull and Duarte, 2011) which are essential to prolonging the shelf life of horticultural commodities (Bill et al., 2014; Barman et al., 2015). One possible explanation for our findings is that precooling might slow the high metabolic rate of mature strawberries (Kuchi and Sharavani, 2019). Another explanation is that low temperatures reduce the cell wall softening mechanisms that solubilise and degrade cell wall polyuronides and hemicelluloses (Huber, 1984). Our findings results 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.

One possible explanation for the fruit weight loss the strawberries within our experiment exhibited over time may be the uninterrupted water loss from the strawberries to the adjacent atmosphere. Another possibility is that precooling strawberries reduced weight loss by slowing down respiration and other metabolic processes. Rahman et al. (2014) reported that loss of weight progressively enhanced over time of storage, and was higher for fully ripe strawberries, in support of the latter theory.

The results of our study indicated that high temperatures resulted in softening of strawberry tissue, with the opposite trend for low temperature. These findings are consistent with Ahmadi-Afzadi et al. (2013), who found that increased metabolic activity and loss of water during storage resulted in fruit softening and reduced strawberry firmness.

The strawberries precooled to a low temperature within our experiment had better surface colour than the higher temperatures. This is consistent with prior research which found that there is a significant relationship between strawberry skin colour and environment due to the thin skin of the strawberry fruit, which makes strawberries sensitive to light intensity and air moisture (Sharma et al., 2006). This is also consistent with prior research showing that the Toyonoko cultivar of strawberry tends to be bright red in colour in cooler temperatures (Shaw, 2004).

The explanation for why precooling the strawberry fruit to a low temperature decreased the fruit decay percentage may lie in fruit metabolism. The fruit decay percentage depends on several factors viz. physical handling, storage environments, fruit maturity etc. Nunes and Morais (2002) reported that decay percentage has previously been reported as being higher in fully matured strawberry fruit compared to partly ripe fruit. Therefore, the possible explanation for why precooling the strawberry fruit decreased fruit decay in stored strawberries may be that the low temperature reduced strawberry metabolism, slowing down the decay process.

Kafkas et al. (2007) reported that pH didn't change dramatically especially in the ripening stage, ranging from 3.33 to 3.43. These results are consistent with this study's findings. Further, the RU-2 strawberry is considered acidic, and the pH values recorded within this study support that assumption. Our research study also found that it was mainly citric and malic acid present in strawberry fruits that directly influenced the cell pH, flavor, and colour (Costa et al., 2011).

Our study found that TSS increased over time and increased with precooling treatment compared to no treatment. One possible explanation for the increase over time is that fruit maturity triggers the fruit to increase sugar content, resulting in greater TSS (Salamat et al., 2013). This may be the hydrolysis of sucrose to invert sugar. One possible explanation for the increase in TSS with precooling treatment is that low temperatures slow down respiration, resulting in less use of soluble solids by the strawberry. 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).

Our results indicate that the low temperatures slow down acid consumption due to respiration, consequently also slowing TA losses within the strawberry during storage. High temperatures reduced strawberry TA content, which is consistent with the findings of Nunes and Morais (2002) where TA was 0.72% of the original TA after three days of storage. However, previous research has indicated that the TA content is mostly influenced by genotypes where some genotypes exhibited more TA content than others (Resende et al., 2008).

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). Variation in ascorbic acid content might be cultivar and climate dependent (Proteggente et al., 2002), though this study considered only one strawberry cultivar.

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. Precooling having an effect on anthocyanin levels is also similar to the results of Lopes da Silva et al. (2003). They mentioned that different environmental factors affect the synthesis, content, and stability of strawberry anthocyanins.

Consistent with our findings regarding DPPH radical scavenging, previous research found storage temperature to be a vital factor in regulating the internal phenolic antioxidant activity of fruits (Alvarez-Suarez et al., 2014). Strawberry fruit stored at 5°C to 10°C had greater antioxidant content compared to 0°C, as reported by Ayala-Zavala et al. (2004).

The low-cost cold storage (CoolBot system) facilities allow growers to preserve locally grown produce for a longer period, in that way efficiently serving more local consumers (Dubey and Raman, 2016a). The installation and operational costs are significantly lower than conventional refrigeration systems reported by Saran et al. (2013), and Boyette and Rohrbach (1993), it has been widely accepted and used in different countries like Ghana, Kenya and India (Kitinoja and Cantwell, 2010; Saran et al., 2010; Kitinoja, 2013). This on-farm cold storage facility offers growers to earn more profit and reduces the need to transport produced for long distances (Dubey and Raman, 2016b). The capability to produce, store and eat food in the vicinity is desired to decrease greenhouse gas (GHG) emissions linked with food transportation. The CoolBot system consumed less electricity compared to a conventional refrigeration system (Saran et al., 2010). Therefore, the CoolBot system offers less operational cost as well as reduces GHG emissions. A large-scale adaptation of the CoolBot system will help to minimise emissions of GHG by lessening the need for food transportation (CDH Energy Corp., 2009; Kumar et al., 2019).

5 Conclusions

A developed cooling facility using CoolBot technology could be a low-cost chilling alternative. The cold storage room should be concealed properly to reach the desired room temperature (4°C). Compared to no precooling, strawberry fruit precooled to 4°C using CoolBot facilities had a greater shelf life, firmness, surface colour brightness, pH, °Brix, TA, ascorbic acid, anthocyanin content, and DPPH radical scavenging. It also caused in less decay of fruit and loss of weight. The CoolBot low-cost technology not only saves fitting and renovation expenses but also retain power and operational cost. The installation cost saving plus less post-harvest losses contributed to net annual profit Tk. 6,777,000. Therefore, the results indicate that CoolBot could be a potential postharvest management tool for precooling strawberries ensuring good post-harvest quality in subtropical environments.

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