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Improve the Cantaloupe Fruit Quality and Shelf Life Using a Forced-Air Cooling System

تحسين جودة ثمار الكنتالوب وفترة التخزين باستخدام نظام الهواء البارد المدفوع

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عبوات الفلين، التبريد السريع، معدل التنفس، فترة التخزين، الفقد في الوزن

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ABSTRACT

Increasing the shelf life of agricultural products is an important challenge of food science engineering. This study aimed to use a forced-air cooling system at a constant airflow rate of 2.4 m^3/s to improve the physico-chemical, texture properties, and shelf life of cantaloupe fruits under cold storage. Different packages (foam, plastic and carton) were used during four storage periods (0, 10, 20 and 30 days). Physio-chemical properties including weight loss, firmness, color, TSS, pH and respiration rate were measured and evaluated. Texture properties (hardness, cohesiveness, chewiness and resilience) were measured. From the experimental data, the final temperatures reached after 140 minutes were 7 and 10ºC for different packages. The cooling times 7/8th ranged from 117.5 to 132 minutes. Significant differences existed for the values of treated fruit properties compared to non-precooled fruit (control). Data also showed that firmness, color, and titratable acidity (TA) values decreased as the postharvest storage period of the fruits increased. Results showed significant differences ($p < 0.05$) in the texture properties values of cantaloupe fruits packed in foam packages that protected the fruits from surrounding environmental changes.

الملخص

هدفت هذه الدراسة لاستخدام نظام الهواء البارد المدفوع مع معدل تدفق هواء ثابت 2.4م^3/ث لتحسين الخصائص الفيزو-كيميائية، خصائص تحليل القوام القطاعي، وفترة التخزين لثمار الكنتالوب تحت ظروف التخزين البارد. تم استخدام ثلاثة أنواع من عبوات التعبئة الفلين، البلاستيك، والكرتون خلال أربع فترات تخزينية (0، 10، 20 و30 يوماً). وأيضا تم قياس وتقييم الخصائص الفيزو-كيميائية مثل الفقد في الوزن، الصلابة، اللون، المواد الصلبة الذائبة، رقم الحموضة ومعدل التنفس. كذلك تم قياس خصائص تحليل القوام القطاعي مثل الصلابة، التماسك، المضغية والرجوعية. أوضحت النتائج التجريبية أن درجة الحرارة المثلى (7، 10 مo) تم الوصول لها بعد زمن 140 دقيقة للعبوات المختلفة. كذلك الزمن اللازم لتبريد 87.5% من ثمار الكنتالوب تراوح بين 117.5 إلى 132 دقيقة. أظهرت النتائج وجود فروق معنوية بين قيم خصائص ثمار الكنتالوب المختلفة المعاملة مقارنة بالثمار غير المعاملة (غير المبردة). كذلك أظهرت النتائج انخفاض قيم كل من الصلابة، اللون، والحموضة الكلية للثمار مع زيادة فترات تخزين ما بعد الحصاد. أيضاً أظهرت النتائج فروقاً عالية المعنوية بين قيم خصائص تحليل القوام القطاعي لثمار الكنتالوب المعبأة في العبوات الفلين والتي تعمل على حماية الثمار من التغيرات البيئية المحيطة.

1. Introduction

Cantaloupe (*Cucumis melo L.*) is an important fruit in the world and especially in Saudi Arabia. It contains major components such as vitamins, minerals and dietary fiber. Cantaloupe production reached 230,246 tons from a cultivated area of 12,101 ha in Saudi Arabia. Maintaining fruit quality and quantity after harvest is a significant standard to increase global food supply in a highly effective manner. Several environmental factors such as temperature and relative humidity affect the quality properties, as well as consumer acceptance of fruits and vegetables sold at department stores. The proper management of temperature is an easy and simple way to reduce deterioration due to physiological activities occurring in fruit and vegetable tissues. In general, the reduction of the postharvest storage temperature offsets the length of shelf life (Nunes and Emond, 2002; Nunes *et al.*, 2009).

Temperature and relative humidity were studied as controlling parameters for respiration rate and physiological disorders through the storage periods of pomegranate fruit (Pareek *et al.*, 2015; Munhuweyi *et al.*, 2016). After harvesting, fruits and vegetables retain part of the sun's heat that is higher than recommended. Therefore, applying postharvest treatments such as precooling could reduce field heat temperature from the fruits to reach suitable storage temperatures (Brennan and Shewfelt, 1989; Aroucha *et al.*, 2016).

A forced-air cooling (FAC) technique was used as a postharvest treatment in the precooling process of fruits and vegetables. The FAC system requires high-capacity fans that move cold air through fruit packaging to increase the convection heat transfer between packaged fruits and the cooling medium (Gillies and Toivonen, 1995; Toivonen, 1997).

Many researchers have mentioned that the efficiency of the precooling process is affected by package design, package arrangement in the cooling room, cooling rates, size and the locations of the ventilation holes (Zou *et al.*, 2006a; Zou *et al.*, 2006b; Opara and Zou, 2007; Opara, 2011; Ngcobo *et al.*, 2012; Defraeye *et al.*, 2013; Delele *et al.*, 2013; Azam *et al.*, 2015; Berry *et al.*, 2015; Berry *et al.*, 2016; Elansari and Mostafa, 2018). Several methods of precooling were applied to the fruits and vegetables for the rapid removal of field heat to reach optimum storage temperature. The most recent studies indicated that precooling methods aim to decrease respiration rate and enzyme activities, keep firmness, help to inhibit pathogenic microbial growth and decrease weight loss (Talbot and Chau, 2002; Abu-Goukh *et al.*, 2015). The most common method for cooling fruits is forced-air cooling which is appropriate for many fruits (Brosnan and Sun, 2001; Elansari, 2009).

Fruit color is a key feature that affects customer acceptance of fruit or vegetable quality (Toivonen and Brummell, 2008). In addition, color is an important quality property that reflects the freshness of many fruits and vegetables (Clydesdale, 1993). Several studies summarized the characteristics related to the initial qualities of cantaloupe such as size, flesh color, skin color and firmness (Hardenburg *et al.*, 1986; Lester, 1996; Guzmán and Barrett, 2000; Kienzle *et al.*, 2011; Silveira *et al.*, 2011; Abu-Goukh *et al.*, 2015). Other studies reviewed the different characteristics related to the internal quality of cantaloupe fruit including the content of soluble solids, appearance, pulp aroma and flavor. These attributes are normally considered in order to evaluate the acceptance of fruit by consumers and are used as an index for grading and marketing (Guzmán *et al.*, 2009).

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Many studies also summarized the effects of packaging type on the quality of fruits and vegetables (Senhofa *et al.*, 2015; Giuggioli *et al.*, 2015; Ozturk *et al.*, 2016; Raseetha and Nadirah, 2018). Mokhtar and Shakak (2011) studied the effect of package type on the quality and shelf life of bananas and muskmelon fruits. The fruits were stored in two types of packaging materials for 15 days at 18 ± 1 °C and 85-90% relative humidity. The first type was an approved package from the Sudanese Standard and Metrology Organization (SSMO), while the other was a commercially available one. The physico-chemical changes (respiration rate, weight loss, peel color, fruit flesh firmness, TSS, titratable acidity, ascorbic acid content and reducing sugar) of the fruits were studied during storage. Results indicated that the SSMO approved packages decreased the respiration rate and weight loss, and hence prolonged the shelf life of the fruits compared to the conventional packages. Syahidah *et al.* (2015) studied the quality changes of fresh cut cantaloupe (*Cucumis melo* L. var Reticulatus cv. Glamour) in different types of polypropylene packaging (PP). They concluded that the PP container with only a lid (control) was suitable for fresh cut cantaloupe during the first 18 days of storage at 2°C.

In recent years, global concern for improvement technologies in postharvest fruits and vegetables helped many researchers develop treatments such as precooling and after harvest storage. Methods to maintain fruit and vegetable quality depend mainly on the improvement of postharvest treatments. Applying a postharvest treatment such as precooling could remove field heat from the fruits to reach suitable storage temperatures and extend the shelf life of fruits and vegetables. Therefore, the aim of this research is to evaluate the effect of packaging materials and storage periods, under forced-air cooling systems, on the quality and shelf life extension of cantaloupe fruits in Saudi Arabia.

2. Materials and Methods

2.1. Plant Materials:

Cantaloupe (*Cucumis melo L.*) was harvested at a mature stage from a private farm in Al Hassa, Saudi Arabia in November 2017. After the harvesting process, fruits with no external surface defects were selected by size (155 mm length, 110 mm diameter), color (L^*, a^*, b^*) ranging between 16 to 21, 17 to 21, and 8 to 15, respectively. All initial measurements were taken on the same day after being transported carefully to the laboratory of the Agricultural Systems Engineering Department, College of Agricultural and Food Sciences, King Faisal University.

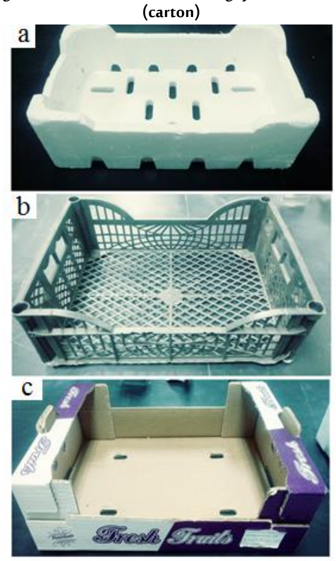
2.2. Treatments and Storage Conditions:

One hundred sixty-two fruits were distributed into three sets of 54 fruits. Each set was divided into three sub-sets of 18 fruits. Fruits in each sub-set were packed in "three packages of six fruits each" foam (polystyrene), plastic (rigid plastic) and carton. The packages were selected as a common method used for packaging cantaloupe fruits in Al-Ahsa, Saudi Arabia. The number and size of the holes varied according to the design of the manufacturer as shown in Figure 1. The dimensions of the three packages (foam, plastic and carton) were (0.49 x 0.39 x 0.15 m). All treated packages (27 packages) were placed in a precooling room under a forced-air cooling system at 10°C and 95% and at a constant airflow rate of 2.4 m^3/s.

The arrangement of the packages inside the cooling room was in rows, with each row containing three packages as shown in Figure 2, and the distance between the different rows was 0.5 m on all sides to allow cold air to pass through the holes on each side of the packages. The arrangement of the packages in the cooling room as shown in Figure 2 was chosen to expose the different packages to cold air at the same time. A centrifugal fan (*Kruger KDD 10/10 750W 4P-1 3SY*) was used in the FAC system to move cold air through the different packages.

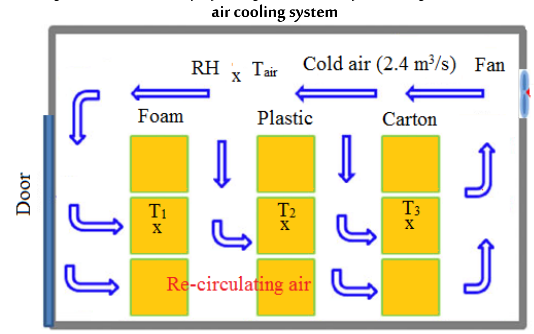
Temperature and relative humidity during the precooling process were monitored using dry and wet bulb thermometers as shown in Figure 2. Internal fruit temperatures were collected every five minutes by inserting the thermocouple (T-type, THERMOCOUPLE PRODUCTS Ltd, Edenvale, South Africa, operating range of -30 to 100°C and accuracy of ± 0.025%) into the core of one fruit per package.

Fig 1. Type of packages used in the forced-air cooling system: a (foam), b (plastic), and c (carton)



An airflow meter was used to measure air velocity under forced-air cooling treatments (Type DCFM8906, USA, airflow volume range of 0 to 99.999 CFM or CMM, air velocity range of 0.4 to 30 m/s, temperature range of -10 to 50°C and accuracy ±3%). Another set of the experiment (control) was placed without cooling at room temperature (23°C and 78% RH). After the precooling process the treated fruits were stored at room temperature (4°C and 90-95% RH) for four storage periods (0, 10, 20, 30 days). The physico-chemical properties of weight loss, firmness, respiration rate, color, TSS and pH with texture properties were measured at the different storage periods.

Fig 2. Arrangement of cantaloupe packages inside the precooling room under a forced-air cooling system



To follow temperatures inside the cooling unit, four thermocouples were set inside the cooling unit. Three thermocouples were set inside the different packages of treated fruit (foam, plastic and carton), and another was set near the air inlet side of the chamber. Temperatures recorded by the thermocouples were collected by a 10X data logger (*Cambell Scientific Ltd., Shepshed, UK*) every 10 minutes. Fruits were removed from the cooling room, when they reached 7/8th (as indicated in the following section) of the cooling time.

2.3. Evaluation of the Cooling Process:

The evaluation of the cooling system performance was limited to the cooling time and cooling coefficient. The measured temperatures during the precooling process were used to calculate the cooling ratio, cooling coefficient, and the $7/8^{th}$ cooling time. The cooling time ($7/8^{th}$) and cooling coefficient are procedural in commercial cooling processes, and they are industry standards and easy to be calculate (Brosnan and Sun, 2001). The cooling ratio (R) is the unaccomplished temperature change as a percentage of the total cooling possible in the forced-air cooling system and it is calculated by the following equation (Saquet *et al.*, 2016):

$$R = T - T_{air} \ / T_i - T_{air} \quad (1)$$

Where T is the flesh temperature (°C) at the time t (h), T_{air} is the aircooling temperature (°C) and T_i is the initial temperature of the flesh (°C).

The slope of the line from a plot of the natural log of the temperature ratio versus the cooling time is known as the cooling coefficient (Guillou, 1960; Becker and Fricke, 2006). The cooling coefficient (C) indicates the change in the fractional unaccomplished temperature difference between the product and its environment per unit change in the cooling time (ASHRAE, 2006). It is calculated by the following equation (Saquet *et al.*, 2016):

$$C = \ln R_1 - \ln R_2 / t_1 - t_2 \quad (2)$$

The cooling time ($7/8^{th}$) is mostly used to evaluate the speed of the precooling treatments, which is known as the time required to decrease 87.5% of the field temperature to air cooling temperature. The $7/8^{th}$ cooling time is time required to reduce the temperature difference between the products and air cooling by 87.5%, and it is calculated by the following equation (Saquet *et al.*, 2016):

$$t_{7/8} = \ln(7/8) / C \quad (3)$$

2.4. Measurements:

2.4.1. Color loss

A minolta colorimeter (CR400 model) was used to measure the differences in skin color (outside surface) and the parameters of fruit (L^*, a^* and b^*), where L* measures lightness (100 L^* indicates white, 0 L^* indicates black), a^* (a^{*+} indicates redness, a^{*-} indicates greenness) and b (b^{*+} indicates yellow, b^{*-} indicates blue). The measurements were carried out during different storage periods to compare them with the initial values before storage (Yam and Papadakis, 2004). Skin color was measured for a fruit at three locations on the skin beginning at the neck region of the fruit, and the average of the three values was determined.

2.4.2. Firmness

A digital instrument (Effe-Gi, Ravenna, Italy) was used for measuring the maximum force (N) required to penetrate the texture with an 8 mm plunger. The results were expressed in Newton.

2.4.3. Weight loss

The weight loss of cantaloupe fruit was calculated by measuring the difference between the initial weight before storing the treated fruits and the final weight at the end of the storage period.

2.4.4. Texture properties

Texture properties were measured using the TA.XT-plus Texture Analyzer, manufactured by Stable Micro Systems, Ltd, Vienna Court, United Kingdom. The texture properties of fruits were determined by measuring the texture profile analysis of two fruits from each package. The structural analysis of the textures was performed by pressing twice on the whole fruit set at a horizontal level. The sample strength was measured at a preset speed 2 mm/s, test speed of 1 mm/s, post-test speed of 2 mm/s, distance at 30% strain, time of 1 s, trigger force of 20 g (Lamikanra and Watson, 2007; Zainal *et al.*, 2013). The biting process included two bites, and the resulting curve was analyzed to obtain the texture properties, (hardness, cohesiveness, adhesiveness, chewiness, springiness and resilience) values.

2.4.5. pH determination

The pH meter (Model #59003-20, Singapore), at range 0-14, accuracy 0.02 and resolution 0.01, was used to measure the pH of cantaloupe flesh. The pH test of fruits was carried out on two fruits from each package; each fruit was cut in half using a sharp knife. The probe of the pH meter was inserted directly into the flesh of the fruit, and the pH value reading was recorded.

2.4.6. Total soluble solids

A few drops from the juice utilized to measure the pH were used to measure the soluble solids concentration of the treated fruits using a refractometer (ABBE ATAGO model 3T, Bellevue) and expressed on the Brix scale. The soluble solids content was determined by correlating the refraction angles and refractive index values established by the refractometer. The total soluble solids from the two fruits were calculated using the refractometer reading by the following equation (Amer and Azam, 2019):

TSS, Brix= dilution factor (3) × Reading in refractometer (4)

2.4.7. Respiration rate

The respiration rate of cantaloupe was measured according to (Lamikanra and Watson, 2007) method. Cut cantaloupe fruit (50 g) was placed into Mason jars (0.5 l), which were fitted with air-tight lids and equipped with rubber septums, and stored at 10°C. At the designated sampling time, a needle syringe attached to a Mocon Pack Check 650 analyzer (MOCON\ Modern Controls, Inc., Minneapolis, MN) was inserted into the rubber septum of the respective jar and a sample of gas (8 cm^3) from the headspace was analyzed for CO_2 and O_2 gases, respectively. Variations in respiration rate were measured by the gas composition between treated fruit during the storage period.

2.5. Data Analysis:

Experimental data were analyzed using SPSS software (ver. 22). Cantaloupe properties, as well as differences among experiments, were collected and then the variation between different treatments was tested for significance by one-way ANOVA using Duncan's multiple range tests.

3. Results and Discussion

3.1. Cooling Times and Cooling Coefficient:

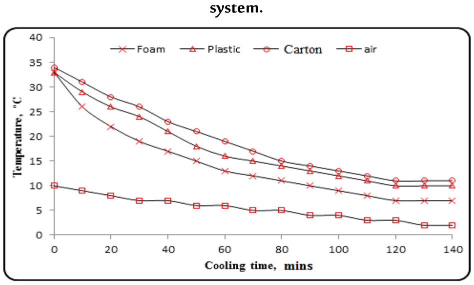
Data plotted in Figure 3 showed that there were minor differences in the initial fruit temperatures between all treatments. The cooling rate was significantly affected by package type. Experimental data for the cooling time ($7/8^{th}$) and cooling coefficient were recorded for all treatments as shown in Table 1 and Figure 3. Cooling rates at the beginning of the process were faster due to the high differences between the warm product temperatures and the surrounding air. The final temperature reached after 140 minutes ranged from 7 to 10°C for different packages. The $7/8^{th}$ cooling time ranged from 117.5 to 132 minutes, which meant that the designed 7/8th cooling time of 120 minutes, was satisfactorily achieved.

Results indicated that the difference between the highest and lowest $7/8^{th}$ cooling time for the treated cantaloupe was an average of 10.5 minutes. Results showed that the higher decreasing rate in field heat removal was recorded in the fruits packed in foam. It was shown that the fruit packed in foam reached the final temperature (7°C) in less time than plastic and carton packages. Results showed that the cooling rate order was foam > plastic > carton packages. In addition, the package of fruits placed in the front of the cold air area received cold air first and was exposed to the cold air from all directions. Meanwhile, the fruit packages in the middle and rear area received warmer air passing through the fruit packages than those in the front area. Table 1 summarizes the 7/8th cooling times measured under a forced-air cooling system for different treatments. Results showed that the foam package recorded the best cooling times maximum (9%, 10%) higher than the plastic and carton packages, respectively. The cooling coefficient values for all packages ranged from -0.324 (foam) to -0.218 min^{-1} (carton). These results can be used to help design better fruit cooling tests and fruit packages for faster cooling rates. Moreover, if the air temperature cannot be held constant during the precooling process, the cooling coefficient based on instantaneous air temperature may be a better means of comparison than the traditional 7/8th cooling time. These results agreed with Anderson *et al.* (2004).

Table 1. Values of cooling coefficient and 7/8th cooling time

Package	Cooling coefficient (min-1)	7/8th cooling time (mins)
Foam	-0.324^{a}	117.5^{a}
Plastic	-0.245^{a}	128^{b}
Carton	-0.218^{b}	132^{b}
LSD	NS	3.79

Fig 3. Measured temperatures (°C) vs cooling time (mins) under a forced-air cooling system.



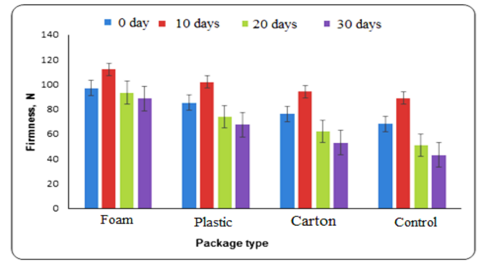
3.2. Firmness:

Results in Figure 4 showed the effect of different storage and packaging type treatments on the firmness of cantaloupe fruits after the precooling process. Treated samples under storage conditions had a noticeable effect on the loss of firmness. Losses in firmness were correlated with extended storage time. Significant differences were shown among the values of treated fruit firmness compared to non-treated fruit (control). Decreasing rates of 13%, 17%, 21% and 31 % were observed in fruit firmness values for different packages (foam, plastic and carton) and non-precooled fruit (control), respectively. Undesirable changes were observed in the control treatment as texture softened at the end of the storage periods. From the experimental results, the fruits packed in foam recorded the lowest changes in firmness.

Firmness values of fruits at the end of the storage period (30 days) were 88.5, 67.5, 53 and 43 N for foam, plastic, carton and control packages, which are less significant (P<0.05) than the first periods which resulted in 96.9, 85, 76 and 68 N. From the results, it can be concluded that applying a forced-air cooling system to cantaloupe fruits reduced the loss of firmness during different storage periods by eliminating the field heat which caused the degradation of the fruit tissues. In addition, the foam package recorded the best values of fruit firmness compared to other packages.

The maximum value of firmness was recorded at the second storage period for all packages, while the minimum value was recorded at the end of the storage period. This variation in firmness values may be due to several physical and chemical factors which contribute to fruit resistance and breakdown such as pectin materials in the cell wall, size of cells, and dry matter content. These results indicated that the best period for handling cantaloupe fruit was recorded during the second period (10 days) from harvest day.

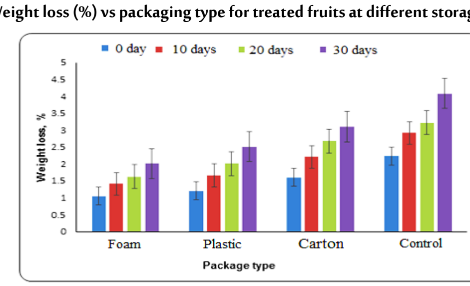
Fig 4. Firmness values (N) vs packaging type for treated fruits at different storage periods



3.3. Weight Loss:

Experimental data recorded lower physiological processes affected fruit weight loss for all treatments. Meanwhile, fruits packed in foam packages had the lowest weight loss values compared to other packages and non-treated fruits under different storage periods (Figure 5). This indicates that moisture loss from fruits packed in foam packages is lower than the other and non-treated fruit packages (Lurie and Ben, 1990). Mean values also showed that foam packages recorded a lower value for fruit weight loss (1.15%) compared to the non-treated fruit that recorded a higher weight loss (3.02%). Results showed that the weight loss reflected the loss of water and nutrients as the storage time increased.

Fig 5. Weight loss (%) vs packaging type for treated fruits at different storage periods.



3.4. Color:

Results in Tables 2, 3 and 4 indicated a variation between skin color parameters (L^*, a^*, b^*) under different treatments. Mean values for lightness (L^*) varied significantly (P<0.05) with a trend towards lower values through time (Table 2). Non-treated fruits recorded a significant decrease in lightness values compared to the other treated fruits (P<0.05). Overall, fruits packed in foam packages showed better results in retaining fruit lightness. Meanwhile, results indicated that L^* values decreased with increasing storage periods. Also, results showed that the differences between the initial storage periods for all packages were significant at the end of the storage periods. The decreasing rates of L^* values for all fruit packages (foam, plastic and carton) were 11.34%, 12.69% and 20.15%, respectively, while it reached 18.90% for the control fruits.

Table 2. Effect of precooling treatments on different packages on L* values of stored cantaloupe

Storage period, day	Foam	Plastic	Carton	Control
0	20.93^{b,c}	16.23^{b,c}	20.55^{a}	16.88^{a}
10	19.71^{a,b}	15.20^{b}	17.44^{a,b}	15.85^{a,b}
20	18.66^{a}	16.49^{a}	16.84^{a}	14.38^{a}
30	18.55^{a}	14.17^{a}	16.41^{a}	13.69^{a}

a,b, c Means within a column which are not followed by a common superscript letter are significantly different (P < 0.05)

Generally, changes in the L^* value of fruits may be associated with the ripeness stage as reported by Simandjuntak *et al.* (1996). It was also related to the development of translucency (Supapvanich and Tucker, 2011). The presence of translucency may reduce the appearance quality of fruits. The a* values (redness-greenness) of cantaloupe fruits varied slightly with the storage periods but without any particular trend among all packages (Table 3). All values remained in a range between 15 to 21. The application of the forced-air cooling system with different packages for all fruits did not show any noticeable effect on the *a** value compared to the control treatment. Table 3 showed a* values of cantaloupe for all packages during the 30 days of storage. There was a significant difference as a* showed the same pattern for all the samples. In addition, a* values varied during different storage periods for all packages. The values decreased during the first and second periods, then increased at the end of the storage period for all packages (Table 3). In contrast, increases in the *a** value indicated a decrease in greenness degree.

Table 3. Effect of precooling treatments on different packages on a* values of stored cantaloupe

Storage period, day	Foam	Plastic	Carton	Control
0	20.15^{a}	17.76^{a}	18.55^{b,c}	18^{a}
10	17.47^{a,b}	19.37^{a,b}	15.48^{b}	18.29^{b}
20	15.43^{a}	21.10^{a}	19.37^{a}	18.47^{a}
30	20.15^{a}	18.89^{a}	13.84^{a}	18.97^{a}
a,b, c Means within a column which are not followed by a common superscript letter are significantly different (P < 0.05)				

The b* values (yellowness-blueness) were used to record changes in the yellow color of cantaloupe during storage (Table 4). Control treatment did not show any significant changes in b* values. However, fruit packed in foam packages recorded higher values (over 10) in comparison to other packages with the exception of the first day of storage. This result indicated that precooling in the foam package is the better alternative for preserving yellowness in fresh cantaloupe. Table 4 shows the b* values of cantaloupe for all packages during the 30 days of storage. There was a significant difference as b* showed the same pattern for all the samples. In addition, the b* value varied during different storage periods for all packages.

Table 4. Effect of precooling treatments on different packages on b* values of stored cantaloupe

Storage period, day	Foam	Plastic	Carton	Control
0	14.74^{a}	13.71^{b}	9.14^{a}	8.26^{a}
10	9.54^{a,b}	13.51^{a,b}	7.71^{a,b}	6.69^{a}
20	11.05^{a}	12.34^{a}	8.41^{a}	8.61^{a}
30	14.07^{a}	11.49^{a}	8.76^{a}	5.52^{a}
a,b, c Means within a column which are not followed by a common superscript letter are significantly different (P < 0.05)				

The values decreased through the first and second periods, then increased at the end of storage period for all packages (Table 4). Maintaining of fruit color is vital where the visual appearance is a key factor to encourage the consumer to accept and purchase the products (Zainal *et al*., 2013). The interaction between packaging type and the storage period under a forced-air precooling system on color properties showed that foam packages recorded the lowest color change compared to other packages during the storage period.

3.5. Total Soluble Solids (TSS) and pH:

Results in Table 5 showed the total soluble solids (TSS) values for all treatments under storage conditions. All treated fruits recorded total soluble solids (Brix) values between 9 and 10. Results did not record any significant differences between all treatments under the different packages. In addition, the precooling treatment did not affect the content of total soluble solids, while there was a significant increase in the TSS values of treated fruit from 9 to 10 Brix during the storage periods. Amorós *et al.* (2003) and Cordenunsi *et al.* (2005) reviewed that any increase in the TSS content in fruits indicated the total sugar content, which was synthesized during storage at a lower temperature. The TSS value increased, non-significantly, in all packages during the storage periods. In the first storage period, the value of TSS in the samples was similar and gradually increased during the second period of storage and then decreased. TSS increased for all the samples, but the changes were non-significant ($p<0.05$).

Table 5. Effect of precooling treatments on different packages on TSS values of stored cantaloupe

Storage period, day	Foam	Plastic	Carton	Control
0	9.56^{a}	9.60^{a}	8.87^{a}	9.17^{a}
10	10.01^{a,b}	10.00^{b}	9.24^{a,b}	9.77^{a,b}
20	9.74^{a}	9.53^{a,b}	8.54^{a}	9.97^{b}
30	9.80^{a}	9.43^{a,b}	9.36^{a}	9.84^{b}
a,b, c Means within a column which are not followed by a common superscript letter are significantly different (P < 0.05)				

All treatments including the control treatment, showed a slight decreasing trend of pH through storage time towards the end of the storage period (Table 6). The approximate pH of cantaloupe was reported as 6.13 to 6.58 (USDA, 2007). The pH values recorded significantly lower values in the treated fruits under the storage periods. Meanwhile, the pH values of the treated fruit remained stable over the 30 days of storage. In addition, the pH values increased non-significantly in all packages during the storage periods, which was similar to TSS values. On storage day 0, the values of pH in the samples were similar and gradually increased during the second period of storage and then decreased during other periods. TSS increased for all the samples, but the changes were non-significant ($p<0.05$).

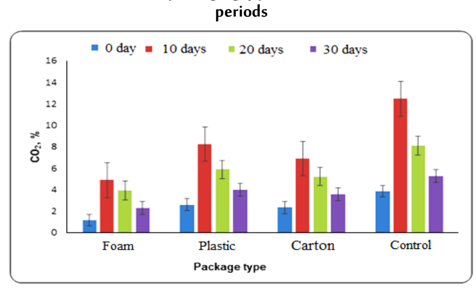
Table 6. Effect of precooling treatments on different packages on pH values of stored cantaloupe

Storage period, day	Foam	Plastic	Carton	Control
0	5.60^{a,b}	5.52^{b}	5.52^{b}	5.52^{a,b}
10	5.71^{b}	5.66^{a,b}	5.66^{a,b}	5.60^{b}
20	5.64^{a}	5.54^{a}	5.54^{a}	5.34^{a}
30	5.42^{a}	5.34^{a}	5.34^{a}	5.21^{a}
a,b, c Means within a column which are not followed by a common superscript letter are significantly different (P < 0.05)				

3.6. Respiration Rate:

Respiration rate is normally measured by the amount of carbon dioxide produced. Mean values of respiration rate presented in Figure 6 indicated a decrease in respiration rates in treated fruit compared to non-treated (control). Experimental data showed a decreasing rate in all samples at the first storage period, while in the third storage period CO_2 production was comparable to other treated fruit. Decreases in respiration rates in treated samples were associated with precooling treatments under a lower storage temperature and package type. Accumulated CO_2 was higher in non-treated fruit (control) compared to treated fruit. Respiration rates of the treated fruit recorded a climacteric peak after 10 days of storage for all of the fruit, both treated and non-treated (control). The CO_2 concentrations of treated fruits were (4.86%, 8.20%, 6.88% and 12.45%) for foam, plastic, carton and control packages, respectively (Figure 6), then decreased to (2.28%, 3.97%, 3.56% and 5.22 %) at the end of the storage period, respectively.

Fig 6. CO_2 concentration (%) vs packaging type for treated fruits at different storage periods



Overall observation in experimental data showed that the respiration rate of the treated fruits (foam) recorded the lowest values compared to the other treatments under all the storage periods. Even though precooled fruits were shelf-stable for the same period, non-treated fruits (control) had a higher respiration rate compared to the other treatments. It can be understood that the untreated fruits had higher permeability to water, O_2 and CO_2 than treated fruits.

3.7. Texture Properties:

Results in Table 7 showed significant effects of packaging type on the texture properties of fruits, including hardness, cohesiveness, adhesiveness, chewiness, springiness and resilience. Differences were highly significant ($p < 0.05$) for hardness, cohesiveness, chewiness, springiness and resilience values of fruit packed in foam (which protects the fruit from surrounding environmental changes). However, fruits packed in plastic were significantly higher for adhesiveness properties as compared to carton or foam. In addition, results showed that fruits packed in plastic gave lower values for hardness, cohesiveness, adhesiveness, chewiness, springiness and resilience. These results are in agreement with Alhamdan and Alsadoon (2004) who reported that eggplant fruits stored in plastic packages had higher elastic modulus than those stored in carton packages. They also, reported that plastic packages had highly significant resistance when tested. This is mainly due to the difference in the water vapor permeability of the package used that had a direct effect on the properties of the eggplant fruits stored inside.

Table 7. Effect of storage periods and packaging type on texture properties of cantaloupe

		Hardness (g)	Cohesiveness	Adhesive-ness (g.s)	Chewiness (g)	Springiness	Resilience
Package	Foam	2984.74^{a}	0.541^{a}	-2312.65^{b}	356.98^{a}	0.485^{a}	3.721^{a}
	Plastic	2732.41^{b}	0.497^{b}	-2439.18^{c}	337.32^{b}	0.447^{b}	3.456^{b}
	Carton	2494.02^{c}	0.453^{c}	2135.24^{a}-	318.77^{c}	0.411^{c}	3.249^{c}
	Control	2464.87^{c}	0.587^{c}	$-2304.43c^{b}$	311.26^{c}	0.388^{d}	3.133^{d}
Storage	0	2820.41^{a}	0.537^{a}	-2260.42^{a}	344.72^{a}	0.471^{a}	3.592^{a}
	10	2763.34^{b}	0.536^{a}	-2343.66^{b}	340.95^{a}	0.461^{a}	3.543^{a}
	20	2740.22^{b}	0.494^{b}	-2334.90^{b}	334.27^{b}	0.436^{b}	3.433^{b}
	30	2632.51^{c}	0.425^{c}	-2323.77^{b}	330.68^{b}	0.422^{c}	3.365^{c}

a,b, c Means within a column which are not followed by a common superscript letter are significantly different ($P < 0.05$)

The effect of storage periods on the texture properties of cantaloupe fruits are listed in Table 7. Changes in the properties of the cantaloupe tissue results showed that all values decreased with increasing storage periods. Moreover, higher values for all texture properties were recorded at the initial periods of storage, while the lower values were recorded at the final periods of storage. This variation in values between storage periods may be due to respiration, enzymatic activities and biological processes contributing to fruit resistance to breakdown, such as pectin materials in cell walls, cell size and dry matter content. The decreasing rates for all properties were 6.66%, 20.86%, 2.80%, 4.07%, 10.40% and 6.32% for hardness, cohesiveness, adhesiveness, chewiness, springiness and resilience, respectively. This is matches the findings of with Alhamdan and Alsadoon (2004) in their study of the effect of storage periods on the mechanical properties of tomato and eggplant fruits. They found that the storage periods affect the mechanical properties, especially with high storage periods. They indicated that, in addition to the increasing storage period, there were several ongoing processes including respiration and the enzymatic activity of biological processes. From the previous results, the texture properties of the foam-packed fruits recorded the lowest values compared to other packages under all storage periods, even though precooled fruits maintained their texture properties for the same period while non-treated fruits (control) recorded the higher loss in texture properties compared to other treatments.

4. Conclusions

This paper discussed the performance of a forced-air cooling system under different type of packages that can help eliminate the field heat of cantaloupe fruits, as well as reduce cooling loads during the following cold storage. Precooling treatment took 140 minutes to precool fruit from the initial temperature (36-38°C) to the final temperature (7-10°C) with a foam package. The $7/8^{th}$ cooling time ranged from 117.5 to 132 minutes, which meant that the designed $7/8^{th}$ cooling time of 120 minutes, was satisfactorily achieved. Results showed that the efficiency of precooling treatments is affected by many factors such as packaging type, air velocity, air temperature and package arrangement in the cooling room. It was also concluded that packed fruit in foam packages are essential as was shown through different post-harvest treatments. Foam packages maintained the quality of fruits stored at 10°C by preserving firmness, weight loss, texture properties and the respiration rate for cantaloupe fruit. It was able to maintain the quality properties by acting as an insulator for heat exchange and moisture from the fruit to the surrounding air. Carton packages recorded an increase in airflow resistance and reduced convective heat transfer from the produce, leading to increased cooling time and energy use. Treated fruits inside the foam packages recorded a long shelf life compared to non-treated fruits (control). The use of foam package is more efficient in rapidly removing field heat from cantaloupe fruit. Future improvements in the forced-air cooling system should focus on package design, arrangement inside the cooling room, better stacking on the pallet, and reducing airflow short-circuits between pallets and the cooling rates of fruits and vegetables.

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