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Hydro-cooling as Means to Retain Fresh Sweet Corn Ears Quality

(Penyejukan Hidro sebagai Kaedah Mengekalkan Kualiti Tongkol Jagung Manis Segar)

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ABSTRACT

Sweet corn ear is a highly perishable produce with short postharvest life due to its high respiration rate which depletes sugar concentration in kernel. As a result, ear loses its sweetness and quality within 1 to 2 days under room temperature. Hydro-cooling after harvest is a good practice as it can reduce the metabolism and respiration rate of the produce. Thus, the objective of this study was to determine the effectiveness of hydro-cooling in retaining quality of sweet corn ears. Freshly harvested sweet corn ears were immersed in hydro-cooler to achieve its half and seven-eighth cooling time. Pre-cooled and non-pre-cooled ears were then stored at 12±2 and 25±2 °C for 8 days and quality index, weight loss, pH, soluble solids concentration, titratable acidity and ascorbic acid of ears were evaluated at 2 days interval. The experiment was arranged in randomized complete block design with factorial arrangement (three cooling times × two storage temperatures × five storage days) and then repeated thrice. Differences between cooling time × storage temperature, cooling time × storage day, storage temperature x storage day and cooling time × storage temperature × storage day were significant on quality index of ears. Storage temperature × storage day was also significant on ears weight loss, soluble solids concentration and pH. Seven-eight cooling time and storage at 12±2 °C provide the best quality index of ears; retain higher soluble solids concentration and pH with significantly lower weight loss compared to other cooling time treatment and 25±2 °C storage temperature. In short, temperature management is crucial in manipulating sweet corn ears quality.

Keywords: Cooling time; pre-cooling; quality index; storage day; storage temperature

ABSTRAK

Tongkol jagung manis merupakan hasil mudah rosak dengan hayat lepas tuai yang pendek kerana kadar respirasinya yang tinggi menghabiskan kandungan gula di dalam biji. Oleh itu, kemanisan dan kualiti tongkol hilang dalam 1 atau 2 hari pada suhu bilik. Penyejukan hidro selepas tuai merupakan amalan bagus kerana ia dapat mengurangkan metabolisma dan kadar respirasi hasil. Oleh itu, objektif kajian ini adalah untuk menentukan keberkesanan penyejukan hidro dalam mengekalkan kualiti tongkol jagung manis. Jagung manis yang baharu dituai direndamkan ke dalam penyejuk hidro untuk mencapai masa penyejukan setengah dan tujuh-per-lapan. Kemudian, tongkol yang dipra-sejuk dan tanpa dipra-sejuk disimpan pada suhu 12±2 dan 25±2 °C selama 8 hari dan indeks kualiti, kehilangan berat, pH, kepekatan pepejal terlarut, keasidan tertitrat dan asid askorbik tongkol dinilai selang 2 hari. Uji kaji disusun dalam reka bentuk blok lengkap secara rawak dengan pengaturan faktorial (tiga masa penyejukan × dua suhu penyimpanan × lima hari penyimpanan) dan diulang sebanyak tiga kali. Perbezaan antara masa penyejukan × suhu penyimpanan, masa penyejukan × hari penyimpanan, suhu penyimpanan × hari penyimpanan dan masa penyejukan x suhu penyimpanan × hari penyimpanan adalah berkesan pada indeks kualiti tongkol. Suhu penyimpanan × hari penyimpanan juga berkesan dalam kehilangan berat, kepekatan pepejal terlarut dan pH tongkol. Tujuh-lapan masa penyejukan dan suhu penyimpanan 12±2 °C memberikan indeks kualiti tongkol yang terbaik; mengekalkan kepekatan pepejal terlarut dan pH yang lebih tinggi serta kehilangan berat yang berkesan dengan lebih rendah berbanding dengan rawatan masa penyejukan yang lain dan suhu penyimpanan 25±2 °C. Secara ringkasnya, pengurusan suhu adalah sangat penting dalam memanipulasi kualiti tongkol jagung manis.

Kata kunci: Hari penyimpanan; indeks kualiti; masa penyejukan; pra-penyejukan; suhu penyimpanan

INTRODUCTION

Sweet corn is a highly perishable vegetable with high respiration rate (Bakry et al. 2015). It was reported that about 60% of the sugar in sweet corn kernel can be converted to starch in a single day if held under 30 °C. The sweetness lost rapidly after harvest due to rapid cellular metabolism depletes sugar concentration in the kernel (Shao & Li 2011). Therefore, loss of sweetness is considered one of the main quality deteriorations during postharvest handling of sweet corn ears. It has been shown that the heat generated from oxidation of sugars, fats, and proteins in the cellular significantly reduce food value (Prusky 2011). Therefore, implementing techniques to reduce cellular metabolism during postharvest handling is crucial to retain quality of sweet corn ears.

Removing field heat of harvested produce is the key to manage the deceleration of cellular metabolism and the series of events that lead to deterioration of fresh produce especially prior to transport or storage (Kongwong et al. 2019). In postharvest, removing field heat as quick as possible after harvesting is essential to prevent temperature accumulation in fresh produce in order to slow down oxidation processes. Pre-cooling has been identified as the first most critical method in postharvest handling. Cooling reduces the metabolism and respiration rate of the produce, retard their senescence, and inhibit growth of pathogens (Bhushan et al. 2015; Samira et al. 2013).

An assessment of precooling technologies for sweet corn by using forced-air, water and vacuum cooling has been carried out by Cortbaoui (2005) in Canada. It was found out that water-immersed treatment resulted in better maintenance of general quality index and of higher soluble solids concentration and moisture content for Canadian grown sweet corn among the three precooling technologies used. Hydro-cooling is one of several cooling techniques that have been proven as effective means to retain and prolong the shelf life of fresh produce. It is commonly practiced for many commodities such as asparagus (King et al. 2008) and broccoli (*Brassica oleracea*) (Iribe-Salazar et al. 2015) that also serves as simultaneous cleaning.

Hydro-cooling is able to perform quick cooling for a wide range of fruit and vegetables (Vigneault et al. 2007). The cooling process is much faster and more uniform as compared to air. This is due to the fact that surface heat transfer coefficient of produce-to-water is much higher than that of air. However, cooling rate is dependent on the size and shape of the produce being cooled. On top of this, hydro-cooling retain higher moisture in produce as compared to air. Since produce is direct contact with water, produce that undergoes hydro-cooling must have a high resistance to wetting and low vulnerability to physical wound caused by water on their surface. Hydro-cooling can be conducted either by showering water on the produce as used in asparagus (King et al. 2008) or by submerging the produce in cold water as found in rockmelon (Zainal et al. 2019).

In Southeast Asia, to the best of our knowledge, report on hydro-cooling on vegetables is very limited. Malaysian sweet corn growers have argued the effectiveness of hydro-cooling to retain the quality and prolong the shelf life of sweet corn ears (personal communication). As such, this study was carried out to convince growers on the importance and benefit of the cooling technique in handling sweet corn ears. The aim of this study was to determine the effectiveness of using hydro-cooling in retaining quality and prolonging the shelf life of sweet corn stored at 12±2 °C (chiller temperature) and 25±2 °C (room temperature) with 70% relative humidity.

MATERIALS AND METHODS

PLANT MATERIALS

Sweet corn (*Zea mays* L.) ears variety of Hybrid F_1 Supersweet was harvested at 8 am in Tanjung Malim, Perak (4°35’ N 101°04’ E) and packed in polypropylene woven sack of 20 kg. The load was then transported to Laboratory of Postharvest, Universiti Putra Malaysia using an air-conditioned 4´4 vehicle with 2 h of journey. Upon arrival, the ears were removed from sack and three ears were randomly selected to monitor its core temperature. The initial temperature was recorded by using a thermometer probe (H19044 Portable Microprocessor K-Type Thermocouple Thermometer) inserted longitudinally into the core of ear. The temperature measured from the three ears was averaged with 30 °C as their initial temperature. Then, the shanks of ears were trimmed to obtain uniform shank length. The ears were randomly divided into 3 lots with each lot consisted of 22 ears for every batch.

HYDRO-COOLING TREATMENT

In this study, an immersion type of hydro-cooler with external dimensions of 1.45 m x 1 m x 0.85 m was used. A 0.75 kW pump (2820 RPM, 220–230 V, single phase, 50 Hz, model: KQ800S, made in Thailand) powered by an electric motor was used to circulate water horizontally. The ears of sweet corn were immersed into hydro-cooler with water temperature of 4 °C. Three ears were instrumented with a thermometer probe as described earlier and temperature was closely monitored. The hydro-cooling process lasted until the temperature of the core decreased approximately to 17 and 7.25 °C to obtain half (1/2) and seven-eighth (7/8) cooling time (CT), respectively, according to the following formula developed by Henry and Bennett (1973):

$$C_c = (T_p - T_a) / (T_i - T_a)$$

where C_c is the cooling coefficient; T_p is the product temperature measured during cooling; T_i is the initial product temperature; and T_a is the water temperature.

After treatment, the corns were drained for 20 min to remove the excessive water from the ears. Corn without underwent hydro-cooling was used as control. Subsequently, the non-hydro-cooled (control) and hydro-cooled ears were stored at 12±2 and 25±2 °C with 70% relative humidity for 8 days. Observation was carried out at every 2 days interval.

QUALITY INDEX DETERMINATION

The quality index of sweet corn ears was determined by observing the colour of husk, shape and turgidity of kernels according to Vigneault et al. (2007) methods. Table 1 shows the description of sweet corn ears quality index. The images of ears were also captured using a digital camera and visual quality was described.

TABLE 1. Sweet corn ears quality index and its description according to Vigneault et al. (2004)

Quality index	Quality	Description
9	Excellent	Husks of freshly harvested turgid appearance, dark green, slightly moist. Silks light-colored (greenish yellow) and turgid. Kernels bright and very turgid. Absence of major defects
7	Good	Green husks, slightly wilting. Silks light-colored, slight loss of turgidity. Kernels reasonably bright and turgid. Absence of major defects
5	Average	Average pale green husks, withered or slightly dry. Silks lightly browning, some dried. Kernels dull but not dented. Absence of major defects
3	Poor	Poor Husks very pale, some yellowing and perhaps browning, much withered and partly dry. Silks brown, soft and possible dry. A few dented kernels. Major defects possible
1	Unmarketable	Husks yellow, straw-colored or brown. Very withered or dry. Many dented kernels. Major defects present

WEIGHT LOSS DETERMINATION

The initial weight of ears was determined at day 0 i.e., prior to the hydro-cooling treatment. Weight loss was taken at day 2, 4, 6, and 8 after storage and then compared with day 0. The percentage of weight loss was calculated by using the following formula according to Ding and Ong (2010) methods:

$$\text{Weight loss (\%)} = \underline{[(\text{Initial weight} - \text{Weight of ears at sampling date})/\text{Initial weight of ears}]} \times 100$$

SOLUBLE SOLIDS CONCENTRATION DETERMINATION

Ten grams of corn kernel were taken randomly from an ear and the juice was collected after pressing using a garlic squeezer. Two drops of sweet corn juice were dropped onto the glass prism of a refractometer and the reading was recorded in percentage according to Ding and Syazwani (2016) methods.

TITRATABLE ACIDITY DETERMINATION

Ten grams of corn kernel were blended with 40 mL of distilled water according to Mohamed et al. (2017) methods. The juice was filtered using cotton wools and 5 mL of the filtrate was added with two drops of 1% phenolphthalein. The filtrate was titrated against 0.1 mol/L NaOH until the original filtrate colour changed to pink. The volume of NaOH of titre used was recorded. The titratable acidity was calculated by using the following formula:

$$\text{Malic acid (\%)} = \text{Titre} \times 0.06705$$

pH DETERMINATION

The remaining filtrate from titratable acidity determination was used for pH determination.

ASCORBIC ACID DETERMINATION

Ten grams of corn kernel was blended with 40 mL of 3% cold metaphosphoric acid according to Siang et al. (2019) methods. The homogenate was filtered using cotton wools and 5 mL of the filtrate was titrated with dye until the colour changes into pink. The volume of 2-6-dichlorophenol indophenol dye or titre used was recorded. The ascorbic acid was calculated by using the following formula:

$$\text{Vitamin C (mg/100 g)} = \text{titre} \times \text{dye factor} \times 100$$

STATISTICAL ANALYSIS

The experiment was conducted in randomized complete block design with factorial arrangement of three CT × two storage temperatures × five storage days. The experiment was repeated using three batches of ears from same source. Data was analysed using Statistical Analysis System (SAS) software version 9.4. The means was separated using Duncan's multiple range test (DMRT) at 5%.

RESULTS AND DISCUSSION

Significant interactions were observed between CT × storage temperature (ST), CT × storage day (SD), ST × SD and CT × ST × SD on quality index of sweet corn ears (Table 2). Figure 1 shows significant interaction between SD × CT on quality index of ears. Regardless CT used; quality index of ears reduced significantly as SD progressed. The quality index of ears sustained for 2 days and deteriorated gradually as SD progressed to SD 6. However, from the significant interaction between CT × ST, it was found out that hydro-cooled ears stored at 12±2 °C have higher quality index compared to 25±2 °C (Figure 2). This indicated that low temperature storage is able to maintain the quality of ears. Similar finding was also reported by Bakry et al. (2015) during sweet corn ears storage where quality of ears stored at 0 °C was better than those stored at 5 °C. In broccoli, lower ST has been shown to reduce oxidative stress and retard the deterioration with markedly slower yellowing of broccoli florets (Zhang et al. 2009).

The deterioration of sweet corn ears quality over extended period of storage is evidently depicted in Figure 3. The kernels of ears for all treatment after two days of storage (day 0 and 2) were turgid and appeared in good condition. The husks also remained green and fresh for both storage temperatures of 12±2 and 25±2 °C. However, by day 4, the kernels of ears stored at both temperatures started to dent except for ears treated with 7/8 CT and storage at 12±2 °C. Non-hydro-cooled sweet corn can only maintain its quality for approximately four days when stored at 12±2 °C, whereas even shorter (two days) when stored at substantially higher temperature of 25±2 °C. Bakry et al. (2015) stored Rugosa variety of sweet corn ears at 0 and 5 °C and found out 0 °C storage retain better quality throughout 28 days of storage. However, this study did not use such low storage temperatures to store sweet corn ears. It is quite impossible for Malaysian growers to use extreme low storage temperature which incur even higher cost in their operation. In Malaysia, infrastructures such as cold room facilities are limited among Malaysian vegetables growers. Furthermore, Malaysian growers are lack of knowledge in postharvest handling where temperature management is essential in retaining produce quality and prolonging shelf life. According to a study by Ruslan et al. (2013), infrastructure and knowledge are among the six factors that influence the implementation of postharvest handling practices among fresh vegetable producers in Malaysia.

At longer storage duration (day 6), most of the sweet corn ears that stored at 25±2 °C were visibly dented with even more severe in 7/8 CT ears where husk has dried up (Figure 3). The deterioration was getting worse by day 8 with evident shriveling. Regardless of hydro-cooling treatment, ears stored at 25±2 °C were completely deteriorated and unmarketable by storage day 8. Contrary, ears stored at 12±2 °C with 7/8 CT were visually better than other treatment by day 8. Irrespective of treatment, ears stored at 12±2 °C has better quality than those stored at 25±2 °C. The difference ears quality performance between 12±2 and 25±2 °C could be due to the interruption in cold chain when transferring ears from 4 °C (hydro-cooling water temperature) to 25±2 °C (storage temperature) with temperature differential of 21±2 °C that caused more stress to the ears as compared to temperature differential of 8±2 °C.

In postharvest, temperature management is a crucial operation in maintaining the quality and extending shelf life of fresh produce. Field heat in the produce after harvest must be removed as quickly as possible to reduce respiration and prevent water loss. Dramatic increase of respiration rate substantially reduces the energy reserve in produce which consequently lead to deterioration in appearance (wilting and shriveling) (Garrido et al. 2015; Zainal et al. 2019). In addition, breaking the cold chain destabilizes the produce with increase in transpiration rate and enhance weight loss are the main causes that decrease the quality in rock melon (Zainal et al. 2019). The present study demonstrates that pre-cooling treatment on sweet corn followed by storage at lower temperature is beneficial in retaining the quality especially over prolonged period.

There was significant interaction between ST × SD on sweet corn ears (Table 2). The weight loss percentage in sweet corns stored at 12±2 and 25±2 °C showed no significant differences during the first four days of storage (Figure 4). However, the weight losses were significantly different at day 6 and 8 with storage of ears at 25±2 °C suffered significantly higher weight loss compared to storage at 12±2 °C. A substantial weight loss in produce stored at higher temperature can be attributed by increased respiration rate, higher transpiration rate and moisture removal from the surface. Similar findings were also reported in pepper (Samira et al. 2013), tomato (Tolesa & Workneh 2017) and sweet corn (Bakry et al. 2015).

Soluble solids concentration (SSC) is an important indicator to estimate total sugar content in sweet corn ears (Bakry et al. 2015). Significant interaction effect was found in between ST × SD on ears SSC (Table 2). There were no significant differences in SSC stored at 12±2 and 25±2 °C during the first four days of storage period (Figure 5). However, ears stored at 25±2 °C contained significantly lower SSC compared to storage at 12±2 °C and continued to decrease as storage period advanced to 8 days. The substantial changes in sweetness is due to the respiratory use of the soluble solids as substrates (Samira et al. 2013). The present study demonstrates that sweet corn ears stored at 12±2 °C were able to maintain its total sugar content by reducing the physiological breakdown of ears constituents.

Similar trends were also observed in pH of sweet corn ears with significant interaction between SD × ST (Table 2). There were no significant differences in pH of ears during the first four days of storage (Figure 6). However, significant changes were observed after 6 and 8 days of storage with sweet corn stored at 25±2 °C leaning towards acidic compared to the relatively neutral pH in sweet corn stored at 12±2 °C. In most cases, pH values tend to increase with low storage temperature as demonstrated in pomegranate (Arendse et al. 2014). Low storage temperature has slowed down metabolism as such less acid being released.

For titratable acidity (TA) and ascorbic acid (AA), there was no significant interaction between CT × ST, CT × SD, SD × ST and CT × ST × SD on sweet corn ears (Table 2). Main effect of CT and ST also did not have any effect on TA of ears. However, as SD progressed TA of ears increased gradually. Irrespective non-hydro-cooled or hydro-cooled treatment, AA of ears was not affected by CT. However, low storage temperature of 12±2 °C could retain higher AA than those stored at ambient temperature of 25±2 °C. As expected, AA of ears lost gradually as SD advanced. This is because vitamin C is water soluble and thus it loses through water stream during water loss process.

From this study, hydro-cooling treatment followed by storage at low temperature is an effective method in maintaining the quality and prolonging the shelf life of sweet corn. Specifically, 7/8 CT and storage at 12±2 °C produced best quality index and appearance as compared to 1/2 CT and non-hydro-cooled ears through visual observation (Figure 3). To achieve 1/2 and 7/8 CT in this study, about 2 and 6 h immersion in 4 °C water was needed, respectively (unpublished data). In a similar work, sweet corn ears with initial temperature of 17 °C needed 2 and 5 h to achieve 5.5 and 4.5 °C of core temperature, respectively (Maurer et al. 1969). This indicated that hydro-cooling is a time-consuming process though it yields better quality sweet corn ears than other precooling methods (Cortbaoui 2005). Practically, it may not be feasible for grower and/or handlers to hydro-cool sweet corn ears for 6 h to achieve 7/8 CT with initial core temperature of 30 °C after considering ears volume, capacity of hydro-coolers and energy consumption to obtain 4 °C of chill water.

This study also showed that uninterrupted cold chain is important to ensure marketability of fresh produce. Retaining cold chain supply is an important management in postharvest handling. The core temperature of 1/2 and 7/8 CT in this study was 17 and 7.25 °C, respectively, while the low storage temperature used was 12±2 °C. Storing ears with core temperature of 7.25 °C in 12±2 °C has broken the cold chain as storage temperature was higher than its core temperature. This may explain non-significant results between 1/2 and 7/8 CT in most of the quantitative analysis. Most probably, lower storage temperature such as 0 °C (Bakry et al. 2015) and 1 °C (Vigneault et al. 2007) should be used to store sweet corn ears. However, these storage temperatures might not be suitable for Malaysian variety as chilling injury may develop. Also, the constraint of infrastructure and knowledge among growers may hinder the practice of 0-1 °C for fresh sweet corn ears in Malaysia.

TABLE 2. Effect of three cooling times, two storage temperatures, and five storage days on quality index (QI), weight loss (WL), soluble solids concentration (SSC), pH, titratable acidity (TA) and ascorbic acid (AA) of sweet corn ears

Factor	QI	WL (%)	SSC (%)	pH	TA (% malic acid)	AA (mg/100 g)
Cooling time (CT)						
0	5.07 b^z	18.84 a	12.22 b	6.91 a	0.017 a	6.08 a
1/2	5.57 a	19.10 a	12.99 a	6.92 a	0.017 a	6.05 a
7/8	5.77 a	15.53 b	13.52 a	6.93 a	0.017 a	6.12 a
Storage temperature ºC (ST)						
12±2	6.24 a	15.30 b	13.91 a	6.95 a	0.017 a	6.33 a
25±2	4.69 b	20.34 a	12.24 b	6.89 b	0.017 a	5.84 b
Storage days (SD)						
0	9.00 a	0.00 e	14.12 a	7.03 a	0.016 b	7.24 a
2	8.50 b	11.49 d	13.38 ab	8.98 a	0.014 c	6.66 ab
4	5.17 c	20.03 c	13.19 b	6.99 a	0.016 bc	6.50 b
6	2.78 d	26.51 b	12.80 b	6.90 b	0.018 a	5.23 c
8	1.89 e	31.08 a	11.89 c	6.69 c	0.019 a	4.78 c
Interaction						
CT × ST	*	NS	NS	NS	NS	NS
CT × SD	*	NS	NS	NS	NS	NS
ST × SD	**	**	*	*	NS	NS
CT × ST × SD	*	NS	NS	NS	NS	NS

NS, *, ** = Non significant or significant or highly significant at P ≤ 0.05. ^{z}Mean separation within columns and factors followed by the same letter are not significantly different by DMRT at P≤ 0.05

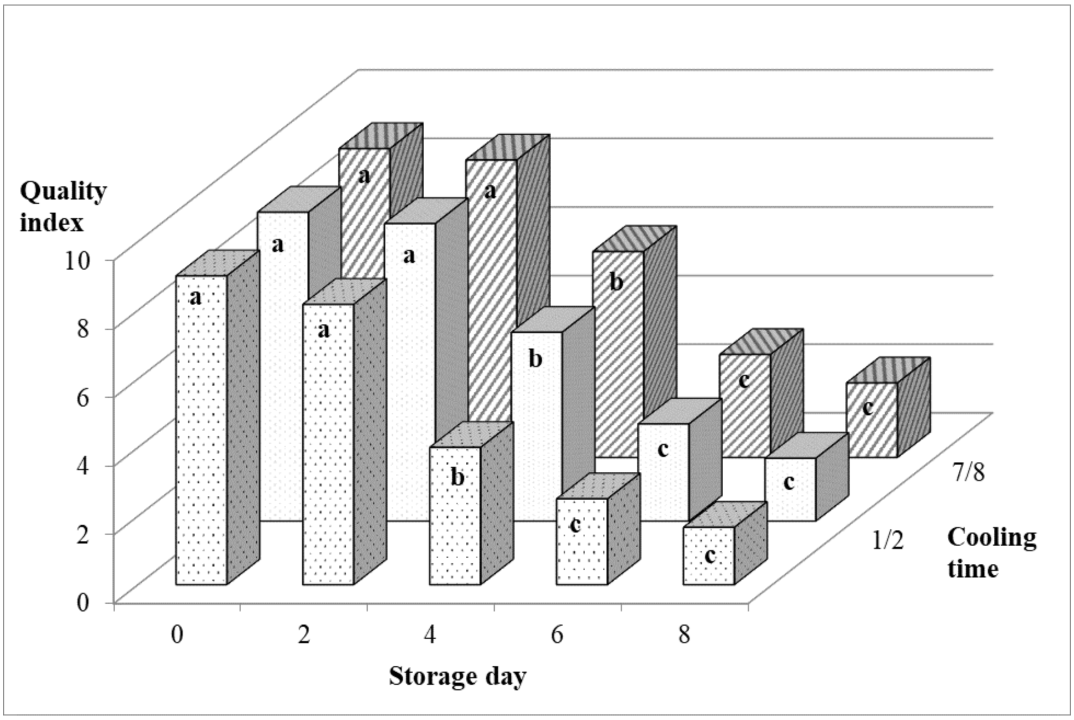

FIGURE 1. Effects of storage day and cooling time on the quality index of sweet corn. Means followed by the same letters within cooling time are not significantly different from each other by DMRT at P≤0.05

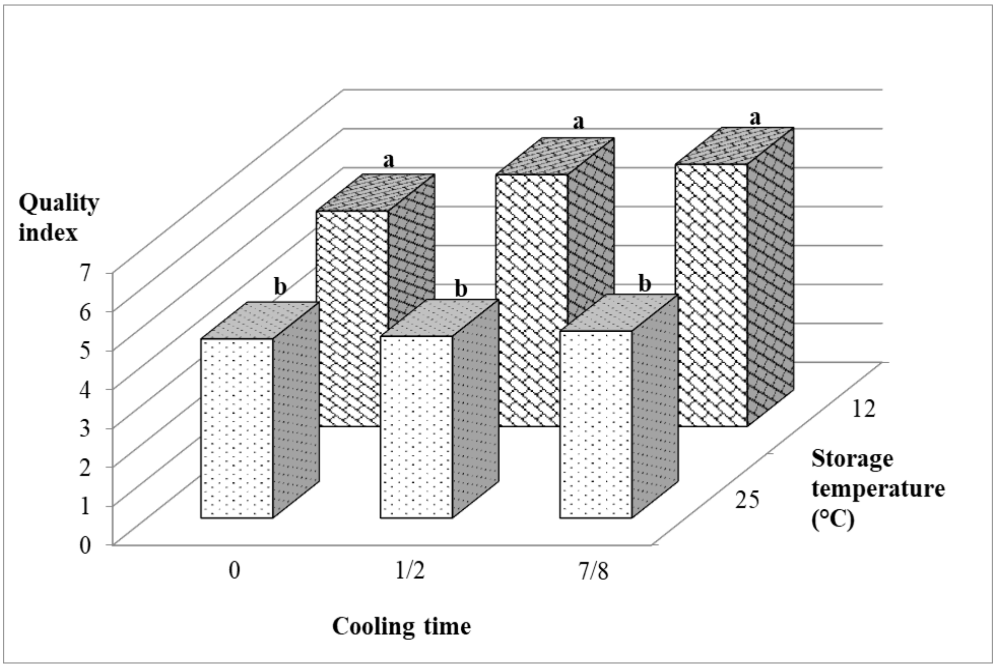

FIGURE 2. Effects of cooling time and storage temperatures on the quality index of sweet corn. Means followed by the different letters indicate significant differences within cooling time by DMRT at P≤0.05

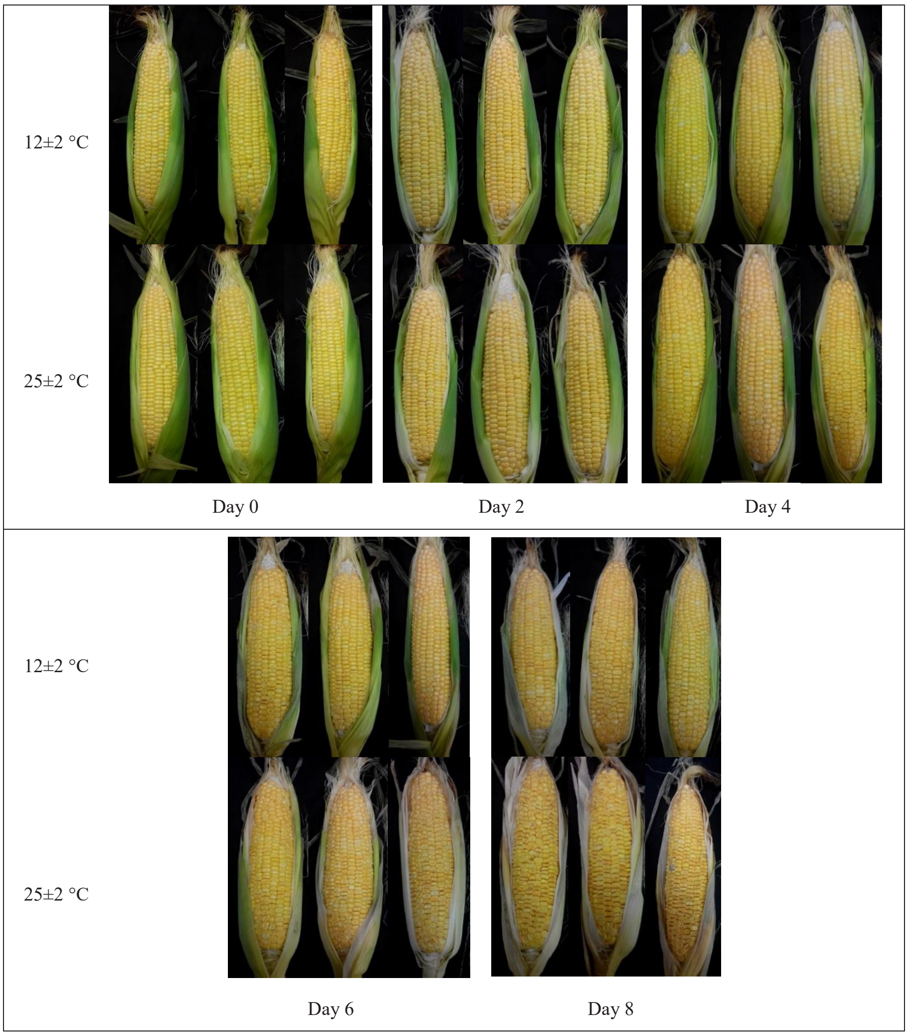

FIGURE 3. Quality index of hydro-cooled sweet corn ears stored at two storage temperatures and five storage days. Images are arranged according to cooling time. Left to right: control, half-cooling and seven-eight cooling time

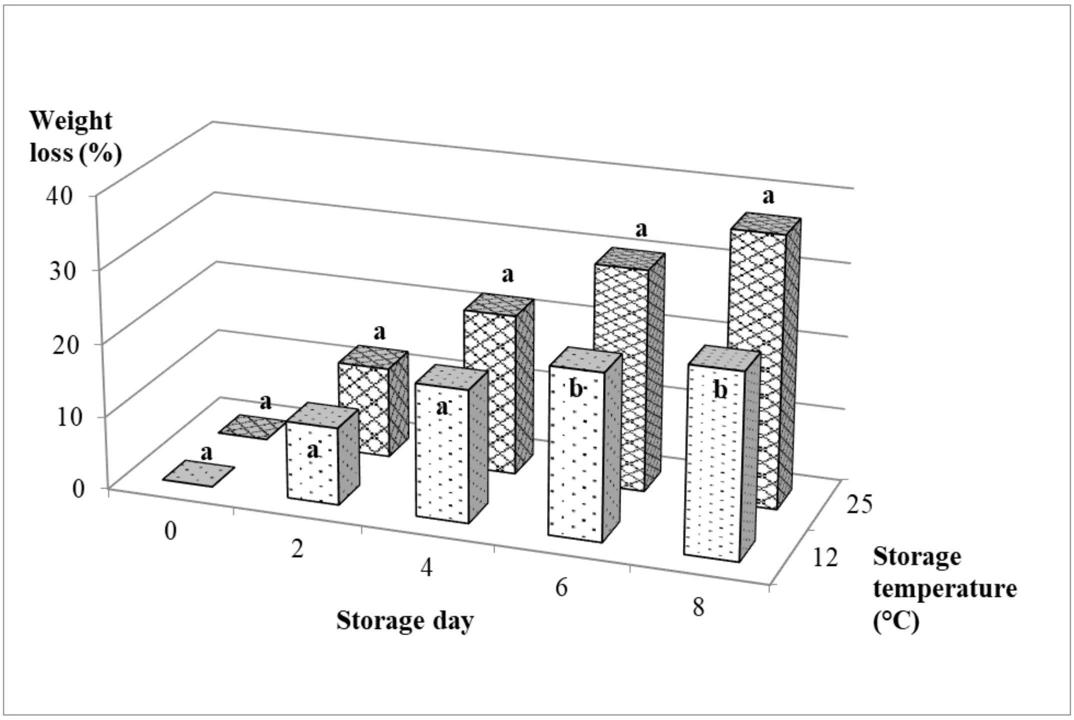

FIGURE 4. Effects of storage day and temperature on the percentage weight loss of sweet corn. Means followed by the same letters within storage day are not significantly different from each other by DMRT at P≤0.05

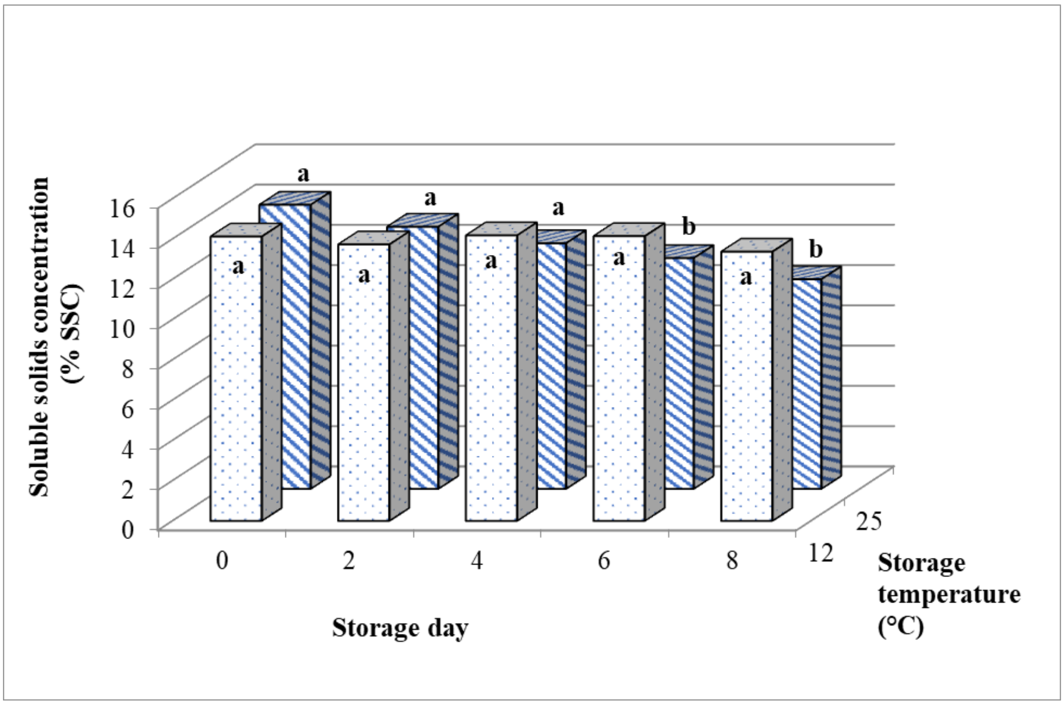

FIGURE 5. Effects of storage day and temperature on the soluble solids concentration of sweet corn. Means followed by the same letters within storage day are not significantly different from each other by DMRT at P≤0.05

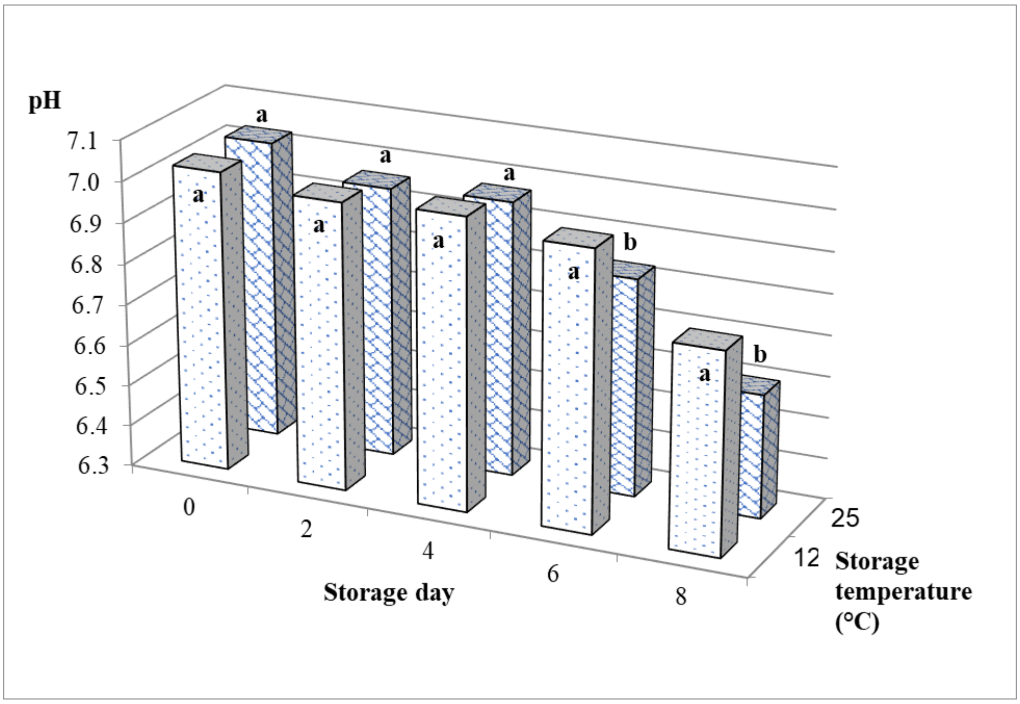

FIGURE 6. Effects of storage day and temperature on the pH of sweet corn. Means followed by the same letters within storage days are not significantly different from each other by DMRT at P≤0.05

CONCLUSION

This study has shown that hydro-cooling and low storage temperature is essential in retaining quality and prolonging shelf life of sweet corn ears. However, a detail study to elucidate lowest storage temperature for Malaysian sweet corn variety is needed to maximize the benefit of hydro-cooling as pre-cooling technology for sweet corn ears. In order to reduce CT, it is advised to harvest sweet corn in the early morning to avoid a buildup of field heat. If hydro-cooling facilities are available, 1/2 CT and 12±2 °C storage temperature is sufficient to retain ears quality for short distant market and consumption period. If no hydro-cooling facilities are available, on top of harvesting when air temperature is low, harvested ears should be placed in cool area without exposing to solar irradiation and avoid heap piling while waiting for distribution. The distribution should be carried out using cold truck to avoid quality depletion especially the sweetness and moisture of corn. For sweet corn, temperature management is crucial to control the main culprit implicating postharvest quality losses.

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