Postharvest Quality of Two Mangosteen (*Garcinia mangostana* L.) Fruit Maturities Held in Ambient and CoolBot-equipped Cold Storage

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**Abstract**

Mangosteen fruit has a good demand in the global market, however, local production is beset with high postharvest losses. The effectiveness of low temperature in maintaining fruit postharvest quality is well known but costly. In this study, the effects of ambient storage and CoolBot-equipped room are determined on two maturity stages of mangosteen. The mangosteen fruit which is classified as reddish purple or dark purple was stored in either ambient conditions (26.7 ± 0.6 °C, 88.4 ± 3.4% RH) or inside a modified cold room using CoolBot (9.9 ± 1.8 °C, 77.8 ± 10.7% RH) and the quality was evaluated weekly. Mangosteen at both maturity stages had at least 8.5 days of shelf life under ambient conditions and 29.8 days under CoolBot storage. Peel color was maintained for less than four days after storage in ambient while 35 days in room with CoolBot. There was a higher total soluble solids (TSS) content in dark purple fruit in both storage conditions. Pericarp hardening of the fruit was observed starting at 7 and 28 days in ambient and CoolBot storage, respectively. Fruit stored in the CoolBot-equipped room had better visual and calyx quality, lower weight loss, higher TSS, and delayed peel color change. Chilling injury which manifested as inner pericarp browning at 35 days did not vary between the two fruit maturities in cold storage. Storage of reddish purple mangosteen fruit using CoolBot maintained the fruit quality until 28 days.

**Keywords:** Chilling injury; CoolBot; Low temperature storage; Pericarp hardening

**Introduction**

Mangosteen (*Garcinia mangostana* L.) is classified under the Clusiaceae (syn. Guttiferae) family which originated from Southeast Asia (Yaacob & Tindall, 1995). It has an edible white aril with a sweet and slightly acidic taste. The fruit has polyphenolic compounds called xanthones that repair damaged cells caused by free radicals.

In ambient conditions, the fruit has a short postharvest life due to its high respiration and ethylene production rates (Piriyavinit et al., 2011). Its visual quality could decline rapidly in ambient conditions with a saleable life of less than a week (Bayogan et al., 2010). However, when mangosteen fruit is stored in low temperature, the rapid deteriorative changes in fruit physiology could be slower (Mustafa et al., 2018). Cold storage can maintain the fruit’s quality and subsequently lengthen its shelf life. However, the price of constructing a cold storage, and the energy costs associated with it can be very expensive with about two to three times more than the traditional storage. Further, the conventional cooling systems use a lot of coolant, a large motor, a wide surface area, and multiple fans which can account for up to 60% of the electrical operating cost (Store It Cold LLC, 2020). Thus, a cheaper
but equally effective alternative to conventional cold storage system is necessary.

A promising alternative to the costly cold storage systems is by utilizing the cooling ability of a standard air conditioning unit using an innovative technology (Store It Cold LLC, 2020). The CoolBot device is reported to be a cheaper alternative to low temperature storage. It is developed with a microcontroller to allow a conventional air conditioning to produce lower temperatures of up to 0°C without ice build-up (Kumar et al., 2019). This device uses multiple sensors, a heating element, and a programmed microcontroller attached directly to the air conditioner (Store It Cold LLC, 2020). It has since become a feasible option, aside from the traditional refrigeration systems, for farmers in the developing world and for small-scale producers as well (Horticulture Innovation Lab 2014).

Physiological disorders such as chilling injury and pericarp hardening also limit marketability of mangosteen fruit (Kader, 2001). Mangosteen can be susceptible to chilling injury when stored below its optimum temperature. Chilling injury includes symptoms of skin darkening and pericarp hardening with increased susceptibility to decay when transferred at higher temperatures after being stored at less than 10°C for more than 15 days, and at 5°C for longer than five days (Kader, 2001). It is therefore necessary to determine the sensitivity of mangosteen fruit to chilling injury when introduced to a cold storage system equipped with CoolBot. In this manner, the storage environment could be modified to alleviate chilling injury and to determine the optimum conditions.

One of the techniques to alleviate chilling injury in tropical and subtropical fruits include the modified atmosphere packaging (MAP) or film packaging (Wang, 2010). In MAP, gas composition inside the package is altered (Dumont et al., 2015). Plastic packaging films such as polyethylene (PE) film bags help maintain high relative humidity and modify the concentrations of O2 and CO2 in the atmosphere surrounding the commodity.

Mangosteen fruit quality is also affected by its maturity stage at harvest (Riyadi et al., 2017). When the fruit is harvested too early before ripening, it may fail to develop a desirable flavor. Meanwhile, transporting overripe fruits is a major concern especially through long distances as the peel may lignify causing pericarp hardening and ultimately, rejection by consumers (Palapol et al., 2009). Considering the factors previously mentioned (i.e., temperature, packaging, and fruit maturity), if mangosteen fruit in a MAP were stored in an optimum cold storage temperature and maturity stage, then its quality could be maintained better and shelf life could be prolonged with minimal or no symptoms of chilling injury. Thus, this study was designed to investigate the response of two maturity stages (reddish purple and dark purple) of PE-bagged mangosteen fruit on CoolBot-equipped insulated room (10°C) and ambient room conditions.

Materials and Methods

Fruit Preparation and Treatment

Mangosteen fruit were acquired from Belviz Farm, Calinan, Davao City, Philippines (7°10’46.5”N, 125°26’41.2”E) and transported to the Postharvest Biology Laboratory in the University of the Philippines Mindanao. Freshly harvested fruit with uniform size (Size Code 2), weight (100±20 g), and “Extra” class quality following the ASEAN Standard (2008) were selected for this study. The fruit were washed with tap water, sanitized with 200 µL L⁻¹ NaOCl solution for 3 minutes and air-dried. The samples were sorted into two maturity stages by visual estimation of peel color: reddish purple and dark purple, and further divided into two lots for the treatments: ambient storage (A= 20.22 m²) and CoolBot-equipped cold storage (A= 5.08 m²). The CoolBot-equipped storage is an insulated room with a digital
air conditioner. The latter storage used a CoolBot device (CoolBot Walk-in Cooler Controller, Store It Cold LLC, USA) which has a controller attached to an air-conditioner simulating a cold room storage (Store It Cold LLC, 2020). The CoolBot device uses temperature sensors, a heater cable, and a programmed microcontroller that manages the air conditioner to operate in such a way as to cool the room to a set temperature between 0.5°C and 18°C without freezing up (Store It Cold LLC, 2020). The thermostat of the air conditioner is heated so that the unit keeps running until the room temperature reaches the CoolBot set point (Kumar et al., 2019).

Each of the treatments was replicated thrice wherein seven fruit samples were packed in an 8” x 14”, 0.002 mm thick polyethylene (PE) bag with 15 pin-prick holes spaced between 1.75” x 1.75” on both sides of the packaging. Two sheets of paper towel were wrapped around the fruit inside the PE bag to serve as a moisture absorber. After which, the PE bag was sealed using a hot sealer. After packing, the samples were placed in two storage conditions: 1) the Postharvest Biology Laboratory served as storage with ambient conditions (26.7±0.6°C, 88.4±3.4% RH) and 2) the CoolBot-equipped cold room (controller set at 50°F; actual reading at 9.9±1.8°C, 77.8±10.7% RH) for storage of mangosteen fruit at low temperature. The fruit quality was evaluated every seven days for 14 days in ambient-stored mangosteen while those stored in CoolBot-equipped room were evaluated every seven days for up to 42 days.

Fruit Quality Evaluation

Fruit quality was evaluated by determining the weight loss, total soluble solids (TSS), visual quality, calyx quality, peel color, degree of chilling injury, and incidence of pericarp hardening. Weight loss (%) was calculated as the proportion of fruit weight lost at the day of evaluation from the initial weight prior to treatment. TSS content was obtained by opening the mangosteen fruit and carefully separating the aril from the seed. Then, the juice from the aril was squeezed using a garlic press and filtered using a cheesecloth. One or two drops of the filtrate was dropped onto the prism of a handheld refractometer (Digital Hand-held “Pocket” Refractometer PAL-1, Atago, Tokyo, Japan) where it was measured. The values were expressed in % Brix.

Peel color was measured quantitatively using a color sensor (Nix Pro Color Sensor, Nix Sensor Ltd., Canada) and the values were expressed as the color space L* (lightness), a* [green (−) or red (+)], b* [blue (−) or yellow (+)], chroma, and hue angle (°) specified by the International Commission on Illumination (CIE). Subjective evaluation of the fruit surface color was also evaluated using a scale (Table 1).

Visual quality, calyx quality, and degree of chilling injury were assessed using their respective rating scales (Table 2). The degree of chilling injury was determined by opening the fruit and evaluating its internal characteristics. The incidence of pericarp hardening was measured by determining the proportion (%) of fruit samples that exhibited hardening and could no longer be opened by hand.

Statistical Analysis

The experiment was laid out in a 2x2 factorial study arranged in a completely randomized design with fruit maturity and storage condition as factors. There were three replications for each treatment combination with seven fruit per replication. The data were subjected to two-way Analysis of Variance (ANOVA). Where there is significant difference in ANOVA, treatment differences were analyzed using Fisher’s Least Significant Difference (LSD) at P≤0.05.
Table 1. Peel color index for mangosteen (Ekman et al., 2019).

<table>
<thead>
<tr>
<th>Peel color index</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Light greenish yellow with scattered pinkish spots</td>
</tr>
<tr>
<td>2</td>
<td>Light greenish yellow or yellowish pink with distinct irregular pink spots</td>
</tr>
<tr>
<td>3</td>
<td>Pinkish spots not as distinct as in 2, reddish pink</td>
</tr>
<tr>
<td>4</td>
<td>Red to reddish purple</td>
</tr>
<tr>
<td>5</td>
<td>Dark purple</td>
</tr>
<tr>
<td>6</td>
<td>Purple black</td>
</tr>
</tbody>
</table>

Table 2. Rating scale for determining visual quality, calyx quality, and degree of chilling injury in mangosteen fruit.

<table>
<thead>
<tr>
<th>Rating scale</th>
<th>Visual quality (Ekman et al., 2019)</th>
<th>Calyx quality (Ekman et al., 2019)</th>
<th>Degree of chilling injury (Kondo et al., 2004)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent, field fresh</td>
<td>Excellent, green, no shrveling at the calyx</td>
<td>No inner pericarp browning</td>
</tr>
<tr>
<td>2</td>
<td>Very good, slight defects</td>
<td>Very good, 1-10% shrveling and browning</td>
<td>Slight, 1-5% browning</td>
</tr>
<tr>
<td>3</td>
<td>Good, defects progressing, limit of acceptability</td>
<td>Good, 11-20% shrveling and browning</td>
<td>Moderate, 6-10% browning</td>
</tr>
<tr>
<td>4</td>
<td>Fair, useable but not saleable</td>
<td>Fair, 21-30% shrveling and browning</td>
<td>Moderately severe, 11-15% browning</td>
</tr>
<tr>
<td>5</td>
<td>Poor, severely deteriorated</td>
<td>&gt;30% shrveling and browning</td>
<td>Severe, &gt;15% inner pericarp browning</td>
</tr>
</tbody>
</table>

Results and Discussion

Results

Weight Loss

Weight loss was lower in mangosteen fruit stored in the CoolBot-equipped cold storage compared to those held in ambient room conditions (Figure 1A). Fruit in cold storage reached the 1% weight loss mark only after 35 days whereas, this condition was reached in just seven days in the ambient-stored lot. There was a significant interaction effect between storage and maturity stage on weight loss of the mangosteen fruit in seven days after storage (Table 3). When the fruit were stored in ambient conditions, weight loss was higher in the dark purple fruit than in the reddish purple ones. At seven days, dark purple fruit stored in ambient conditions had higher weight loss (0.98%) compared to reddish purple fruit (0.71%). However, weight loss in fruit under cold storage did not differ in both maturity stages wherein the average maximum weight...
Table 3. Effect of storage and maturity, and their interaction effect on the physicochemical qualities of mangosteen fruit stored for 7 and 14 days.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Weight loss (%)</th>
<th>Total soluble solids (%)</th>
<th>Peel color index L*</th>
<th>Chroma</th>
<th>Hue angle</th>
<th>Visual quality</th>
<th>Calyx quality</th>
<th>Incidence of pericarp hardening</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storage period (day)</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>14</td>
<td>7</td>
<td>14</td>
</tr>
<tr>
<td>Storage (S)</td>
<td>*</td>
<td>*</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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<tr>
<td>Maturity (M)</td>
<td>*</td>
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<td>*</td>
<td>*</td>
<td>*</td>
<td>*</td>
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</tr>
<tr>
<td>S x M</td>
<td>*</td>
<td>*</td>
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</table>

Loss reached at the end of storage was at 1.66%.

**Total Soluble Solids**

Storage conditions affected the total soluble solids (TSS) until 14 days of storage while fruit maturity affected its TSS only up to seven days. Initially, dark purple fruit had higher TSS than reddish purple mangosteen fruit (Figure 1B). After seven days, the reddish purple fruit reached a similar TSS value (20% Brix) as the dark purple mangosteen fruit. After seven days, TSS declined in mangosteen fruit regardless of its maturity stage and storage conditions. Dark purple fruit stored in Coolbot-equipped room had higher TSS all throughout the storage period compared to dark purple fruit in ambient and reddish purple fruit stored either in ambient or cold storage. No significant interaction was observed on TSS as influenced by both storage and fruit maturity (Table 3).

**Peel Color Index**

Both fruit maturity and storage condition played a significant effect on the peel color of mangosteen fruit for the entire storage period. Cold storage maintained the peel color of both maturity stages more effectively compared to fruit stored in ambient room conditions (Figure 2A). Mangosteen stored in ambient conditions reached the purple black stage after four days, regardless of its initial maturity stage. This suggests a faster color development in fruit stored in ambient mode.

There was a significant interaction effect between storage and maturity on the peel color index and color space values L*, a*, b*, chroma, and hue angle of mangosteen fruit at 7 and 14 days of storage (Table 3). Reddish purple fruit stored in CoolBot-equipped room maintained higher L*, a*, b*, and chroma in the peel better than the dark purple fruit (Figure 2B-E). Further, reddish purple fruit appeared to be lighter and vivid, with more red and yellow color components in the
Figure 1. Weight loss (A) and total soluble solids (B) of mangosteen fruit as influenced by two maturity stages (reddish purple or dark purple) and storage conditions: ambient (26.7±0.6°C, 88.4±3.4% RH) or CoolBot-equipped cold room (9.9±1.8°C, 77.8±10.7% RH). Bars depict significant difference between factors using Fisher’s LSD at P ≤ 0.05.

peel. Meanwhile, mangosteen fruit stored in ambient conditions appeared to be the opposite as a*, b*, and chroma declined soon after the start of storage. Mangosteen stored in CoolBot-equipped cold storage exhibited lower hue angle (18-23°, orange red) than those held in ambient conditions (102-119°, green) (Figure 2F). Further, between the two maturity stages of fruit stored in cold storage, dark purple fruit had lower hue angle which was in the orange red spectrum of the color space while the reddish purple was at the orange spectrum.

Visual Quality

The visual quality deteriorated over time with cold storage producing a significant effect on fruit visual quality (Figure 3A). The fruit stored in the CoolBot-equipped cold storage had better visual quality than those stored in ambient room conditions. Further, a good visual quality was maintained longer in cold-stored fruit. The fruit attained a visual quality rating of 3 (limit of acceptability) starting at seven days after storage in ambient conditions whereas it was 21 days in cold storage, regardless of the maturity stage. The initial maturity at harvest time did not affect the visual quality during storage. No interaction effect was observed between storage and maturity on the visual quality of mangosteen fruit (Table 3).

Calyx Quality

Fruit maintained good calyx quality up to 21 days in cold storage while it was only seven days in ambient-stored fruit (Figure 3B). Mangosteen fruit stored in CoolBot-equipped cold storage had better calyx quality which was maintained all throughout the storage period. Further, the CoolBot-equipped cold storage delayed the browning and shriveling of the mangosteen calyx. Meanwhile, maturity stage did not affect the calyx quality. There was also no interaction effect between storage and maturity on the calyx quality of mangosteen fruit (Table 3).
**Pericarp Hardening**

Neither storage nor maturity stage significantly affected the incidence of pericarp hardening of mangosteen fruit (Figure 3D). Although it is not statistically significant, mangosteen harvested at dark purple stage had earlier onset of pericarp hardening at seven days in ambient conditions (14.3%) and 28 days in CoolBot-equipped cold storage (4.8%). Reddish purple fruit exhibited pericarp hardening after 14 (28.6%) and 35 (33.3%) days under ambient and cold storage, respectively. No significant interaction was noted between storage and maturity on the incidence of pericarp hardening of mangosteen fruit (Table 3).

**Chilling Injury**

Maturity stage did not affect the degree of chilling injury in mangosteen fruit stored in CoolBot-equipped cold storage (Figure 3D). Chilling injury started to manifest after 14 days of storage in a CoolBot-equipped room. The degree of chilling injury intensified as it reached 35 days showing moderately severe symptoms. At the end of storage period (at 42 days), the mangosteen fruit already showed severe chilling injury symptoms with more than 15% of the inner pericarp exhibiting browning regardless of its maturity stage. Reddish purple and dark purple mangosteen fruit did not differ in the degree of chilling injury after holding in cold storage.

**Discussion**

Weight loss in mangosteen fruit was significantly reduced by cold storage in CoolBot-equipped room (9.9±1.8°C, 77.8±10.7% RH) compared to when it was stored in ambient room conditions (26.7±0.6°C, 88.4±3.4% RH). Mangosteen fruit weight loss might have been hampered in cold storage due to low temperature causing enzymes to slow down and decrease their rate of interaction with substrates thus slowing metabolism. This was also observed in a mangosteen study by Castro et al. (2012) wherein fruit stored at 25°C had high weight loss of 34.4% while those held in 13°C storage had significantly lower weight loss at 8.9%. In terms of fruit maturity, there was no significant difference in weight loss between reddish purple and dark purple fruit in cold storage similar to the results of Widodo et al. (2017). However, there was a slight difference found with those stored in ambient. Dark purple fruit tended to have higher weight loss than the reddish purple mangosteen in ambient storage condition.

Total soluble solids (TSS) were initially higher in dark purple fruit because it was riper unlike the reddish purple that has not reached the optimum TSS. This suggests that harvesting more mature fruit that are sweeter can be maintained longer if stored in low temperature. The low temperature in CoolBot-equipped room was able to maintain a higher TSS in mangosteen as it slowed down the fruit’s metabolism which uses sugars as the primary substrates (Kaur & Dhillon, 2015). The decline in TSS over time could be attributed to the utilization of sugars in order to maintain the fruit’s various metabolic processes.

Color is an important characteristic for determining the maturity of mangosteen fruit. Color development depends on several factors including temperature, maturity stage, and storage duration, and are deemed essential in maintaining important color characteristics during storage (Tadesse et al., 2015). In the present study, maturity stage and storage condition affected peel color during storage. In ambient storage, the reddish purple and dark purple fruit swiftly turned purple black, the last stage (peel color index 6) of color development in mangosteen, after four days in storage. This was also observed in mangosteen by Palapol et al. (2009), and in tomato by Tadesse et al. (2015). Storage in the CoolBot-equipped cold room maintained the peel color and delayed its development in reddish purple and dark purple mangosteen.
Figure 2. Peel color index (A), L* (B), a* (C), b* (D), chroma (E), and hue angle (F) of mangosteen fruit as influenced by two maturity stages (reddish purple or dark purple) and storage conditions: ambient (26.7±0.6°C, 88.4±3.4% RH) or CoolBot-equipped cold room (9.9±1.8°C, 77.8±10.7% RH). Bars depict significant difference between factors using Fisher’s LSD at P≤0.05.

fruit. The delay in color development could be attributed to the slowed activity of enzymes under low temperature which are responsible for anthocyanin accumulation and chlorophyll degradation (Manurakchinakorn et al., 2008). Pericarp color changes in mangosteen are manifested by both the degradation of existing chlorophyll and the synthesis of new
Figure 3. Visual quality (A), calyx quality (B), incidence of pericarp hardening (C), and degree of chilling injury (D) of mangosteen fruit as influenced by two maturity stages (reddish purple or dark purple) and storage conditions: ambient (26.7±0.6°C, 88.4±3.4% RH) or CoolBot-equipped cold room (9.9±1.8°C 77.8±10.7% RH). Bars depict significant difference between factors using Fisher’s LSD at P≤0.05.

Anthocyanin, a phenolic compound. The purple red color of mangosteen is composed of anthocyanin with cyanidin-3-sophoroside and cyanidin-3-glucoside as the major and minor pigments, respectively (Du & Francis, 1977). Further, there were studies reporting that chilling injury in fruits stored under low temperature delayed color development such as in tomato (Luengwilai & Beckles, 2013; Tadesse et al., 2015) and kiwifruit (Mworia et al., 2012).

CoolBot-equipped cold storage maintained a better visual quality of mangosteen fruit and prolonged its shelf life by 21 days instead of seven days in ambient condition, regardless of the maturity stage when it was treated. Cold storage at 10°C extended the shelf life of mangosteen up to four weeks similar to the reports of Martin (1980) and Castro et al. (2012). One of the major factors that limit the storage life of mangosteen is the shriveling and browning of the calyx (Vo et al., 2016) as similarly observed in the present study with ambient-stored fruit. The perforated polyethylene bag that contained the samples might have also reduced chlorophyll loss as observed under low O₂ and high CO₂ in modified atmosphere packaging (Manurakchinakorn et al., 2008; Pakkasarn et al., 2003).

Pericarp hardening is caused by lignification due to pericarp injury that may be caused by
improper handling (Bunsiri et al. 2003). It could also be brought about by weight loss due to water loss from the rind (Ahmad et al. 2013) as observed in those that were stored in ambient room conditions from the present study. Pericarp hardening and browning could also be a manifestation of chilling injury (Dangcham et al., 2008). In the present study, the degree of chilling injury increased over time. It could be caused by stresses due to water loss, change in temperature, ethylene production, composition and exchange of gases, and senescence (Castro et al., 2012). Further, it has been reported that when pericarp hardening occurred, pericarp firmness and lignin contents also increased (Dangcham et al., 2008). An analysis of enzyme activity by Dangcham et al. (2008) suggested that the increase in pericarp firmness of mangosteen fruit resulted from induction of lignin synthesis with concomitant increase in phenylalanine ammonia lyase (PAL) and peroxidase (POD) activities and subsequent gene expression. Another factor reported to affect chilling injury in mangosteen is fruit maturity where more mature mangosteen fruit were more sensitive to chilling injury because of its higher lignin content (Dangcham & Ketsa, 2007). However, in the present study, chilling injury did not vary between the two maturity stages used.

Conclusion

This study revealed that the use of CoolBot device is a potential technology to modify an insulated room with an air conditioner for storage of fresh produce. Reddish purple and dark purple mangosteen could be stored for seven days at ambient room conditions while storage in an insulated room with an air conditioner equipped with CoolBot set at 10°C extended storage life up to 21 days. For cold-stored mangosteen fruit, chilling injury which manifested as inner pericarp browning at 35 days did not vary between fruit maturity stages. This storage of reddish purple mangosteen fruit in a modified cold storage using CoolBot has demonstrated its potential in maintaining fruit quality until 28 days. This technology has a promising potential in enabling farmers and traders to build a low-cost walk-in cold room for storing mangosteen fruit.

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