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Effect of harvest season, maturity and storage temperature on storability of carambola 'Honglong' fruit

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ABSTRACT

Averrhoa carambola L. cv. Honglong is a species newly bred in Taiwan for commercial purposes. However, few studies have been conducted on the storage and transportation of this fruit. Accordingly, the present study investigated the influences of harvest reasons, fruit maturity, and storage temperature on the food quality and storage life of 'Honglong' fruits. The results showed that the color and firmness of summer fruits were superior to those of winter fruits; the winter fruits at 70% or 80% maturity had a significantly longer the storage life than the corresponding summer fruits. Fruits with 70% maturity (i.e., when half of the fruit is yellow) are bright green-yellow, high in total soluble solids (7.1°Brix for winter fruits and 7.5°Brix for summer fruits), and low in titratable acidity (0.34% for winter fruits and 0.32% for summer fruits). In addition, the storage life and cold resistance of fruits with 70% maturity had a longer life and were more resistant to cold than those with 60% maturity were. The transportation storage temperature of 5 °C caused slight chilling injury but was optimal for maintaining food quality, storage life, and shelf life. Storage temperatures of 0 and 3 °C caused severe chilling injury, and 10 °C caused the fruits to rapidly turn yellow and rot. We suggest that 'Honglong' fruits be harvested at 70% maturity and be stored at 5 °C to achieve optimal quality for commercial production.

1. Introduction

Averrhoa carambola L. cv. Honglong is a member of the Oxalidaceae family. Carambola fruit is oval or elliptical with three to five longitudinal ribs. The fruit derives its vernacular name "starfruit" from its star-shaped cross section; it was a potent natural antioxidant food and contained abound in phenolic compounds (Tongchitpakdee, 2012; Yan et al., 2013). Carambola fruit has a sour tart or mildly sweet taste depending on the species and level of maturity. The fruit can be eaten fresh or after processing (Morton, 1987; Wu et al., 2004).

Prior to 2010, the main cultivars of carambola fruits exported from Taiwan was *Averrhoa carambola* L. cv. Chang Tsey ('Chang Tsey' carambola), accounting for 40% of carambola fruit exports. In recent years, 'Chang Tsey' carambola crops were often damaged by pests and disease, and the frequent use of pesticide increased production costs. Accordingly, the agricultural area for cultivating 'Chang Tsey' carambola gradually reduced, and another species, 'Honglong,' became dominant for cultivation. Fengshan Tropical Horticultural Experiment Branch first cultivated 'Honglong' with self-seedlings obtained from the species 'Jakarta.' The peel of the fruit is orange-red and has thick, firm ribs; it is considered delicious, suitable for storage and transportation, and is therefore preferred by for export. Currently, 'Honglong' carambola is the main species exported from Taiwan (Liu, 2009).

When managed properly, carambola fruits can be harvested three times annually (Wu et al., 1993). In Florida, carambola fruits are harvested from June to February; however, the main harvest periods are August–October and December–February. In Malaysia, the fruit is harvested throughout most of the year; however, the main harvest periods are April–May, July–August, and November–December (Tongchitpakdee, 2012). In Taiwan, except for the low harvest from May to July, most harvests during other periods are exported. Product quality and nutritional quality are influenced by the climate. For example, lettuce is typically grown at low temperatures and has a firm head with a mild flavor. If lettuce is grown at high temperatures or during droughts, its leaves will be less tender even if the flavor quality of the head excellent (Peirce, 1987).

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Harvest maturity is crucial for quality management and has a marked influence on product quality (Braman et al., 2015). It can also influence the metabolic responses of vegetables and fruits. Therefore, it is a crucial factor that determines product quality, storage potential, and storage disorder (O'Hare, 1993; Siddiqui and Dhua, 2010). Currently, to prevent mechanical damage to carambola fruits during long-distance transportation and after-harvest handling, exporters suggest that the fruit should be harvested at the color-break stage (O'Hare, 1993). Because total soluble solids (TSS) content in carambola fruits increases with maturity, Warren et al. (2007) suggested that the fruit of *Averrhoa carambola* L. cv. Arkin ('Arkin' carambola) should be harvested after the color-break stage to ensure excellent food quality.

Cold storage is commonly used to transport fruits to international markets, however, tropical fruits are susceptible to chilling injury (Mustafa et al., 2016). The influence of storage temperature on the quality of fruits and vegetables depends on the metabolic rates of them. Dodd and Bouwer (2014) suggested that the optimum temperature and relative humidity for storage of carambola fruits were 7–10 °C and 85–95%, respectively. Under these conditions, the storage life of the fruits is approximately 21–35 days. Cantwell (2002), however, suggested that the optimum storage temperature and relative humidity were 9–10 °C and 85% to 90%, respectively. Under these conditions, the storage life of the fruit is approximately 3–4 weeks. Numerous reports have indicated that for this fruit, storage temperature ≤5 °C causes chilling injury (CI), which becomes severe with longer storage times (Miller and McDonald, 1997; Wan and Lam, 1984; Warren et al., 2007).

'Honglong' is a newly bred species that has been widely accepted by farmers and consumers in Taiwan. Furthermore, it has become a major carambola cultivar. However, few studies have examined the physical, storage, and transportation characteristics of this cultivar to derive a reference for business operators regarding the optimum storage and transportation conditions. Accordingly, in the present study, the influences of the harvest season, fruit maturity, and storage temperature on the fruit quality and storage life of 'Honglong' were investigated.

2. Materials and methods

2.1. Experiment I. Harvest maturity

'Honglong' fruits were harvested in Ligang Township (Pingtung County, Taiwan) during winter (February 26th) and summer (September 10th) in 2012. Fruit maturity was determined through visual inspection, and three levels of maturity were determined: 60% maturity (one-quarter of the fruit had turned yellow), 70% maturity (half of the fruit had turned yellow), and 80% maturity (three-quarters of the fruit had turned yellow). The inspection criteria are defined as follows: 60% maturity: the fruit is not fully developed, the outer edge of its ribs appear dark green, and the ribs appear light green (approximately 65–75 days after blossoming for summer fruits and approximately 100–110 days after blossoming for winter fruits); 70% maturity: the fruit is fully developed, the outer edge of its ribs appear light green, and approximately half of its ribs are yellow (approximately 70–80 days after blossoming for summer fruits and approximately 105–115 days after blossoming for winter fruits); and 80% maturity: the color of a fruit has begun changing, but the outer edge of its ribs remain green (approximately 80–90 days after blossoming for summer fruits and approximately 115–125 days after blossoming for winter fruits). The fruits were selected and sent to a laboratory. Fruits were removed if they were over- or under-ripened or affected by pests, disease, or mechanical damage. The remaining fruits were stored in a refrigerator at 5 °C and their storage life, quality, and CI index were investigated. At 7, 14, 21, 28, 35, and 42 days, fruits were stored at 25 °C to investigate their shelf life. Each analysis was carried out 5 replications and each replication included two fruit samples.

2.2. Experiment II. Storage temperature

During winter (February 4th) and summer (August 27th) in 2013, fruits having 70% maturity were harvested and sent to the laboratory. The 70% maturity of carambola is mainly harvest maturity for commercial exportation in Taiwan. Fruits were removed if they were over- or under-ripened or affected by pests, disease, or mechanical damage. The remaining fruits were stored in a refrigerator at 0, 3, 5, or 10 °C and their storage life, chilling injuring index, and quality investigated. After 7, 14, 21, 28, 35, and 42 days of storage, the fruits were then stored at 25 °C and their shelf life was investigated. Each analysis was carried out 5 replications and each replication included two fruit samples.

2.3. Quality characteristics

2.3.1. Color

The color of the rib peel was determined at three points (top, middle, bottom) and a mean value was calculated for each piece of fruit. A color difference meter (ZE-2000, Nippon Denshoku) was used to measure the lightness and to obtain the values of a and b. The lightness values ranged from 0 to 100, with lower values representing darker colors. Hue value (θ value = $\tan^{-1}|b/a|$) was used to represent the color change in the fruit (0° = red-purple, 90° = yellow, 180° = blue-green, and 270° = blue). Color intensity was represented by $C = [(a^2 + b^2)^{1/2}]$, with higher values indicating higher color intensity (McGuire, 1992).

2.3.2. Firmness

A property analyzer EZ-test 500N, Shimadzu with a No. 5 probe (diameter, 5 mm) was employed to measure the fruit firmness. The probe depth was set to 10 mm. Measurements (N) were performed at the top, middle, and bottom parts of the ribs, and a mean value was calculated for each piece of fruit.

2.3.3. Total soluble solid

The TSS content in the juice was measured using a hand-hold refractometer N-IE, Atago; the TSS value was presented in °Brix. The TSS of the top, middle, bottom parts of the ribs of each fruit were measured and the mean TSS value was calculated for each fruit.

2.3.4. Titratable acidity

Carambola pulp of 10 g was added to 100 mL of distilled water; the mixture liquid was filtered by using filter paper (Whatman No. 1). Subsequently, 25 mL of filtrate was removed and titrated in 0.1 M NaOH. An automatic potentiometric titrator (DL53, Mettler Toledo) was employed to titrate the filtrate until its pH was 8.1. The NaOH titration of the sample was converted into the chemical equivalent of citric acid to obtain the total titratable acidity (TA) (%) of the sample (Teixeira et al., 2008; Ashok et al., 2011).

2.4. Chilling injury

Chilling injury (e.g., black or brown depressed spots) due to low temperature was assessed through visual observation. Three CI index were determined (index 0–2). The criteria were defined as follows: CI index 0: the peel is bright and without CI; index 1: the peel exhibits slight CI with brown depressed spots covering less than 20% of the peel; and index 2: the peel shows clear CI with brown depressed spots covering more than 20% of the peel. The CI