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Modeling 'Tommy Atkins' mango cooling time based on fruit physicochemical quality

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ABSTRACT

Mango physicochemical quality can potentially affect fruit cooling time. In that case, an efficient cooling time should take into account fruit quality parameters. The objective of this study was to develop models that can be used to predict 'Tommy Atkins' mango cooling time based on fruit physicochemical quality. The prediction models were developed using 150 fruit harvested at maturity stages ranging from 2 to 4. Two thermocouples were fixed in each fruit, one immediately below the epidermis and the other close to the endocarp. From the total number of fruit, 83 were subjected to hydrothermal treatment and 67 were maintained at room temperature (25 °C). The hydrothermal treatment was applied by keeping the mangoes in water bath at 46 °C for 75 min. This treatment is commercially used as a phytosanitary method for mangoes exported to North America and Asian countries. After hydrothermal treatment, treated and non-treated fruit were kept in a cold room to determine the cooling time of the flesh immediately below the epidermis and close to the endocarp, until reaching 12 °C. After reaching storage temperature, each fruit was evaluated for physicochemical characteristics, which were used to obtain the cooling time prediction models. Quality attributes presenting the highest to the lowest influence on fruit cooling time were fruit weight, flesh and skin color (Chroma, Hue angle and Lightness), soluble solids, dry matter, fruit diameter, fruit length, flesh thickness and seed thickness. Cooling time prediction models were generated with these variables by multiple linear regression (MLR) and exhibited high prediction accuracy for fruit without hydrothermal treatment (R^2_{SEC} = 88% RMSEC 42.1% R^2_{SEP} = 85.5% RMSEP = 52.2%) and with hydrothermal treatment (R^2_{SEC} = 72.2% RMSEC 42.4% R^2_{SEP} = 73.6% RMSEP = 47.2%). According to the results, the models developed based on physicochemical parameters can predict with relatively high accuracy the cooling time of 'Tommy Atkins' mangoes. These models can be used in the mango industry to determine the most effective cooling time required to maintain fruit quality.

1. Introduction

Mango (*Mangifera indica* L.) is a climacteric fruit cultivated in tropical and subtropical regions. The largest mango producing countries in the world are India and China (Marques et al., 2016). Brazil occupies the seventh place in the world mango production, with a planted area of 52,400 ha, 51% of which is produced in the São Francisco Valley, located between the states of Pernambuco and Bahia (Cepea, 2017).

Low storage temperatures are used to prolong the postharvest life of fruit. Ideal storage temperatures for 'Tommy Atkins' mango ranges from 10 to 13 °C, depending on growing condition and maturity stage (Zhang et al., 2017). Lower temperatures may lead to chilling injury (Zhang et al., 2012), while higher temperatures can increase fruit metabolism and reduce postharvest life. In the cold chain, rapid and efficient cooling technologies are important to remove fruit thermal load, reducing metabolism, maintaining quality and increasing postharvest life without injury (Teruel, 2008).

High fruit consumption is stimulated by high fruit quality, which is affected by temperature conditions during the cold chain from harvest to consumers. Previous studies have shown that modeling can be used

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to predict quality components in food such as water, protein, fat, and carbohydrates, but significant discrepancies may exist between predicted and reference values due to modeling approaches that do not take into account food changes over time (Nesvadba, 2005; Ramaswamy and Marcotte, 2005; Toledo, 2006). For example, studies have developed models to predict fruit thermophysical properties at a specific maturity stage based on its water content and temperature (Laohasongkram et al., 1995; Bon et al., 2010; Sousa et al., 2016). However, these studies do not consider the fruit a living organ that changes over time due to ripening related processes, which can potentially lead to discrepancies between predicted and reference values.

Mangoes are climacteric fruit that undergo major physicochemical changes along the ripening process. In addition, mangoes exported to countries such as United States and Japan must necessarily be subjected to hydrothermal treatment for phytosanitary control (USDA-APHIS, 2002), which may alter the physicochemical changes predicted during the ripening (Osuna-Garcia et al., 2015; Alvindia and Acda, 2015).

Developing precise models to predict fruit cooling time requires identifying the quality parameters that strongly affect thermophysical properties of fruit flesh. The models should also take into account variations in these quality parameters along the ripening process, as well as the use of hydrothermal treatment. These models are potential tools to efficiently manage the use of the cold chain from harvest to consumers by precisely determining the necessary cooling time required to ensure high quality and prolong the postharvest life of the fruit.

This study aimed to develop models that can be used to predict 'Tommy Atkins' mango cooling time based on fruit physicochemical characteristics.

2. Material and methods

2.1. Fruit sample and temperature analysis

The study was carried out at the Postharvest Physiology and Technology Laboratory at Embrapa Semi-Arid, Petrolina, PE, Brazil. A total of 150 fruit with different physicochemical characteristics, representing different maturity stages, were harvested from an irrigated commercial orchard in Juazeiro, BA, Brazil (Table 1). After harvest, two T-type thermocouples (copper and constantan) were crosswise introduced at the equatorial region in each fruit, one located immediately below the epidermis, referred to as fruit surface temperature (ST), and the other located on the endocarp surface, referred to as fruit center temperature (CT). After insertion, the thermocouples were isolated using silicone (Silva, 2013) and attached to two multiplexers of a CR10X datalogger(Campbell Scientific, São Paulo, Brazil). Flesh temperatures data were collected every five minutes in each fruit ST and CT thermocouple.

2.2. Improvement of T-type thermocouple precision

T-type thermocouple (Omega, Stanford, EUA) precision (± 1.0 °C) was improved by calibrating each sensor using the T-107 thermistor (± 0.01 °C) (Campbell Scientific, São Paulo, Brazil) as reference. The calibration was accomplished in water at three temperatures (8, 20, and 60 °C) with data collection accomplished every minute. Linear equation was developed using the data collected in water by the T-107 thermistor reference and each T-type thermocouple. Then, equations were made for each thermocouple to minimize error and increase precision during temperature measurement (Balbinot and Brusamarello, 2011). After calibration, all temperature data were corrected by the following equation Eq. (1), which improved T-type thermocouple precision to ± 0.15 °C.

$$Y = 0.8749x + 5.3905\ (R^2\text{: } 85\%) \quad (1)$$

(Y) Temperature Thermistor (T-107); (X) Temperature Thermocouple type T

Table 1
Variation range for physicochemical characteristics and cooling time of 'Tommy Atkins' mangoes harvested at different maturity stages and subjected (HT) or not (NHT) to hydrothermal treatment prior to refrigerated storage at 12 °C.

Parameter	HT		NHT	
	Range	CV (%)*	Range	CV (%)
Chemical characteristics				
Soluble solids (%)	8.0–21.7	24.0	7.1–21.9	27.4
Citric acid (%)	0.01–1.55	27.0	0.33–1.52	24.2
Skin lightness	10.33–52.79	30.0	14.66–50.24	24.3
Skin chroma	31.29–61.24	17.0	30.26–62.84	17.0
Skin hue angle	18.83–116.82	51.0	19.6–115.91	46.2
Flesh lightness	33.58–76.71	13.0	43.78–69.95	11.8
Flesh chroma	55.04–85.64	7.0	63.72–85.91	6.7
Flesh hue angle	85.55–115.7	7.0	81.1–115.84	8.2
pH	2.6–4.8	16.0	2.8–4.7	11.5
Physical characteristics				
Firmness (N)	0.615–12.65	72.5	1.093–13.58	70.9
Weight (g)	332.29–595.79	14.0	332.29–693.82	15.0
Flesh thickness (mm)	23.66–38.29	10.0	24.62–38.32	8.5
Seed thickness (mm)	16.35–28.44	9.0	12.5–25.67	11.0
Seed length (mm)	64.18–109.2	9.0	73.2–111.3	10.4
Fruit length (mm)	89.6–155.12	7.0	92.92–132.67	6.5
Fruit diameter (mm)	67.54–93.07	6.0	63.3–96.05	6.4
Dry matter (%)	16.95–30.95	11.0	11.02–28.85	13.5
Cooling time (minutes)				
CT (min)**	110–720	42	60–510	63
ST (min)***	40–355	48	15–365	73.6

* CV = coefficient of variation.
** Center Temperature.
*** Surface Temperature.

2.3. Hydrothermal treatment and cooling conditions

All 150 fruit were kept at 25 °C and had the same ST and CT at the beginning of the study. After placing the calibrated thermocouples in each fruit, 83 mangoes were subjected to hydrothermal treatment (HT) followed the recommendations of time and temperature for fruit exported to countries such as United States, Japan and Chile (Kim et al., 2009). HT mangoes were maintained in a water bath Quimis (Quimis, Diadema, Brazil) at 46 °C for 75 min. The remaining 67 mangoes were not subjected to hydrothermal treatment (NHT) and were kept at 25 °C. After hydrothermal treatment, treated (HT) and non-treated (NHT) fruit were stored in a cold room at 12 °C. The dimensions of the cold room used in the study were 3 × 2 × 3 m (length x width x height) (GEFRIO, Fortaleza, Brazil). The cold unity was placed in the upper central position at the end of the cold room with air flow of 2 m s^{-1}. After reaching the storage temperature of 12 °C, the cooling times of the flesh immediately below the epidermis (ST) and on endocarp surface (CT) were determined as the time required for the ST and CT to reach the storage temperature of 12 °C in fruit subjected to hydrothermal treatment (HT) or not subjected to hydrothermal treatment (NHT).

2.4. Physicochemical quality analysis

After cooling all fruit, each individual fruit was subjected to physicochemical analysis, which was accomplished only on the fruit side where temperature data were collected.

2.5. Fruit weight and flesh firmness

Fruit weight was determined using a precision balance model M (Bell Engineering, Piracicaba, Brazil) and the results were expressed in gram. Flesh firmness was determined, after removing 1 mm of skin,