Colegio de Postgraduados

Postharvest characteristics of Ataulfo mango grown in Soconusco, Chiapas

Salvador-Figueroa, Miguel[1]; Rosas-Quijano, Raymundo[1]; Martínez-Luzuriaga, Jhinson D.[1], Gómez-Estrada, José A.[1]; Vázquez-Ovando, Alfredo[1]; Gálvez-López, Didiana[1*]

[1] Instituto de Biociencias, Universidad Autónoma de Chiapas, Tapachula, Chiapas, México, C.P. 30798.
* Correspondence: didiana.galvez@unach.mx

ABSTRACT
Objective: To determine the main evolution indexes of the postharvest ripening of the Ataulfo mango variety grown in Soconusco, Chiapas, Mexico.
Design/Methodology/Approach: The variables determined were, mango skin color (B*, a*, and b*), starch index, total soluble solids (TSS) (°Brix), pH, fruit firmness, and color/skin firmness correlation.
Results: As the fruit ripeness evolution advances from stage 1 to stage 5, the values of the B*, a*, and b* (color) variables, the TSS, and the pH also increase; however, starch concentration and skin firmness decrease. The negative correlation between the B*, a*, and b* (color) and the fruit firmness,suggests the use of the color variable to measure the ripeness of the Ataulfo variety.
Study Limitations/Implications: The ripeness evolution of mango has been the subject of several studies, focused on different varieties (*e.g.*, Tommy Atkins, Keitt, Alphonso, etc.), particularly in Ataulfo mangoes grown in different regions of Mexico. Understanding the physicochemical evolution of the Ataulfo mango grown in Soconusco, Chiapas is fundamental for the producers.
Finding/Conclusions: The results obtained could help to determine the ripeness state of the Ataulfo mango, under the environmental conditions of Soconusco, Chiapas.

Keywords: Color, °Brix, skin firmness, pH, starch.

Citation: Salvador-Figueroa, M., Rosas-Quijano, R., Martínez-Luzuriaga, J. D., Gómez-Estrada, J. A., Vázquez-Ovando, A., & Gálvez-López, D. (2023). Postharvest characteristics of Ataulfo mango grown in Soconusco, Chiapas. *Agro Productividad*. https://doi.org/10.32854/agrop.v16i7.2544

Academic Editors: Jorge Cadena Iñiguez and Lucero del Mar Ruiz Posadas

Received: February 11, 2023.
Accepted: May 15, 2023.
Published on-line: July 12, 2023.

Agro Productividad, 16(6). June. 2023. pp: 57-71.

INTRODUCTION

Ataulfo mango (*Mangifera indica* L.) is native from Tapachula, municipality of Tapachula, in the southern Mexican state of Chiapas, Mexico. As a result of its organoleptic characteristics, the export quotas of this variety have increased. Additionally, mango is a tropical fruit that is mainly harvested at the beginning of its physiological ripeness, in order to minimize the quality loss resulting from the post-harvest handling and transportation (Padda *et al.*, 2011). During the beginning of its physiological ripeness, mango has a hard or firm texture, a low soluble solids content, and a high acidity. Consequently, it requires a ripeness period to achieve organoleptic maturity —*i.e.*, the desired flavor and texture at the moment of consumption (Cortés *et al.*, 2016; Ibarra-Garza *et al.*, 2015).

Mexico has a protected appellation of origin for some of its products. This "protected appellation origin" label belongs to the geographical location where a specific good is

Image by u_e5c33shc37 at Pixabay

grown or produced. The label establishes a certain production and sowing process and specific characteristics. The goods are considered as a unique product that must be legally protected. The Ataulfo mango was awarded the "Ataulfo mango of Soconusco, Chiapas" protected appellation origin in 2012 (Mendoza-Hernández *et al.*, 2020; DOF, 2012).

The ripening process of mango includes a series of significant molecular, physiological, and biochemical changes. These changes cause ethylene production, an increase in the respiration rate, a remodeling of structural polysaccharides through a coordinated action of the enzymes that cause fruit softening —the result of the progressive depolymerization of pectic and hemicellulosic polysaccharides, which causes a significant galactose, arabinose, and mannose residues loss—, chlorophyll degradation, and carotenoid biosynthesis (Gill *et al.*, 2017; Lawson *et al.*, 2019; Yashoda *et al.*, 2005).

Among the thousand mango varieties grown worldwide, the commercial brands that dominate the market include Tommy Atkins, Haden, Kent, Keitt, Alphonso, and Ataulfo (Lawson *et al.*, 2019). The Mexican states with the largest sowing areas are Chiapas, Sinaloa, and Guerrero. Meanwhile, the most productive state is Sinaloa (>423,517 t), followed by Guerrero (404,561 t), Nayarit (334,914 t), and Chiapas (272,384 t) (SIAP, 2021). Mango exports from Mexico to USA reached 312,390.42 and 346,250.42 tonnes in 2021 and 2022, respectively (Agtools, 2023). Sixty-five percent of the mangoes produced in Mexico is consumed in the USA. Ataulfo is the most produced mango variety in Mexico and it has the highest volume of exportation (Sánchez *et al.*, 2017). Ataulfo mango is grown all along the Pacific coast, from Chiapas to southern Sinaloa.

The protected appellation origin of the Ataulfo mango of Soconusco, Chiapas (Mendoza-Hernández *et al.*, 2020; Villa-Corrales *et al.*, 2010) establishes all the quality parameters for its commercialization (NOM-188-SCFI-2012). Additionally, the post-harvest quality criteria of various mango varieties have been widely described. The main physicochemical attributes of mango related to fruit ripeness quality are pulp firmness, total soluble solids content, and the aroma volatile compounds (Ellong *et al.*, 2015; Liguori *et al.*, 2020). The National Mango Board (NMB) —an agency that defines fruit quality for the American market— has established specific reception and ripeness protocols for Ataulfo mango. These protocols are based on a fruit ripeness guideline, which includes such parameters as the visual index of the pulp color on mangoes cut by half, range of the soluble solids content, and pulp firmness (NMB, 2015). Although these physicochemical criteria are available for Ataulfo mango, developing *in situ* criteria to determine the ripeness evolution of this variety could be useful for local producers. This process would establish the ripeness degree of a recently harvested fruit under the same weather conditions of the region, before it is included in the commercialization process.

Fruit ripeness evolution has been studied in other fruit species such as papaya, tomato, apple, banana, and pear (Basulto *et al.*, 2009; Okiror *et al.*, 2017; Zhang *et al.*, 2021; Li *et al.*, 2011; Saquet 2019) and their findings are used today as criteria to define the commercial quality of those fruits. Currently, most of the researches about mango ripeness have focused on the Tommy Atkins, Keitt, and Alphonso varieties, among others. However, post-harvest quality can differ depending on the variety (Lawson *et al.*, 2019); consequently, specific studies about every local mango variety are required. In this regard, producers must be aware of the evolution process of the Ataulfo's physicochemical criteria. Therefore, the objective of this study was to determine the main post-harvest ripeness evolution indexes for Ataulfo mangoes grown in Soconusco, Chiapas, establishing alternative measures at harvesting time.

MATERIALS AND METHODS

Biological material

Ataulfo mangoes were collected from four certified orchards, located in the municipalities of Acapetahua (15.27985 N, 92.94173 W), Frontera Hidalgo (14.79168 N, 92.21614 W), Huehuetán (15.02958 N, 92.34744 W), and Tapachula (14.85765 N, 92.34577 W). These municipalities constitute the protected appellation origin area of the Ataulfo mango in Soconusco, Chiapas (DOF, 2012). The fruits were sampled from January to June, 2022, and their physiological ripeness was determined according to the ripeness guide of the NMB. In order to avoid variability, 15 fruits (caliber 6) were collected exclusively from one tree per municipality.

The biological material was transported to the Genética de Poblaciones laboratory of the Instituto de Biociencias-UNACH. Afterwards, the samples were washed with water and detergent and were kept at room temperature in order to carry out the analysis. Subsequently, the following stages were established: stage 1 (day 0 or cutting day); stage 2 (day 3 after the harvest (DAH)); stage 3 (5 DAH); stage 4 (7 DAH); and stage 5 (9 DAH). The fruits were kept constantly at room temperature (27 °C average) until the analysis was completed.

Determination of the skin color

The color variable was analyzed following the methodology proposed by Lawson *et al.* (2019), using a MiniScan EZ Hunter Lab colorimeter and quantifying the B*, a*, and b* indexes (*i.e.*, the CIELAB color space). The measurements were carried out in three areas of the fruit, along its longitudinal axis: apical, central, and basal. These indexes are located within the color chromaticity, where B* indicates luminosity-brightness (from 0 = black to 100 = white); a* indicates color directions (+a* = red, −a* = green); and b* indicates color directions (+b* = yellow, -b* = blue). Additionally, the exterior of the fruits was monitored using a Nikon D3300 professional camera. The pictures were taken at a distance of 30 cm from the fruits.

Starch analysis

The starch analysis was carried out using the iodine-starch test (Pitts and Cavalieri, 1988). This test consists of the reaction created by the iodine in contact with the starch granules; the latter are transformed into sugar, thus resulting in a dark purple (almost black) coloration of the pulp. The lower the amount of starch, the lower the coloration. In order to carry out this test, the fruit was cut lengthways, very close to the seed, and, using tweezers, the fruit was placed face down in a stray with a 0.5% I2-KI solution. The internal face was observed after 5 minutes. The results were photographed with a Nikon D3300 professional camera. The pictures were taken 30 cm apart from the fruits.

Determining the physicochemical variables

The physicochemical variables analyzed included total soluble solids (TSS) (°Brix), pH, and firmness (N). Each evaluation was carried out using 15 fruits per tree as replicates and each sample was analyzed in triplicate for all the measurements.

Total soluble solids (°Brix)

The TSS (°Brix) were evaluated according to the NOM-188-SCFI-2012, using a digital refractometer (ATAGO). The TSS was determined cutting the pulp in small portions and then pressing and squeezing the portions in order to obtain a concentrated juice, which was finally filtered. The reading of the concentrated juice of each fruit was performed in triplicate.

Determining the pH

The pH was measured using a HANNA digital potentiometer, following the method proposed by Maldonado-Astudillo *et al.* (2016). The pulp was homogenized using a common blender; a 25 g solution was prepared from the pulp for each of the five ripeness stages and distilled water was poured into a volumetric flask until the mixture reached 100 mL. Afterwards, the suspension was filtered, and the result was used to determine the pH.

Firmness

Firmness is one of the quality measures for fruits and vegetables. This variable was expressed in Newtons (N) and was evaluated using a LLOYD Instruments Plus® texture analyzer with a 2-mm wide plunger. The measurements were carried out in the equatorial sector of the unpeeled fruit. The parameters were: preload/tension (5.6000 N); preload/tension/speed (30.000 mm/min); speed (30.000 mm/min); limit (30.000 mm); and length of the test (30.000 s).

Statistical analysis

All the measured variables were subjected to an analysis of variance (ANOVA) and an analysis of mean differences (Tukey's Test; $\alpha < 0.05$), using the Infostat v. 2016 software (Di Rienzo *et al.*, 2016). Additionally, the skin firmness with B*, a*, and b* color and the skin during the different ripeness stages of the fruit were subjected to a correlation analysis. The Infostat v. 2016 software was used for this purpose, taking into account a significance value of $p < 0.05$.

RESULTS AND DISCUSSION

Determining skin color

During the ripening process, skin brightness (B*) increased from stage 1 to stage 4, with mean values of 59.77and 67.65, respectively. Subsequently, a reduction of the mean value (65.5) was recorded during stage 5 (Figure 1A). There were significant differences between the ripeness stages ($p < 0.005$), but not between municipalities.

Meanwhile, the a* values of the skin recorded significative differences between the ripeness stages ($p < 0.005$), but there were no differences between municipalities. In average, an increase was recorded from stage 1 (−3.98; unripe fruit) to stage 5 (20.88; yellow fruits). These values showed clear changes in every ripeness stage. The values were negative when the fruit was green (stages 1 and 2); however, the values became positive in stages 3, 4, and 5. These results indicate that the a* skin value can be a useful indicator during the monitoring stages of fruit ripening (Figure 1B).

Meanwhile, the b* values of the skin increased from stage 1 to 4, with mean values of 59.77 and 67.65, respectively. A reduction was recorded during stage 5 (Figure 1C). The skin color of the fruit changed from green to yellow during the ripeness stage. Significative differences were recorded between ripeness stages ($p<0.005$), but not between municipalities.

Starch analysis

As the ripeness physiology of the Ataulfo mango advanced, the fruit changed its color, recording the highest starch degradation during stages 1, 2, and 3 (Figure 2). Meanwhile, starch degradation was lower or null during stages 4 and 5. On the one hand, when Ataulfo mango is unripe —*i.e.*, it has not reached the cutting point—, the pulp is white and, therefore, the starch test turns the fruit completely black. On the other hand, during the cutting point, the amount of starch accumulated in the mesocarp is high and, consequently, the color is dark with some yellow lines. At this point, the °Brix are low (5 °Brix in average); however, this is a sign that the degradation of the accumulated starch has started, transforming it

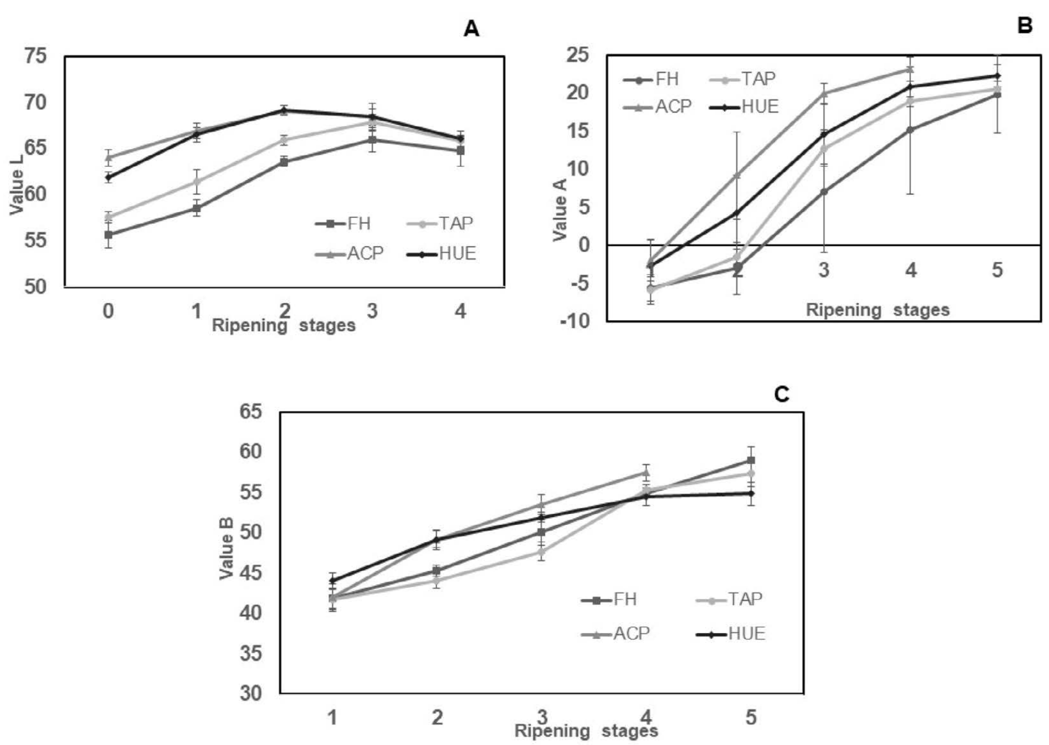

Figure 1. Skin color of the Ataulfo mango during different ripeness stages, in Soconusco, Chiapas: Frontera Hidalgo (FH), Tapachula (TAP), Acapetahua (ACP), and Huehuetán (HUE). A) B* skin brightness. B) a* skin color components. C) b* skin color components.

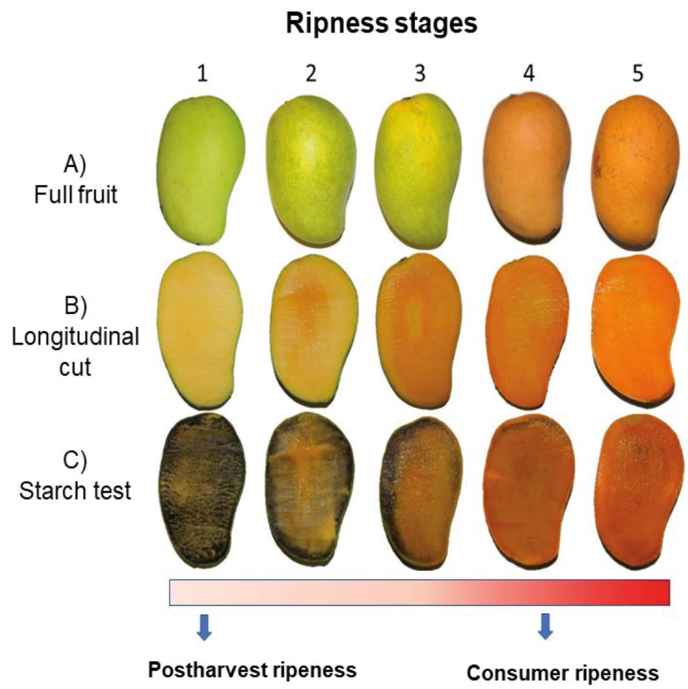

Figure 2. A) Visual appearance of uncut Ataulfo mangoes during each ripeness stage. B) Visual appearance of the insides of Ataulfo mangoes during each ripeness stage. C) Color of the fruit during the starch test.

into soluble sugars. In contrast, during the last ripening phase, the coloration of the starch is almost non-existent, because the fruits have reached their maximum ripeness and all the starch has become soluble sugars. This is the point where the desirable degree of sweetness is reached.

Determining the physicochemical variables

Total soluble solids

Significative differences were found ($p<0.005$) regarding the sugar content (°Brix) during the ripeness evolution of the Ataulfo fruit. Meanwhile, °Brix increased from stage 1 (average 8.14) to stage 4 (20.53). However, sugar concentration decreased in stage 5 (19.10 °Brix) (Figure 3).

Determining the pH

The pH variable recorded significant differences ($p<0.005$) between the different ripeness stages. The pH increased from stage 1 to stage 5, reaching 3.93 and 5.67, respectively (Figure 4).

Firmness

There were significant differences ($p<0.05$) regarding the firmness values of the stages evaluated in the different municipalities. Skin firmness values reached their peak during stage 1 (a 286.34 N average value). However, firmness values drastically decreased (50.24 N) during stage 5. As the ripeness days advanced, ripeness values decreased (Figure 5).

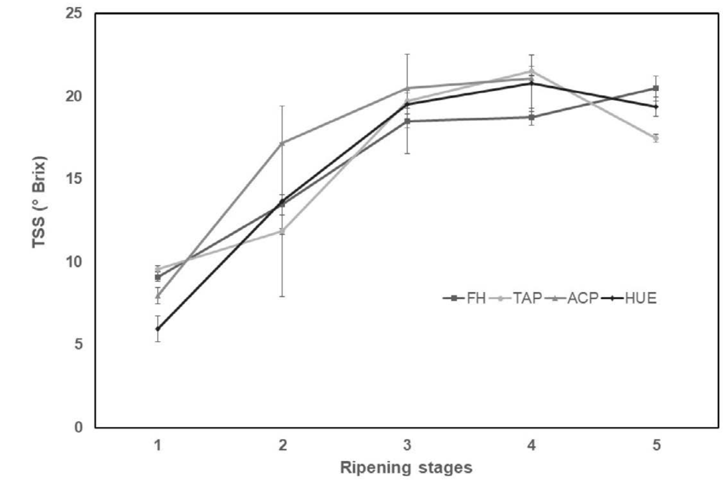

Figure 3. Total soluble solids (°Brix) during the different ripeness stages in the municipalities of Frontera Hidalgo (FH), Tapachula (TAP), Acapetahua (ACP), and Huehuetán (HUE).

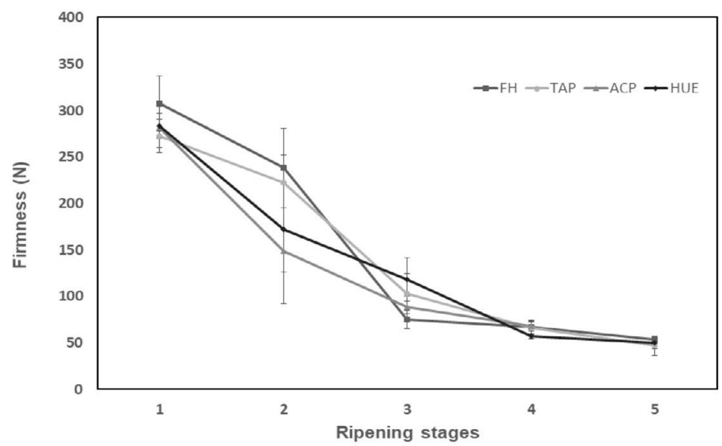

Figure 4. pH of the pulp of the Ataulfo mango during different ripeness stages in the municipalities of Frontera Hidalgo (FH), Tapachula (TAP), Acapetahua (ACP), and Huehuetán (HUE).

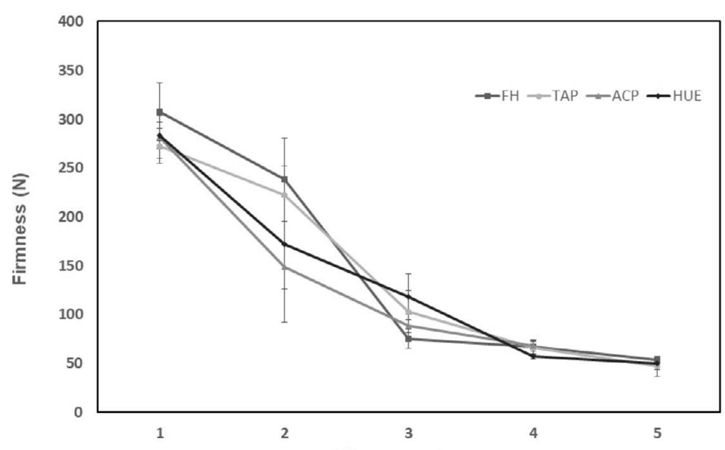

Figure 5. Skin firmness of Ataulfo mangoes during different ripeness stages in the municipalities of Frontera Hidalgo (FH), Tapachula (TAP), Acapetahua (ACP), and Huehuetán (HUE).

Skin firmness/skin color correlation

There is a highly significative negative correlation in all the municipalities between skin firmness and fruit color (B*, a*, and b*) (Table 1). As the ripeness evolves, the fruit loses its firmness and the color variable increases. Therefore, a lower firmness entails a higher brightness (B*), reduces the direction of green (a*); and increases yellow (b*).

Several authors have described the post-harvest quality criteria of different varieties of mangoes. The National Mango Board (NMB) has defined specific reception and ripeness protocols for the Ataulfo mango and its approval for the American market. These protocols are based on fruit ripeness guidelines, which include parameters such as: visual index of the color of the pulp (fruit cut in half), ranges of the soluble solids content, and pulp firmness. However, the color index only works if the guidelines are used in an appropriate manner (National Mango Board, 2015). These parameters are used by both exporters and marketers in Mexico and by the NMB in USA. Nevertheless, there are no guidelines for the ripeness evolution of the Ataulfo mango in Soconusco, Chiapas. Such guidelines could help to establish the ripeness degree of a freshly cut fruit, before it becomes part of the commercialization process.

Studies about the ripeness evolution of other fruits have also been carried out with other species. These fruits have included papaya (Santamaría-Basulto *et al.*, 2009), tomato (Okiror *et al.*, 2017), apple (Zhang *et al.*, 2021), banana (Li *et al.*, 2011), and pear (Saquet, 2019). This study shows that the evaluated parameters prove the ripeness evolution of the Ataulfo mango. Our results were able to determine the ripeness degree of the fruit with greater accuracy.

Table 1. Correlation between skin firmness and the B*, a*, and b* color variables during the fruit ripening.

Municipality		Firmness (N)	Value A	Value L	Value B
Frontera Hidalgo	Firmness (N)	1	−0.876**	−0.962**	−0.884**
	Value A		1	0.853**	0.941**
	Value L			1	0.872**
	Value B				1
Tapachula	Firmness (N)	1	−0.964**	−0.926**	−0.914**
	Value A		1	0.853**	0.942**
	Value L			1	0.814**
	Value B				1
Acapetahua	Firmness (N)	1	−0.963**	−0.949**	−0.923**
	Value A		1	.945**	.905**
	Value L			1	.857**
	Valor B				1
Huehuetán	Firmness (N)	1	−.773**	−.620*	−.891**
	Value A		1	.660**	.923**
	Value L			1	.698**
	Value B				1

** The correlation is significant at the 0.01 level (bilateral).

The skin color of Ataulfo mangoes is an empirical parameter used by producers in the production areas. Producers base their decisions on the color or pigmentation of the fruits or in the degree to which the peduncle is split at the shoulder of the fruit. However, sometimes fruits do not reach the ripeness degree desired by the market and, consequently, they are rejected. Although other models have also used a colorimeter to measure skin color, marketers do not trust that this test can define the post-harvest ripeness of the fruits. If the Ataulfo mangoes are not harvested at the appropriate post-harvest ripeness time, they will never reach the desirable color values. Additionally, the visual attribute of fruit skin color defines the preference of the consumers in certain countries (Kayesh *et al.*, 2013), particularly regarding Ataulfo mango: if the fruits do not reach the market with the desired color (yellow), the costumer will not buy them.

Color development is an important phenomenon that the fruit undergoes in the various stages of its physiological ripeness (Hernández-Estrada *et al.*, 2022; Kapoor *et al.*, 2022). There were significant differences in this study regarding the B* variable; nevertheless, they were similar to those recorded by Rivera-Castro *et al.* (2022), who registered 50.23 to 68.90 values for Ataulfo mangoes grown in the state of Guerrero. Our results are also similar to the findings of Karanjalker *et al.* (2018), who reported that brightness was significatively higher (62.86) for the yellow Arka Anmol variety than for the green Amrapali variety. Meanwhile, the lowest value was recorded for the red Janardhan Pasand variety. Regarding the a* variable, the results of the Ataulfo mango of Chiapas match the Amrapali varieties, whose negative values for stages 1 and 2 indicate an unripen fruit (−8.66); however, these results differ from the findings of Liu *et al.* (2013), who reported values of 10.5, 10.87, 10.31, and 9.80 for the Keitt, Irwin, Tainong No. 1, and JinHwang varieties, respectively. These differences can be attributed to the different shades of red that characterize the skin of these varieties, while the skin of the Ataulfo mango is yellow. Meanwhile, the b* values reported in this study are supported by the work of Rivera-Castro *et al.* (2022), who reported 40.34-52.30 values for Ataulfo mango during stages 1 and 5. These values are also similar to the findings of Karanjalker *et al.* (2018), who recorded that the highest value (48.86) was obtained by the Arka Anmol variety. They also reported a significatively lower value for the Amrapali and Janardhan Pasand varieties. These results also match the findings of Liu *et al.* (2013), who recorded similar results, obtaining values of 49.67, 52.39, 48.01, and 52.27 for the Taining No. 1, Irwin, JinHwang, and Keitt varieties, respectively.

Meanwhile, the starch metabolism of fleshy fruits is a complex and dynamic process, characterized by its accumulation and degradation (Thammawong and Arakawa, 2007). On the one hand, starch accumulation takes place during fruit development and until fruits have completed their cellular division —*i.e.*, when they stop growing (Nardozza *et al.* 2010, 2013). On the other hand, starch degradation starts when fruits begin their ripeness process. Consequently, almost all the starch of the fruits has transformed into soluble sugars after the harvest, increasing and providing the sweetness associated with a ripe fruit (Cordenunsi-Lysenko *et al.*, 2019). In the case of climateric fruits such as mango, ethylene production and respiration rate increase after the harvest and until the fruit reaches its complete ripeness. This process is simultaneously associated to the starch content loss. Shafique *et al.* (2006) reported that, as the sugar levels of the fruits slowly increase, the tritatable acidity rate slowly increases until it reaches its the maximum value, before it ultimately decreases.

Doerflinger *et al.* (2015) applied a tincture to Gala, Honeycrisp, McIntosh, and Empire apple varieties in order to observe their starch concentration and found that starch concentrations linearly diminished after the post-harvest. These results match the findings of Zhang *et al.* (2021), who studied Fuji apples and proved that the apple quality indicators are significatively different during different harvest ripeness stages. Additionally, they reported that the starch index in apples gradually diminished during different post-harvest ripeness stages. This test is very frequently used by apple producers and marketers. It is a highly trustable test and it is unexpensive. Consequently, it could be used to complement the studies about the ripeness of Ataulfo mango. This test has also been used for the color evolution analysis in fruits such as tomato (Huang *et al.*, 2017; Steinhauser *et al.*, 2010), melon (Dai *et al.*, 2011), and peach (Lombardo *et al.*, 2011).

Meanwhile, the TSS and the sugar/acid indexes (TSS/AT) are used as primary indexes to determine the fruit quality of the acceptable ripeness state for commercialization. The minimum requirements to accept the fruits specify the appropriate TSS concentrations and the TSS/AT proportions for each crop (Daniels *et al.*, 2019). These concentrations depend on the solubilization of the sugars in the pulp, which will be the key for the final sweetness of the fruit. The NMB defines the °Brix range for the different mango varieties, according to their ripeness degree. For example, the initial indexes for the Tommy Atkins and Keitt varieties have ranges from 5 to 7, while the Kent, Haden, and Francis varieties have an acceptance range of 6 to 8 or 9. These concentrations guarantee the physiological ripeness of the fruit (National Mango Board, 2015).

In the case of the Ataulfo variety, the NMX-FF-058-SCFI-2006 standard indicates that the minimum acceptable value for fruit ripeness is 2.9 °Brix. For its part, the NOM-188-SCFI-2012 standard specifies that the minimum acceptable range for its commercialization is 8 °Brix, while the NMB uses a range of 5-7 °Brix (National Mango Board, 2015). Slightly differences were found in this study between municipalities. These differences can be the result of the genetic nature of the Ataulfo mango (Salvador-Figueroa *et al.*, 2008). However, these data are similar to the results reported by Rivera-Castro *et al.* (2022), who recorded values of 6.02 °Brix for the Ataulfo variety during the cutting stage. Other mango varieties, such as Langra and Khirshapath (Islam *et al.*, 2013), also recorded values similar to those of the Ataulfo mango. Therefore, the NOM-188-SCFI-2012 standard should be updated to include 5 °Brix for the Ataulfo mango.

Regarding the ripeness evolution of the fruit, the TSS values at the cutting stage increased from stage 1 until they reached their maximum values in stage 4 (when it reached its maximum sweetness). Finally, a slight decrease was recorded during stage 5. These results match the findings of Islam *et al.* (2013), who reported that the TSS values (°Brix) of the Langra and Khirshapath varieties evolved with a similar behavior, because the TSS quickly increased from the first day to the sixth day and then significatively decreased. Ranges have already been established for this TSS attribute for several commercial mango varieties; however, it changes depending on the evaluated variety and the region or location of the said variety. Some mango varieties store lower or higher amounts of sugar in the pulp, ranging from 3 to 8 °Brix during physiological ripeness and reaching 23 °Brix when the fruit is in advanced stage of ripeness (Jha *et al.*, 2010). Finally, the NMB establishes a maximum value of 18 °Brix, while the Ataulfo mango of Soconusco reaches up to 20.5 °Brix.

Regarding the pH variable, Ataulfo mango evolved from 3 to 5.67, which matches the findings of Liu *et al.* (2013), who reported pH values of 3.95, 4.56, 4.90, and 5.58, for the Tainong No. 1, Irwing, JinHwang, and Keitt varieties, respectively. The pH values are also similar to those reported by Shafique *et al.* (2006), who recorded 2.5-5.4 pH values for the Fazli, Ashina, Langra, Surjapuri, Khirshapat, Gopalbhog, Kisanbhog, Mohanbhog, Latabombai, and Ranipasand varieties. Cissé *et al.* (2020) recorded 4.8 pH values for the Kent variety, while Islam *et al.* (2013) obtained 3.5-7 pH values for the Langra and Khirshapat varieties. Their results also support the findings of this study. The NMX-FF-058-SCFI-2006 standard and the NOM-188-SCFI-2012 official protected designation origin standard do not mention optimal pH values for the Ataulfo variety; however, understanding the evolution of this variable during the ripeness stage is a useful indicator of fruit quality.

Meanwhile, fruit firmness is an important physical parameter that the mango industry frequently seeks. Additionally, it is widely used to determine the ripeness state of the fruit (Jassi *et al.*, 2019). Depending on the marketer or producer requirements, this variable can be measured using a texture analyzer, which can be fixed (in a lab) or handheld (portable or that can be used on the field). In the case of Ataulfo mango, fruit firmness is not a parameter specified in the NOM-188-SCFI-2012 standard, although, the NMB carries out this test in order to receive the fruits. According to the ripeness guideline of the NMB, fruit firmness must be measured in the pulp of a peeled fruit, using a penetrometer with an 8-mm tip. The values reported by the NMB range from 209 to 97.8 N, during the initial organoleptic maturity, and 13 to 4.4 N when the ripeness state advances. In this study, firmness was measured in an unpeeled fruit. An average of 286 N was recorded for Ataulfo mango in the cutting day. This measure decreased under the environmental conditions of the Soconusco region, reaching 50 N during the last ripeness stage.

The skin firmness of the analyzed fruits of the four municipalities decreased throughout the different ripeness stages. This decrease can be the result of the different metabolic changes that take place during the ripeness process of mango, as a consequence of the ethylene production and the hydrolase enzymes of the polysaccharides. This situation causes several biochemical changes, a respiration rate increase, the remodeling of the structural polysaccharides of the cellular wall, and consequently fruit softening (Gill *et al.*, 2017). The fruits analyzed in this study had similar values to those reported by Cissé *et al.* (2020) for the Kent and Côte d'Ivoire varieties (45-50 N). For their part, Aular and Natale (2013) mentioned that fruit texture has a series of internal and external characteristics that depend on environmental and nutrient factors, as well as on the parameters used to program the equipment used for the analysis (texturometers and tools). Therefore, the skin firmness could be a useful variable in the analysis of fruit quality and should be included in the update of the NOM-188-SCFI-2012 standard for Ataulfo mango.

Finally, in other studies about other climacteric fruits —such as oriental persimmon (Salvador *et al.*, 2006) and papaya (Santamaría-Basulto *et al.*, 2009)—, the correlation between the B*, a*, and b* values and the fruit firmness allowed the use of color as an unequivocal value to measure fruit ripeness. Consequently, according to the high negative correlation found between the firmness of the unpeeled fruit and the color values (B*, a*, and b*), the non-destructive color variable could be used to determine the physiological ripeness of the Ataulfo mango of Soconusco, Chiapas. This variable could also accurately be used in the field, replacing the empirical measurement made by the producers.

CONCLUSIONS

We established the main ripeness indexes and physicochemical characteristic found during the post-harvest ripeness evolution of the Ataulfo mango variety from Soconusco, Chiapas. According to the obtained results, the generated data are a trustful and easily reproduced guideline that can help producers and marketers to determine the fruit ripeness quality of the Ataulfo mango variety.

ACKNOWLEDGEMENTS

The CONACYT-APN/2017: 6427 project was funded by the Consejo Nacional de Ciencia y Tecnología. The infrastructure used to carry out this project was acquired through the CONACYT-INFR-2015-01: 254256 project. The authors would like to thank the producers from the certified plantations from the Soconusco region, Chiapas, who provided the fruits for this study.

REFERENCES

Agtools® Inc. 2023. Consultado el 18-febrero-2023 [https://www.agtechtools.com/]

Aular, J., & Natale, W. (2013). Nutrição mineral e qualidade do fruto de algumas frutíferas tropicais: goiabeira, mangueira, bananeira e mamoeiro. *Revista Brasileira de Fruticultura, 35*(4), 1214–1231. https://doi.org/10.1590/s0100-29452013000400033

Basulto, F. S., Duch, E. S., Gil, F. E. Y., Plaza, R. D., Saavedra, A. L., & Santamaría, J. M. (2009). Postharvest ripening and maturity indices for maradol papaya. *Interciencia, 34*(8), 583–588.

Cissé, M., Silue, Y., Cissé, M., Kouadio, A. D. S., & Nindjin, C. (2020). Effect of Calcium Carbide Treatment on Ripening Time and Physicochemical Properties of Mango (*Mangifera indica* L.) Variety "Kent", Côte d'Ivoire. *Current Journal of Applied Science and Technology, 39*(38), 24–30. https://doi.org/10.9734/cjast/2020/v39i3831092

Cordenunsi-Lysenko, B. R., Nascimento, J. R. O., Castro-Alves, V. C., Purgatto, E., Fabi, J. P., & Peroni-Okyta, F. H. G. (2019). The starch is (not) just another brick in the wall: The primary metabolism of sugars during banana ripening. *Frontiers in Plant Science*, 10(April). https://doi.org/10.3389/fpls.2019.00391

Cortés, V., Ortiz, C., Aleixos, N., Blasco, J., Cubero, S., & Talens, P. (2016). A new internal quality index for mango and its prediction by external visible and near-infrared reflection spectroscopy. *Postharvest Biology and Technology*, 118, 148–158. https://doi.org/10.1016/j.postharvbio.2016.04.011

Dai, N., Cohen, S., Portnoy, V., Tzuri, G., Harel-Beja, R., Pompan-Lotan, M., Carmi, N., Zhang, G., Diber, A., Pollock, S., Karchi, H., Yeselson, Y., Petreikov, M., Shen, S., Sahar, U., Hovav, R., Lewinsohn, E., Tadmor, Y., Granot, D., … Schaffer, A. A. (2011). Metabolism of soluble sugars in developing melon fruit: A global transcriptional view of the metabolic transition to sucrose accumulation. *Plant Molecular Biology, 76*(1–2), 1–18. https://doi.org/10.1007/s11103-011-9757-1

Daniels, A. J., Poblete-Echeverría, C., Opara, U. L., & Nieuwoudt, H. H. (2019). Measuring Internal Maturity Parameters Contactless on Intact Table Grape Bunches Using NIR Spectroscopy. *Frontiers in Plant Science*, 10(November), 1–14. https://doi.org/10.3389/fpls.2019.01517

Doerflinger, F. C., Miller, W. B., Nock, J. F., & Watkins, C. B. (2015). Relationships between starch pattern indices and starch concentrations in four apple cultivars. *Postharvest Biology and Technology*, 110, 86–95. https://doi.org/10.1016/j.postharvbio.2015.07.012

Ellong, E. N., Adenet, S., & Rochefort, K. (2015). Physicochemical, Nutritional, Organoleptic Characteristics and Food Applications of Four Mango (*Mangifera indica* L.) Varieties. *Food and Nutrition Sciences, 06*(02), 242–253. https://doi.org/10.4236/fns.2015.62025

Gill, P. P. S., Jawandha, S. K., Kaur, N., & Singh, N. (2017). Physico-chemical changes during progressive ripening of mango (*Mangifera indica* L.) cv. Dashehari under different temperature regimes. *Journal of Food Science and Technology, 54*(7), 1964–1970. https://doi.org/10.1007/s13197-017-2632-6

Hernández-Estrada, M. E., Rosas-Quijano, R., Vázquez-Ovando, A., & Gálvez-López, D. (2022). Pigmentation and vitamin production in mango (*Mangifera indica* L.). *Agro Productividad, 15*(2), 109–125.

Huang, B., Routaboul, J. M., Liu, M., Deng, W., Maza, E., Mila, I., Hu, G., Zouine, M., Frasse, P., Vrebalov, J. T., Giovannoni, J. J., Li, Z., Van Der Rest, B., & Bouzayen, M. (2017). Overexpression of the class D MADS-box gene Sl-AGL11 impacts fleshy tissue differentiation and structure in tomato fruits. *Journal of Experimental Botany, 68*(17), 4869–4884. https://doi.org/10.1093/jxb/erx303

Ibarra-Garza, I. P., Ramos-Parra, P. A., Hernández-Brenes, C., & Jacobo-Velázquez, D. A. (2015). Effects of postharvest ripening on the nutraceutical and physicochemical properties of mango (*Mangifera indica* L. cv Keitt). *Postharvest Biology and Technology*, 103, 45–54. https://doi.org/10.1016/j.postharvbio.2015.02.014

Islam, M. K., Khan, M. Z. H., Sarkar, M. A. R., Absar, N., & Sarkar, S. K. (2013). Changes in acidity, TSS, and sugar content at different storage periods of the postharvest mango (*Mangifera indica* L.) influenced by Bavistin DF. *International Journal of Food Science*, 2013. https://doi.org/10.1155/2013/939385

Jha, S. N., Narsaiah, K., Sharma, A. D., Singh, M., Bansal, S., & Kumar, R. (2010). Quality parameters of mango and potential of non-destructive techniques for their measurement - A review. *Journal of Food Science and Technology, 47*(1), 1–14. https://doi.org/10.1007/s13197-010-0004-6

Kapoor, L., Simkin, A. J., George Priya Doss, C., & Siva, R. (2022). Fruit ripening: dynamics and integrated analysis of carotenoids and anthocyanins. *BMC Plant Biology, 22*(1), 1–22. https://doi.org/10.1186/s12870-021-03411-w

Karanjalker, G. R., Ravishankar, K. V., Shivashankara, K. S., Dinesh, M. R., Roy, T. K., & Sudhakar Rao, D. V. (2018). A Study on the Expression of Genes Involved in Carotenoids and Anthocyanins During Ripening in Fruit Peel of Green, Yellow, and Red Colored Mango Cultivars. *Applied Biochemistry and Biotechnology, 184*(1), 140–154. https://doi.org/10.1007/s12010-017-2529-x

Kayesh, E., Shangguan, L., Korir, N. K., Sun, X., Bilkish, N., Zhang, Y., Han, J., Song, C., Cheng, Z. M., & Fang, J. (2013). Fruit skin color and the role of anthocyanin. In *Acta Physiologiae Plantarum* (Vol. 35, Issue 10, pp. 2879–2890). https://doi.org/10.1007/s11738-013-1332-8

Lawson, T., Lycett, G. W., Ali, A., & Chin, C. F. (2019). Characterization of Southeast Asia mangoes (*Mangifera indica* L.) according to their physicochemical attributes. *Scientia Horticulturae, 243*(May 2018), 189–196. https://doi.org/10.1016/j.scienta.2018.08.014

Li, W., Shao, Y., Chen, W., & Jia, W. (2011). The Effects of Harvest Maturity on Storage Quality and Sucrose-Metabolizing Enzymes During Banana Ripening. *Food and Bioprocess Technology, 4*(7), 1273–1280. https://doi.org/10.1007/s11947-009-0221-z

Liguori, G., Gentile, C., Sortino, G., Inglese, P., & Farina, V. (2020). Food quality, sensory attributes and nutraceutical value of fresh "Osteen" mango fruit grown under mediterranean subtropical climate compared to imported fruit. *Agriculture (Switzerland), 10*(4). https://doi.org/10.3390/agriculture10040103

Liu, F. X., Fu, S. F., Bi, X. F., Chen, F., Liao, X. J., Hu, X. S., & Wu, J. H. (2013). Physico-chemical and antioxidant properties of four mango (*Mangifera indica* L.) cultivars in China. *Food Chemistry, 138*(1), 396–405. https://doi.org/10.1016/j.foodchem.2012.09.111

Lombardo, V. A., Osorio, S., Borsani, J., Lauxmann, M. A., Bustamante, C. A., Budde, C. O., Andreo, C. S., Lara, M. V., Fernie, A. R., & Drincovich, M. F. (2011). Metabolic profiling during peach fruit development and ripening reveals the metabolic networks that underpin each developmental stage. *Plant Physiology, 157*(4), 1696–1710. https://doi.org/10.1104/pp.111.186064

Maldonado-Astudillo, Y. I., Navarrete-García, H. A., Ortiz-Morales, Ó. D., Jiménez-Hernández, J., Salazar-López, R., Alia-Tejacal, I., & Álvarez-Fitz, P. (2016). Propiedades físicas, químicas y antioxidantes de variedades de mango crecidas en la costa de Guerrero. *Revista Fitotecnia Mexicana, 39*(3), 207–214. https://doi.org/10.35196/rfm.2016.3.207-214

Mendoza-Hernández, C., Rosas-Quijano, R., Vazquez-Ovando, A., & Galvez-Lopez, D. (2020). Retos y controversias del mango Ataulfo. *Revista Mexicana de Ciencias Agrícolas, 11*(7), 1633–1645. https://doi.org/10.29312/remexca.v11i7.2199

Monika Jassi, Sandhya Malhotra, Ramandeep Kaur, A. K. S. (2019). Biochemical characterization of langra mango at different stages of ripening. *International Journal of Scientific Research and Review, 07*(04), 463–467.

Nardozza, S., Boldingh, H. L., Osorio, S., Höhne, M., Wohlers, M., Gleave, A. P., MacRae, E. A., Richardson, A. C., Atkinson, R. G., Sulpice, R., Fernie, A. R., & Clearwater, M. J. (2013). Metabolic analysis of kiwifruit (*Actinidia deliciosa*) berries from extreme genotypes reveals hallmarks for fruit starch metabolism. *Journal of Experimental Botany, 64*(16), 5049–5063. https://doi.org/10.1093/jxb/ert293

Nardozza, S., Boldingh, H. L., Richardson, A. C., Costa, G., Marsh, H., MacRae, E. A., & Clearwater, M. J. (2010). Variation in carbon content and size in developing fruit of *Actinidia deliciosa* genotypes. *Functional Plant Biology, 37*(6), 545–554. https://doi.org/10.1071/FP09301

National Mango Board. (2015). Protocolo para el Manejo y la Maduración del Mango Presentado por la National Mango Board. http://www.mango.org/Mangos/media/Media/Documents/Research And Resources/Downloads/Industry/Marketsupport/Mango_Handling_and_Ripening_Protocol_Spn.pdf

Okiror, P., Lejju, J. B., Bahati, J., Rugunda, G. K., & Sebuuwufu, C. I. (2017). Maturity indices for tomato (*Solanum lycopersicum* L.), cv. Ghalia 281 in Central Uganda. *African Journal of Agricultural Research, 12*(14), 1196–1203. https://doi.org/10.5897/AJAR2017.12150

Padda, M. S., do Amarante, C. V. T., Garcia, R. M., Slaughter, D. C., & Mitcham, E. J. (2011). Methods to analyze physico-chemical changes during mango ripening: A multivariate approach. *Postharvest Biology and Technology, 62*(3), 267–274. https://doi.org/10.1016/j.postharvbio.2011.06.002

Pitts MJ y Cavalieri RP. (1988). Objective assessment of apple maturity based on starch location. *Transaction of the ASAE* 31:962-966. DOI: 10.13031/2013.30807.

Riviera-Castro, V. M.; Bahena-Ortega, A. C.; Valenzuela-Lagarda, J. L.; Montaño-López, A.; Mancillas-Paredes, J. M. Cambios fisicoquímicos durante maduración en condiciones locales de venta de frutos de mango Ataulfo de San Marcos Guerrero, Mex. *Química Hoy Chemistry Sciences*. (2022). 11(1), 22-5.

Reddy, I. V. S. (2022). *Sap burn damage of Mango* (*Mangifera indica* L.) *and its management in Telangana. 11*(4), 828–833.

SAGARPA. (2017). *Aumenta 46 por ciento exportaciones de mango hecho en México en 2017*. 2. [http://www.sagarpa.gob.mx/Delegaciones/distritofederal/boletines/2017/mayo/Documents/JAC_00158_02.PDF].

SIAP. 2023. Consultado el 28-enero-2023 [https://nube.siap.gob.mx/cierreagricola/].

Salvador A., Arnal L., Carot J.M., Carvalho C.P., Jabaloyes J.M. 2006. Influence of diferente factor son firmness and color evolution duting the storage of Persimmon cv. 'Rojo brillante'. *Journal of Food Science. 71*(2): S169 - S175.

Salvador-Figueroa, M.; Torres-De Los Santos, R.; Ovando-Medina, I.; Vázquez-Ovando, A.; Adriano-Anaya, M. Análisis de variabilidad genética del huerto padre del *Mangifera Indica* L. var. Ataulfo. *Quehacer Científico en Chiapas*. 2008, 1, 29-34.

Sánchez, A.M.; Sánchez, A.I.M.; Chávez, J.M.; González, J.M.Á.; Vázquez, K.E.V. Identificación del sistema local de comercialización del mango Ataulfo en el municipio de Huehuetán, Chiapas. *Revista Mexicana de agronegocios*. 2017, 40, 571-582.

Sánchez, M., Sánchez, M., Inna, A., Chávez, M., González, Á., Manuel, J., Vázquez, V., Elvira, K., Del, I., Local, S., Del, D. E. C., En, A., & Municipio, E. L. (2017). Identificación Del Sistema Local De Comercialización Del Mango Ataulfo En El Municipio De Huehuetán, Chiapas. *Revista Mexicana de Agronegocios, XXI*(40), 571–582.

Saquet, A. A. (2019). Storage of pears. *Scientia Horticulturae, 246*(March 2018), 1009–1016. https://doi.org/10.1016/j.scienta.2018.11.091

Secretaría de Agricultura y Desarrollo Rural. (2021). *El mango, producto estrella en México*. 1–5. https://www.gob.mx/agricultura/articulos/el-mango-producto-estrella-en-mexico

Shafique, M., Ibrahim, M., Helali, M., & Biswas, S. (2006). Studies on the Physiological and Biochemical Composition of Different Mango Cultivars at Various Maturity Levels. *Bangladesh Journal of Scientific and Industrial Research, 41*(1), 101–108. https://doi.org/10.3329/bjsir.v41i1.279

Steinhauser, M. C., Steinhauser, D., Koehl, K., Carrari, F., Gibon, Y., Fernie, A. R., & Stitt, M. (2010). Enzyme activity profiles during fruit development in tomato cultivars and *Solanum pennellii*. *Plant Physiology, 153*(1), 80–98. https://doi.org/10.1104/pp.110.154336

Thammawong, M., & Arakawa, O. (2007). Starch degradation of detached apple fruit in relation to ripening and ethylene. *Journal of the Japanese Society for Horticultural Science, 76*(4), 345–350. https://doi.org/10.2503/jjshs.76.345

Villa-Corrales, L., Flores-Prieto, J. J., Xamán-Villaseñor, J. P., & García-Hernández, E. (2010). Numerical and experimental analysis of heat and moisture transfer during drying of Ataulfo mango. *Journal of Food Engineering, 98*(2), 198–206. https://doi.org/10.1016/j.jfoodeng.2009.12.026

Yashoda, H. M., Prabha, T. N., & Tharanathan, R. N. (2005). Mango ripening - Chemical and structural characterization of pectic and hemicellulosic polysaccharides. *Sugar Research, 340*(7), 1335–1342. https://doi.org/10.1016/j.carres.2005.03.004

Zhang, B., Zhang, M., Shen, M., Li, H., Zhang, Z., Zhang, H., Zhou, Z., Ren, X., Ding, Y., Xing, L., & Zhao, J. (2021). Quality monitoring method for apples of different maturity under long-term cold storage. *Infrared Physics and Technology, 112*(October 2020), 103580. https://doi.org/10.1016/j.infrared.2020.103580