Baeza-Herrera L *et al.* (2024)
Notulae Botanicae Horti Agrobotanici Cluj-Napoca
Volume 52, Issue 1, Article number 13522
DOI:10.15835/nbha52113522
**Research Article**

# Changes in mango postharvest quality due to nitrogen-phosphorus-potassium dose and production season

Liliana BAEZA-HERRERA[a], David JAEN-CONTRERAS[b], Cesar SAN-MARTÍN-HERNÁNDEZ*, Sergio H. CHÁVEZ-FRANCO*, Alfredo LÓPEZ-JIMÉNEZ, Alfonso MURATALLA-LUA, Cecilia GARCIA-OSORIO

*College of Postgraduates in Agricultural Sciences Campus Montecillo, Montecillo, State of Mexico, Mexico; baeza.liliana@colpos.mx; djaen@colpos.mx; sanmartin.cesar@colpos.mx (*corresponding author); sergiocf@colpos.mx (*corresponding author); lopezja@colpos.mx; muratalla@colpos.mx; gcecilia@colpos.mx*
*[a,b]These authors contributed equally to this work*

## Abstract

This study analysed the impact of two production seasons (PS): off-season (OS) and main-season (MS); plus, three fertilization doses (FD): proposed (PR), regional (RE) and no fertilization (NF); and the PSxFD interaction, on the quality of 'Ataulfo' mango produced in a commercial orchard. A completely randomized factorial design with four replications was used. The experimental unit was a 12-year-old mango tree. The variables evaluated at physiological maturity and maturity of consumption were firmness, color, titratable acidity (TA), total soluble solids (TSS), TSS/TA ratio, total sugars (TS), reducing sugars (RS), β-carotene, total phenols, vitamin C and weight loss (5, 10 and 15 days) only at the stage of maturity of consumption. PS and FD differentially affected (according to fruit maturity stage) the physicochemical and nutraceutical quality. A similar behavior was observed for the PSxFD interaction. The outstanding results were, at physiological maturity, the PR dose elevated TSS, phenols and TSS/TA ratio; in PS, OS increased Hue, TA, TSS and phenols. At maturity of consumption, the RE dose increased TSS, TSS/TA ratio, phenols, β-carotene and RS; at PS, OS increased TS, luminosity, TSS/TA ratio, β-carotene and vitamin C. The best fruit quality is achieved with the MS:PR combination at physiological maturity and OS:RE at maturity of consumption. Depending on the degree of maturity of the fruits, this study showed how the fertilization dose, the production seasons, and their interaction modify the physicochemical and nutraceutical quality of mango fruits.

***Keywords:*** ascorbic acid; gallic acid; fruit color; fruit maturity; *Mangifera indica* L

## Introduction

The 'Ataulfo' mango (*Mangifera indica* L.) is a variety with denomination of origin in Soconusco, Chiapas, Mexico and is produced in 23 states. The main producing states are Sinaloa, Nayarit, Chiapas, Oaxaca, Michoacan and Guerrero, this last state occupies the first place in production and in the last five years, 615

*Received: 17 Nov 2023. Received in revised form: 18 Feb 2024. Accepted: 26 Feb 2024. Published online: 12 Mar 2024.*
From Volume 49, Issue 1, 2021, Notulae Botanicae Horti Agrobotanici Cluj-Napoca journal uses article numbers in place of the traditional method of continuous pagination through the volume. The journal will continue to appear quarterly, as before, with four annual numbers.

thousand tons of 'Ataulfo' mango were produced in Mexico (Astudillo-Miller *et al*., 2020; SIAP, 2021). The United States of America is the country where up to 90% of the production of this cultivar has been exported (Mendoza-Hernández *et al*., 2020). This mango variety has a great acceptance in the national and international market due to its postharvest quality. In quality attributes, NOM-188-SCFI-2012 specifies the levels of firmness, colour and shelf life required for export (Maldonado-Astudillo *et al*., 2016; Guzmán-Camposeco *et al*., 2021).

As part of plantation management, in 'Ataulfo' mango it is necessary to keep nutrients available to cover the metabolic needs that impact fruit quality. Quality indices are affected both pre-harvest and post-harvest. Among the primary nutrients are nitrogen (N), phosphorus (P) and potassium (K), which play a vital role in plant metabolism with an impact on fruit production and quality (Pérez and Rodríguez, 2017). Applications of combined dose of N-P-K (1000-750-750 g tree$^{-1}$) in 'Dusehri' mango crop significantly raised the levels of total soluble solids (TSS) 24.53%, TSS/titratable acidity ratio 73.5, vitamin C 57.63 mg 100$^{-1}$ g and total sugars 20.48% of the fruit, compared to the treatment without fertilization (Azam *et al*., 2021). It has also been reported that in N-P-K fertilization dose (960-80-150 g tree$^{-1}$) applied for three years of evaluation, do not alter the quality in mango from the Chapay region, maintaining the TSS concentration between 19.2 and 25.2% (Nasreen *et al*., 2014).

Supplying dose of N-P-K (960-80-150 g tree$^{-1}$) in 'Ewaise' mango for two consecutive years, allows maintaining unchanged fruit quality in total sugars 14.3 to 14.4%, TSS 24.7 to 24.9%, TA 0.38 to 0.36% and vitamin C from 41.10 to 43.0 mg 100$^{-1}$ g (Harhash and Ahmed, 2018). Application of N-P-K (0.6-0.3-0.6 kg tree$^{-1}$) on a mango orchard negatively affected quality by reducing TSS concentration 10.04%, Vitamin C 2.03%, TA 0.253% and TSS/TA ratio 35.73% of the fruit compared to fruit managed with a combination of N-P-K fertilization (0.3-0.06-0.07) plus organic fertilization of sheep manure with an N-P-K input (0.30-0.24-0.53) (Feng *et al*., 2020).

Production season is another factor that has shown effects on postharvest performance and shelf life of agricultural products (Ali *et al*., 2011; Mosqueda-Lazcares *et al*., 2011). In mango, one or two harvests per year can be obtained depending on the management of the plantation. The first harvest corresponds to "forced" off-season production through the use of growth regulators paclobutrazol and/or ethephon (2-chloroethyl phosphonic acid-ethylene), to advance flowering and achieve better fruit prices (Cárdenas and Rojas, 2003; Zainuri *et al*., 2019; Husen *et al*., 2021). The use of growth regulators is done individually or in combination with foliar applications of potassium nitrate from 2 to 6% to advance flowering in mango (Morales-Martinez *et al*., 2020). In Guerrero, Mexico the off-season harvest of 'Ataulfo' mango is carried out in the months of January to March and the second harvest main season from April to June, which is obtained from normal natural flowering (San-Martín-Hernández *et al*., 2023). 'Royal Special' mango quality harvested off-season in October 2012 showed increases of 62% in total sugars, 138% in reducing sugars, 64% in starch, 50% in TSS, 30% in ascorbic acid, 28% in titratable acidity, 25% in phenols, 291% in flavonoids, and 92% in carotenoids, compared to the main season in June 2013, but these values may vary depending on prevailing weather conditions (Prasad *et al*., 2015; Kaviarasu *et al*., 2017).

Currently, there is a concern among producers to have fertilization doses of the three main essential elements with proven effectiveness in both production and fruit quality of 'Ataulfo' mango, given the economic importance of this cultivar in the generation of foreign exchange through exports to the United States of America. Although N-P-K fertilization doses have been tested, in 'Ataulfo' mango, the doses of these nutrients that promote higher productivity and fruit quality are still unknown. Also, there are still no studies that report fruit quality from off-season crops compared to that from normal production or main-season. This work hypothesized that the physicochemical quality of the fruit reaches its best levels both by a particular dose of N-P-K fertilization in this cultivar, but also, by a particular production season. Therefore, the objective of this work was to evaluate at two stages of fruit maturity, the changes in physicochemical quality induced by the effect of three doses of N-P-K fertilization and two harvesting seasons on 'Ataulfo' mango grown in San Marcos, Guerrero, Mexico.

## Materials and Methods

*Experimental site and cultivation conditions*

The research was carried out in the 2022-2023 production cycle, in a 14-year-old commercial 'Ataulfo' mango plantation, located in Alto de Ventura, San Marcos, Guerrero, Mexico, at coordinates 21° 27' 22" north latitude, 105° 27' 0.5" west longitude and between 30 and 60 m above sea level. The planting was rectangular with 7 m between plants and 13 m between rows. During the experiment, the plantation was managed by weed, pest and disease control on a routine basis at this site and without irrigation. At the base of the tree stem, 25 mL of Cultar® (paclobutrazol) was applied in 3 L of water on July 20, and at the beginning of November, three foliar flowering inductions were made with 4% potassium nitrate sprays up to the drip point and at one-week intervals for each spray. The soil has a clay loam texture, pH 6.5 and organic matter content of 2% determined in a sample composed of 15 subsamples (0-20 cm depth) obtained in a zigzag pattern at the experimental site of the orchard. Using a CONAGUA weather station in the state of Guerrero, the maximum temperature of 35 °C, minimum of 17 °C and precipitation of 1.2 to 217 mm were recorded from July 2022 to May 2023 during the experimental period as shown in Figure 1.

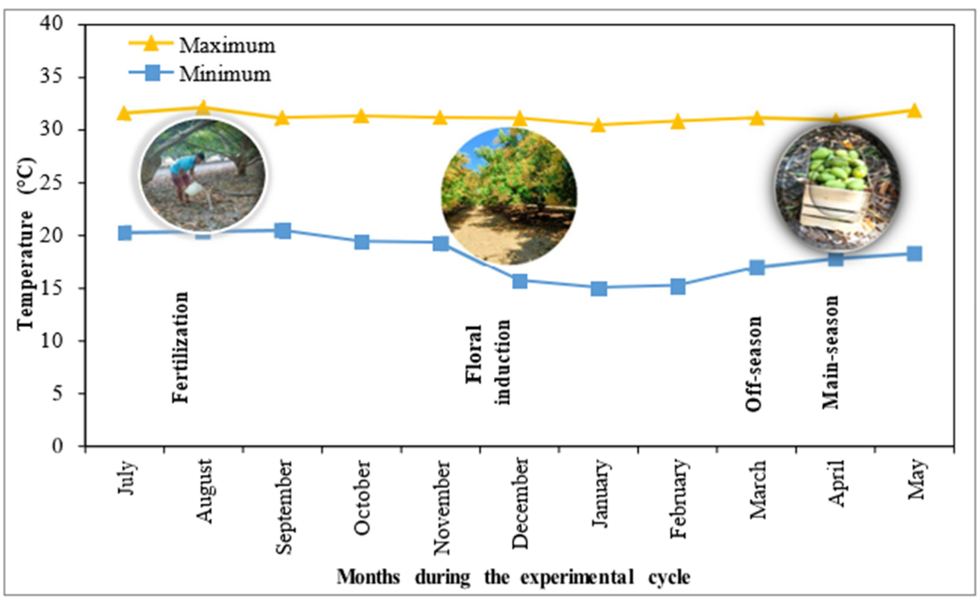


**Figure 1.** Average monthly maximum (35°) and minimum (17°) temperatures during the experimental cycle in the 'Ataulfo' mango orchard from July 2022 to May 2023

This research was carried out using a randomized complete factorial treatment design. Factor one was the production seasons or harvest with two levels: Off-season (OS) and main-season (MS); and factor two was the dose of fertilization with three levels: proposed fertilization "proposed" (PR), regional fertilization "regional" (RE) and no fertilization (NF). The combination of both factors generated six treatments, represented with four replications. The experimental unit was a mango tree in full canopy production, with homogeneous health and age.

In the year 2022, three doses of fertilization based on N-$P_2O_5$-$K_2O$ in kg ha$^{-1}$ were applied: no fertilization (control); regional (123-89-58); and proposed (45-30-95) which was defined based on a yield goal of 15 t ha$^{-1}$ and recovery efficiency of 35% in N, 25% in P and 40% in K. Fertilization was divided into 4 applications, the first on August 15, the second on September 2, the third on September 16, during the rainy season, and the fourth by dissolving the fertilizer in 40 L of water per tree at the beginning of flowering in the first half of December. The solid fertilizer was distributed in four cardinal points of the tree, making the first three fertilizations in solid form for the rainy period from June to September, while, in the fourth application, the fertilizer was dissolved in water. The fourth fertilization was made during the first flowering, on December 12 to favour the fruits of the off-season production and for the second flowering in January-February for main-season, fertilizer was no longer applied due to drought conditions.

Fruit sampling was done in two harvests, the first one coming from off-season production in the first week of March and the second one generated from main-season in the third week of April 2023. Fruits sampled at physiological maturity were transported to the postharvest quality laboratory of Fruticultura, Colegio de Posgraduados, Montecillo, Mexico. Fruits were selected on the basis of uniform size, colour and without mechanical damage, washed with soap, disinfested with 150 ppm sodium hypochlorite solution for 2 min, rinsed with tap water and allowed to dry. For the physicochemical determinations of the fruit, 9 fruits per experimental unit were considered, using three fruits for the analysis at physiological maturity, three fruits for the variables at maturity of consumption and three fruits to evaluate weight loss.

The physicochemical quality of the fruit was determined at physiological maturity and maturity of consumption, at stages 2 and 5, respectively, according to the National Mango Board of USA (NMB, 2019) for 'Ataulfo' mango at the harvesting site. Physicochemical analysis at physiological maturity was done immediately after harvest, while at maturity of consumption was done at 15 d of storage (fruits were subjected to a temperature of 13 ±2 °C for 10 days and then moved to a ripening temperature of 22 ±2 °C for 5 days) in plastic boxes with paper on the bottom side. After measuring the colour and firmness of fruits at physiological maturity and maturity of consumption, the pulp without pericarp from the equatorial zone was chopped into squares of ≤0.5 cm, three independent samples of 10 g of fresh pulp were taken and stored in plastic bags at -20 °C until chemical analysis.

*Evaluated variables*

Firmness

On two opposite sides of the equatorial zone of each fruit, pericarp sections of 2 cm diameter (ø) were removed to measure firmness with a digital penetrometer (Texture Analyzer Brookfiel CT3®, USA) equipped with a 4 mm ø spherical probe (TA39), recording the values in Newton (N).

Colour

Colour attributes were analysed at two opposite points of the equatorial zone of the fruit. On the flesh inside each sliced lateral 'cheek' section of the fruit, $L^*a^*b^*$ values were obtained from the CIE $L^*a^*b^*$ colour space, using a digital colorimeter (LS170 45/0, Linshang Technology®, China) and LScolor software (Shenzhen Linshang Technology Co., Ltd.®, China). The $L^*a^*b^*$ values obtained were expressed in lightness (L), Hue and Chroma (McGuire, 1992).

Weight loss

The fruits were subjected to 13 ±2 °C with 55% RH for 10 days and then transferred to a ripening temperature (22 ±2 °C with 70% RH) for 5 days, recording the weight on an analytical balance. Weight loss was quantified from the initial and final weight of each evaluation from 0, 5, 10 and 15 days of storage and the values were expressed as a percentage of the initial weight (Luna *et al.*, 2006). Consumption maturity was reached on the last evaluation date.

Titratable acidity (TA)

The titratable acidity was obtained (equation 1) with method 942.15 (AOAC, 1990). A 10 g sample of pulp was ground in a blender (Osterizer®, Mexico) with 50 mL of distilled water, an aliquot of 5 mL was taken, two drops of phenolphthalein were added and titrated with 0.1N sodium hydroxide to equivalence point at pH 8.2. The results were reported in percentage of citric acid because it is part of the organic acids in greater proportion in mango (Maldonado-Celis *et al*., 2019).

$$\text{Citric acid (\%)} = \frac{\text{(mL NaOH used) (N NaOH) (Meq citric acid 0.064) (100))}}{\text{Sample weight}} \qquad \text{Equation 1}$$

Total soluble solids (TSS)

TSS were determined using about 3 g of pulp at maturity of consumption and for physiological maturity the pulp was finely chopped, placed in cloth (muslin), squeezed to obtain an extract and three drops of the extract were placed in a digital refractometer (Atago-Pelette® PR-10, Japan) which recorded the values in %.

TSS/TA ratio

The TSS/TA ratio was obtained by dividing the TSS values by the TA value, its value being dimensionless (San Martín-Hernández *et al*., 2012).

Total sugars

Total sugars were obtained (Dubois, 1956) by placing 3 g of pulp plus 60 mL of ethanol in a 125 mL flask, brought to a slow boil at 78 °C, until a 15 mL sample of the extract was obtained. 300 µl of the sugars extract was transferred into a test tube, 300 µl of 5% phenol was added, 1.5 mL of 98% sulfuric acid was added, allowed to stand for 20 min and then read in the spectrophotometer (Thermo® model Genesys 10 UV, USA) at a wavelength of 490 nm. Sugars were determined based on a calibration curve with glucose standard (Sigma-Aldrich, USA). Expressing the values in g $100^{-1}$ g fresh pulp (FP).

Reducing sugars

This variable was analyzed by the DNS (3,5-Dinitrosalicylic acid) method proposed by Miller (1959). Sugars were obtained by placing 3 g of pulp plus 60 mL of ethanol in a 125 mL flask, which was subjected to slow boiling at 78 °C until a 15 mL sample of the extract was obtained. In a test tube 1 mL of sugars extract plus 1 mL of DNS solution was added, exposed in a water bath for 5 min and then in an ice bath to stop the reaction. Quantification was done in a spectrophotometer (Thermo® genesys 10 UV, USA) at a wavelength of 575 nm. The concentration of sugars was determined using a glucose calibration curve (Sigma-Aldrich, USA), expressing the values in g $100^{-1}$ g of fresh pulp (FP).

Ascorbic acid

This variable was analysed according to method 967.21 (AOAC, 2002) with modifications in sample weight. A sample of 5 g FP was ground in a blender (Osterizer®, Mexico) with 50 mL of a 0.5% oxalic acid solution, an aliquot of 5 mL was taken and titrated with Tillman's solution (2,6-dichlorophenol indophenol 0.02%, DCIP from Sigma-Aldrich® USA) until a change in colour to faint pink for 15 s. The concentration of L-ascorbic acid was determined by means of a calibration curve with an L-ascorbic acid standard (Sigma-Aldrich® USA) and the values were expressed in ascorbic acid equivalents (mgAAE $100^{-1}$ g FP).

Total phenols

A 1 g sample of pulp was added to 10 mL of 80% methanol in a 20 mL vial, shaken for 15 min at room temperature, then the sample was transferred to a 50 mL polypropylene tube and centrifuged at 5000 rpm for 5 min. The supernatant was recovered in a 10 mL tube, then 40 µL of the extract was transferred into a 5 mL test tube, 1.56 mL of distilled water plus 0.1 mL of Folin Ciocalteu 1N was added, it was kept at rest for 3 min, 0.3 mL of 20% sodium carbonate was added and let it rest for 60 min. The sample was analysed at a wavelength of 765 nm in a spectrophotometer (Thermo® genesys 10 UV, USA) and the phenols were obtained with respect to a calibration curve with an authentic gallic acid standard (Sigma-Aldrich® USA), expressing the results in gallic acid equivalents (g GAE $100g^{-1}$ FP).

β-carotene

This variable was obtained by placing 1 g of pulp in a 50 mL polypropylene tube, homogenized with 10 mL of the solvent mixture hexane, ethanol, acetone (50:25:25 v:v) and 1.5 mL distilled water was added. Subsequently, the sample was passed into a separatory funnel, which was allowed to settle and the yellow supernatant organic phase was recovered in a 50 mL test tube. Then the previous step was repeated, making a re-extraction with the same mixture of solvents and volume used. The two extractions were pooled and the final volume obtained was measured. The sample was analyzed at a wavelength of 450 nm in a spectrophotometer (Thermo® genesys 10 UV, USA) using 5 mL quartz cells and quantification was done by reference to a β-carotene standard calibration curve (Sigma-Aldrich® USA) expressing the results in mg β-carotene $100^{-1}$ g FP.

*Statistical analysis*

The data obtained for the response variables were analysed with a factorial effects model with a completely randomized arrangement (equation 2).

$$Y_{ijk} = \mu + A_i + B_j + (AxB)_{ij} + E_{ijk} \qquad \text{Equation 2}$$

Yijk = Response variable; μ= overall mean; Ai= Factor A (production season "PS") with levels of A: ij = 2 (off-season and main-season); Bj= Factor B (fertilization dose "FD") with levels of B: j= 3 (no fertilization, proposed fertilization and regional fertilization); (AxB)ij = Interaction of factors AxB (production season x fertilization dose) with levels of AxB: ij = (off-season and main-season) per (proposed fertilization, regional fertilization and no fertilization); Eijk= Experimental error.

With the data, analysis of variance was performed, the averages were compared with Tukey's test ($p \leq 0.05$) adding the standard deviation (SD) and compliance with homogeneity (Bartlett) and normality (Shapiro-Wilk) was verified with the SAS Ver. 9.4 statistical package.

## Results and Discussion

The production season (PS) showed main effects on physicochemical quality and differentially by fruit maturity: at maturity of consumption the impact was on total sugars, colour (L, C, Hue), TA, TSS, TSS/TA ratio and weight loss (5 and 15 d); and at physiological maturity on firmness, colour (chroma and hue), TA, TSS and weight loss (5 and 10 d). While, for fertilization dose (FD) at both maturity stages, the main effects were on AT, TSS and TSS/AT ratio, although at maturity of consumption these effects were limited only to total sugars and weight loss (5 d). The PS*FD interaction showed significant differences (simple effects) according to maturity in: colour (chroma and hue), TA, TSS and TSS/TA ratio for both maturity stages; total sugars and weight loss (5 and 15 d) for maturity of consumption; and firmness at physiological maturity (Table 1).

**Table 1**. Effect (p-value) of production season (PS), fertilization dose (FD) and their interaction (PSxFD), on reducing sugars, total sugars, total soluble solids (TSS), titratable acidity (TA), TSS/TA ratio, firmness, colour (luminosity, chroma and hue) and weight loss at 5, 10 and 15 days (d) at physiological maturity and maturity of consumption in 'Ataulfo' mango fruit

| Variable | Maturity | Source of variation | | | CV (%) |
|---|---|---|---|---|---|
| | | Production season (PS) | Fertilization dose (FD) | PS×FD | |
| Firmness | Physiological | 0.0024 * | 0.2307 ns | 0.0445 * | 7.4 |
| | Consumption | 0.2487 ns | 0.1328 ns | 0.2135 ns | 6.9 |
| Reducing sugars | Physiological | 0.4463 ns | 0.2093 ns | 0.1927 ns | 15.6 |
| | Consumption | 0.1787 ns | 0.0683 ns | 0.5193 ns | 12.4 |
| Total sugars | Physiological | 0.0737 ns | 0.7610 ns | 0.0838 ns | 18.3 |
| | Consumption | 0.0059 * | 0.0034 * | 0.0016 * | 18.4 |
| Luminosity | Physiological | 0.7246 ns | 0.0884 ns | 0.2720 ns | 1.9 |
| | Consumption | <.0001 * | 0.1552 ns | 0.0110 * | 2.5 |
| Chroma | Physiological | <.0001 * | 0.8187 ns | 0.0018 * | 4.0 |
| | Consumption | <.0001 * | 0.3221 ns | <.0001 * | 1.7 |
| Hue | Physiological | <.0001 * | 0.6696 ns | <.0001 * | 0.9 |
| | Consumption | 0.0002 * | 0.3254 ns | 0.0387 * | 2.5 |
| TA | Physiological | 0.0346 * | 0.0349 * | 0.0040 * | 3.7 |
| | Consumption | 0.0162 * | 0.0111 * | 0.0048 * | 20.8 |
| TSS | Physiological | 0.0008 * | 0.0002 * | 0.0001 * | 2.8 |
| | Consumption | <.0001 * | 0.0047 * | <.0198 * | 2.5 |
| TSS/TA | Physiological | 0.2728 ns | 0.0063 * | 0.0104 * | 4.4 |
| | Consumption | 0.0014 * | 0.0004 * | 0.0004 * | 9.1 |
| Weight loss 5 d | Consumption | <.0001 * | 0.0041 * | <.0001 * | 8.3 |
| Weight loss 10 d | Consumption | 0.1896 ns | 0.3655 ns | 0.1751 ns | 9.0 |
| Weight loss 15 d | Consumption | <.0001 * | 0.1381 ns | <.0001 * | 10.7 |

*Significant ($p \leq 0.05$); CV: Coefficient of variation. ns: not significant.

*Firmness*

Among the factors studied, firmness was affected only by the production season at physiological maturity. In main-season, fruit firmness was 11% higher than that obtained in off-season production and the MS:PR combination achieved the highest firmness, a value that was 20% higher than the OS:RE combination (Table 2). The firmness of 'Neelum' mango harvested off-season in September showed a reduction of 1%, compared to the fruit from main-season production which recorded the maximum value (25.6 N) at physiological maturity (Venkatesan and Tamilmani, 2011). In this work, a similar trend was observed, the reduction was 11% at physiological maturity. For the commercialization of this mango variety, 153 N of firmness (NMX-FF-058-SCFI-2006) measured with a 0.794 and 1.11 mm ø flat prop is required (NMX-FF-058-SCFI-2006). However, the equipment included in this investigation used a 2 cm ø spherical probe, so the values recorded will be different from those established by the standard. Fruits with low water content, but higher concentration of total soluble solids and cell density, have higher firmness (Maldonado-Peralta *et al*., 2021).

**Table 2.** Firmness at physiological maturity and maturity of consumption of 'Ataulfo' mango fruit by effect of production season (PS), fertilization dose (FD) and PS:FD combinations

| Factors and levels of study | Firmness (N) | |
|---|---|---|
| | Physiological maturity | Maturity of consumption |
| PS | | |
| Off-season (OS) | 75.8±5.2 b | 2.3±0.2 a |
| Main-season (MS) | 84.3±8.0 a | 2.2±0.1 a |
| HSD | 5.07 | 0.13 |
| FD | | |
| Proposed (PR) | 82.5±9.9 a | 2.2±0.2 a |
| Regional (RE) | 80.3±8.1 a | 2.3±0.1 a |
| No fertilization (NF) | 77.3±5.1 a | 2.2±0.2 a |
| HSD | 7.55 | 0.20 |
| Combinations PS:FD | | |
| OS:PR | 75.2±4.0 b | 2.2±0.2 a |
| OS:RE | 74.5±6.2 b | 2.4±0.2 a |
| OS:NF | 77.6±6.2 ab | 2.1±0.2 a |
| MS:PR | 89.8±8.4 a | 2.3±0.0 a |
| MS:RE | 86.1±4.9 ab | 2.3±0.0 a |
| MS:NF | 76.9±4.8 ab | 2.2±0.2 a |
| HSD | 13.30 | 0.35 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, $p \leq 0.05$); HSD: honest significant difference.

*Colour*

For the three colour attributes and the two fruit maturity stages, the effects were observed for the production season and the combination of the study factors (PS:FD), except for lightness at physiological maturity(Table 3).

*Luminosity*

At maturity of consumption, lightness was 11.5% higher in Off-season than in main-season. Among combinations, OS:NF had the highest lightness, although without differences with OS:RE, but it was 13, 14 and 15% higher than MS:PR, MS:RE and MS:NF, respectively (Table 3). On this colour attribute, the literature is contradictory. On the one hand, fruit brightness of this species increases from 55.9 at physiological maturity to 59.9 at maturity of consumption (Maldonado-Astudillo *et al*., 2016). While, in other studies, average reductions of 21% in lightness are reported as ripening advances to consumption in 'Ataulfo' and 'Tommy Atkins' mangoes in which the magnitude of change is not clarified (Villamizar-Vargas *et al*., 2019; Jiménez-Maldonado *et al*., 2022). In this research, fruit brightness experienced a similar reduction from physiological maturity to consumption. In broccoli harvested in winter-spring, lightness has been reported to be lower than in winter, spring, and summer-fall growth cycle productions (Conversa *et al*., 2020).

*Chroma*

At physiological maturity, main-season mango had the highest chroma and was 9% higher than off-season; in contrast, at maturity of consumption, mango off-season had 13% more chroma than main-season. On the other hand, at physiological maturity, the MS:PR and MS:RE combinations achieved 11% more chroma in the fruit than the OS:NF treatment, although without differences with MS:NF and OS:PR; while, at maturity of consumption, the OS:RE, OS:PR and OS:NF combinations achieved up to 12.6% more chroma on average than main-season fruit at the three fertilization doses evaluated (Table 3). As the ripening process progresses, fruit chroma value increases from 40.3 to 46.8 when moving from physiological maturity to maturity of consumption (Maldonado-Astudillo *et al*., 2016). The production seasons imposes significant changes in the chroma of broccoli flower heads, achieving their maximum values (around 15) in winter, spring and summer-autumn harvests, compared to that obtained in winter-spring (Conversa *et al*., 2020).

*Hue*

At physiological maturity, the off-season mango had the highest hue than the main-season, while at maturity of consumption, the main-season had 5% higher hue than the off-season. In both maturity conditions, there was a reduction in hue from physiological maturity to maturity of consumption, which means that the hue changed from yellow to orange-yellow. Similar responses were achieved at physiological maturity, where OS:PR, OS:RE and OS:NF combinations were on average 3% higher in hue than MS:PR, MS:RE and MS:NF; whereas, at maturity of consumption, the MS:PR combination was 6 and 8% higher than OS:NF and OS:PR, respectively, but without statistical differences with MS:RE, MS:NF and OS:RE (Table 3). Carotenoids are pigments that provide colour to the fruit, which upon ripening triggers the synthesis of yellow-toned xanthophylls initially and then the process continues with the production of orange-toned carotenes (Venkateswarlu and Krishna, 2014). Likewise, in mango hue reductions from 100° to around 62° are reported for the change from physiological maturity to maturity of consumption (Maldonado-Astudillo *et al*., 2016; Jiménez-Maldondo *et al*., 2022). In 'Ataulfo' mango ripening there are two opposite events: a positive relationship between carotenoid concentration and a* values measured in CIE*L*a*b** colour space; and a negative relationship between pigment level and hue value, reaching the highest carotenoid concentration with low hue (≈60°) than with high hue (Ornelas-Paz *et al*., 2010), similar responses in hue were observed in this work. In broccoli, effects by production season have been obtained, with the best visual quality or higher hue (123.8°) being achieved in the winter-spring (April) flower head harvest, with respect to its lower values (<120°) in the winter (February), spring (June) and summer-autumn (November) crop cycle productions, results that align with the higher chlorophyll and carotenoid concentrations in the April harvest (Conversa *et al*., 2020). In 'Golden Smoothie' apple, a discrete reduction of hue from 116° at full commercial harvest to 109° has been reported for late harvest fruit (Ríos-Velasco *et al*., 2023).

**Table 3.** Colour at physiological maturity (physiological) and maturity of consumption (M. consumption) in 'Ataulfo' mango fruit, by effect of production season (PS), fertilization dose (FD) and PS:FD combinations

| Factors and levels of study | Colour | | | | | |
|---|---|---|---|---|---|---|
| | Luminosity | | Chroma | | Hue (°) | |
| | Physiological | M. Consumption | Physiological | M. Consumption | Physiological | M. Consumption |
| PS | | | | | | |
| Off-season (OS) | 76.9±1.2 a | 67.1±2.1 a | 49.8±2.0 b | 75.7±0.9 a | 89.4±0.7 a | 70.4±2.7 b |
| Main-season (MS) | 77.1±1.9 a | 60.2±1.9 b | 54.4±1.8 a | 67.2±1.4 b | 87.0±0.9 b | 73.7±9.9 a |
| HSD | 1.27 | 1.60 | 1.8 | 1.12 | 11.48 | 1.51 |
| FD | | | | | | |
| Proposed (PR) | 76.4±1.3 a | 62.7±2.4 a | 52.4±2.7 a | 71.4±4.6 a | 88.1±1.8 a | 71.5±3.4 a |
| Regional (RE) | 78.0±1.1 a | 64.2±4.5 a | 52.0±3.3 a | 71.9±4.5 a | 87.4±1.0 a | 72.8±2.2 a |
| No fertilization (NF) | 76.6±2.0 a | 64.0±5.1 a | 51.8±3.5 a | 70.9±5.1 a | 88.4±1.6 a | 71.7±2.2 a |
| HSD | 1.89 | 2.06 | 2.68 | 7.2 | 7.64 | 2.25 |
| Combinations PS:FD | | | | | | |
| OS:PR | 77.0±1.1 a | 64.6± 1.2 b | 50.3±1.4 abc | 75.7± 0.9 a | 89.6±0.6 a | 68.6±1.7 c |
| OS:RE | 77.5±1.4 a | 68.2±1.0 ab | 49.6±2.8 bc | 75.9±1.1 a | 89.0±0.3 ab | 72.3±3.1 abc |
| OS:NF | 76.2±1.2 a | 68.5±0.9 a | 49.3±2.2 c | 75.3±1.0 a | 89.5±1.0 a | 70.2±2.0 bc |
| MS:PR | 75.8±1.0 a | 60.7±1.5 c | 54.6±1.7 a | 67.2±0.2 b | 86.6±0.8 c | 74.4±0.8 a |
| MS:RE | 78.5±0.6 a | 60.2±1.8 c | 54.5±1.0 a | 67.9±1.6 b | 87.1±0.2 bc | 73.2±0.9 ab |
| MS:NF | 77.0±2.7 a | 59.5±2.6 c | 54.2±2.8 ab | 66.4±2.1 b | 87.3±1.3 bc | 73.3±0.9 ab |
| HSD | 3.33 | 3.63 | 4.72 | 3.6 | 3.79 | 3.97 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, $p \leq 0.05$); HSD: honest significant difference.

*TA*

Fruits harvested off-season significantly exceeded 6 and 8% TA concentration, with respect to main-season fruits, at physiological maturity and maturity of consumption, respectively. On the other hand, the treatment no fertilization increased TA by 6% with respect to the regional fertilization, but this was statistically similar to the proposed fertilization at physiological maturity; while, at consumption, the proposed fertilization exceeded the other two fertilization levels by 7% in TA. Among the combinations, MS:RE mango had 10 to 13% less TA at physiological maturity than OS:PR, OS:RE, OS:NF, MS:PR and MS:NF; while at maturity of consumption, MS:PR fruit was statistically similar in TA to MS:NF, but different from OS:PR, OS:RE, OS:NF and MS:RE, however, the MS:PR combination achieved 14% more TA than MS:RE (Table 4). In 'Royal' mango at eating maturity, the production season was not determinant in TA, obtaining statistically equal results in this variable with 0.32% in off-season production and 0.25% in the main-season fruit (Prasad *et al*., 2015). In a mango orchard, changing the dose and source of chemical fertilization (kg tree$^{-1}$) from 0.60-0.30-0.60 to chemical fertilization 0.30-0.06-0.07 (N-P-K) plus organic sheep manure with 0.30-0.24-0.53, discretely reduced TA from 0.25 to 0.24% (Feng *et al*., 2020). On the other hand, fertilization dose impacted TA in 'Dusuhri' mango, reporting that N-P-K fertilization (1000-750-750) with a value of 0.26% in this attribute was statistically lower than TA levels (≤0.49%) obtained with individual fertilizations of N (1000), P (750) and K (750) (Azam *et al*., 2021). Factors such as variety, maturity stage, pH, lesions and water concentration in the fruit modify the TA content (Maldonado-Astudillo *et al*., 2016). The increase TA when there is a higher K>P ratio and foliar P>Ca and S (Torres *et al*., 2009).

*TSS*

At physiological maturity, mangoes from Off-season had 4% more TSS than main-season (7.2%), in contrast to maturity of consumption, in which mangoes from main-season had 20% more TSS than those from off-season production (TSS 15%). Regarding fertilization dose, at physiological maturity, the proposed fertilization achieved the highest TSS level (7.7%) and was 7% higher than the regional fertilization and no fertilization treatments; while at maturity of consumption, the proposed and regional fertilization doses were 4% and 5% higher than the no fertilization treatment, respectively. Likewise, among combinations, at physiological maturity, the OS:PR combination had the highest TSS percentage with 7.9% and was significantly higher than the other combinations (except TE:PR), reaching 13% more TSS than the MS:RE combination with the lowest TSS concentration (7%). Meanwhile, maturity of consumption, the highest TSS (18.5%) was recorded in the MS:RE combination, which was statistically similar to MS:PR and MS:NF, but was significantly 28% higher with the lowest value (14.5%) obtained in OS:NF (Table 4). The amount of TSS of 'Royal' mango at maturity of consumption statistically decreased from 21% in off-season production to 14% in main-season (Prasad *et al*., 2015). In a study conducted on 'Kent' mango, it was found that an increase in normal fertilization rate of 381-367-296 and high fertilization (normal + 50% of normal rate) (N-P-K g tree$^{-1}$), TSS concentration improved 9.4 to 10.0% at physiological maturity, and 15 to 17.6% at maturity of consumption, respectively (Nolasco-González and Osuna-García, 2017). In a mango orchard, changing the dose and source of chemical fertilization from (0.60-0.30-0.60) kg tree-$^{1}$ N-P-K to chemical fertilization (0.30-0.06-0.07 kg tree$^{-1}$ N-P-K) plus sheep manure organic with N-P-K input (0.30-0.24-0.53), significantly increased TSS from 10.04 to 12. 81% respectively (Feng *et al*., 2020). The reception of 'Ataulfo' mangoes at a packinghouse for marketing should have a minimum of 2.9% TSS, according to NMX-FF-058-SCFI-2006. The foliar application of 6% $KNO_3$ before flowering favors the increase of TSS, because K promotes the translocation of photosynthates in the plant and to the fruit (Sarker and Rahim, 2013; Quijada *et al*., 2008). The increase in sugars is related to their accumulation in leaf and fruit, as well as by climate during fruit growth and maturity due to hydrolysis of starch and polysaccharides in the cell (Almanza-Merchán *et al*., 2016). (Almanza-Merchán *et al*., 2016).

*TSS/ TA ratio*

At production season, Off-season increased the TSS/TA ratio by 18% compared to main-season fruit at maturity of consumption. At physiological maturity, the treatment no fertilization decreased the TSS/TA ratio by 5%, compared to the proposed and regional fertilization; however, at maturity of consumption, the regional fertilization and no fertilization treatments exceeded the proposed fertilization by 29 and 21%, respectively. On the other hand, at physiological maturity, the OS:PR combination exceeded the TSS/TA ratio from 9 to 12% compared to the OS: RE, OS:NF and MS:NF treatments; while, at maturity of consumption, the MS:PR combination decreased the TSS/TA ratio from 42 to 70% compared to the other combinations evaluated (Table 4). In 'Haden' and 'Keit' mango fruit harvested at two different times, in May-July and July-August, showed significant differences in the TSS/TA ratio with 32.3 and 22.6, respectively (Siller-Cepeda *et al*., 2009). In the literature it has been reported that fertilizations in 'Kent' mango with normal (g tree$^{-1}$) doses of 381-367-296 (N-P-K) and high (normal + 50%), did not affect the TSS/TA ratio (values observed between 13 and 14) at physiological maturity, but at maturity of consumption, this TSS/TA ratio decreased from 37 to 24, respectively (García *et al*., 2015). In a mango orchard the application of doses (kg tree$^{-1}$) of N-P-K fertilization (0.60-0.30-0.60) showed a significant difference in TSS/TA ratio with 19% lower than treatments with doses of chemical fertilization (0.30-0.06-0.07) plus organic fertilization of sheep manure with a contribution of N-P-K (0.30-0.24-0.53) (Feng *et al*., 2020). The increase in the TSS/AT ratio is related to stressful osmotic conditions (Goykovic and Saavedra, 2007). The decrease in TSS/TA is subject to the nutrient ratios K>P, K>Mg, K:Ca and K:S, in the fruit (Torres *et al*., 2009).

**Table 4.** Titratable acidity (TA), total soluble solids (TSS) and TSS/TA ratio at physiological maturity (physiological) and maturity of consumption (M. consumption) in 'Ataulfo' mango fruit, by effect of production season (PS), fertilization dose (FD) and PS:FD combinations

| Factors and levels of study | TA (% citric acid) | | TSS (%) | | TSS/TA ratio | |
|---|---|---|---|---|---|---|
| | Physiological | M. Consumption | Physiological | M. Consumption | Physiological | M. Consumption |
| PS | | | | | | |
| Off season (OS) | 3.5±0.1 a | 0.20±0.03 a | 7.5±0.3 a | 15.0±0.6 b | 2.17±0.1 a | 99.4±12.3 a |
| Main-season (MS) | 3.3±0.2 b | 0.16±0.01 b | 7.2±0.3 b | 18.0±0.6 a | 2.12±0.2 a | 84.0±15.4 b |
| HSD | 0.11 | 0.037 | 0.18 | 0.35 | 0.08 | 9.47 |
| FD | | | | | | |
| Proposed (PR) | 3.4±0.1 ab | 0.21±0.05 a | 7.7±0.3 a | 16.6±1.3 a | 2.23±0.2 a | 79.6±16.0 b |
| Regional (RE) | 3.3±0.2 b | 0.16±0.04 b | 7.2±0.3 b | 16.8±2.0 a | 2.29±0.1 a | 102.5±10.9 a |
| No fertilization (NF) | 3.5±0.1 a | 0.16±0.03 b | 7.2±0.2 b | 16.0±1.8 b | 2.05±0.1 b | 96.3±8.99 a |
| HSD | 0.17 | 0.05 | 0.27 | 0.52 | 0.12 | 6.3 |
| Combinations PS:FD | | | | | | |
| OS:PR | 3.4±0.1 a | 0.17±0.02 b | 7.9±0.2 a | 15.5±0.4 b | 2.32±0.0 a | 91.2±8.0 a |
| OS:RE | 3.5±0.1 a | 0.17±0.05 b | 7.4±0.2 b | 15.0±0.4 bc | 2.12±0.1 bc | 109±12.8 a |
| OS:NF | 3.5±0.1 a | 0.14±0.02 b | 7.2±0.3 b | 14.5±0.5 c | 2.08±0.1 bc | 100.6±11.6 a |
| MS:PR | 3.5±0.2 a | 0.26±0.05 a | 7.4±0.3 ab | 17.8±0.4 a | 2.10±0.2 abc | 64.2±6.9 b |
| MS:RE | 3.1±0.1 b | 0.16±0.03 b | 7.0±0.1 b | 18.5±0.2 a | 2.25±0.1 ab | 96±1.0 a |
| MS:NF | 3.5±0.2 a | 0.18±0.03 ab | 7.1±0.1 b | 17.6±0.6 a | 2.08±0.1 c | 92±3.5 a |
| HSD | 0.30 | 0.08 | 0.47 | 0.91 | 0.22 | 3.13 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, $p \leq 0.05$); HSD: honest significant difference.

*Total and reducing sugars*

Among the sugars analysed, the effects were limited to total sugars in the fruit at eating maturity. In this variable, Off-season exceeded main-season by 27.8% in total sugars concentration. The PR and RE doses were higher than NF by 45.7 and 34%, respectively. The OS:PR combination achieved 168.5% more total sugars than MS:NF (Table 5). Concentrations of 13.29 g $100^{-1}$ g total sugars have been obtained in 'Royal Special' mango fruits produced off-season compared to 8.19 g $100^{-1}$ g in main-season (Prasad *et al*., 2015), achieving a 62 % difference in total sugars content, which was found to be higher than that observed in this research. Azam *et al*. (2021) obtained higher content (41%) of total sugars in 'Dusehri' mango fruits under NPK fertilization, with respect to the treatment no fertilization. The results obtained are consistent with the dose with higher potassium supply (PR) and, the role of potassium in carbohydrate translocation, stomata opening and closing, etc. (López *et al*., 2017). On the other hand, individual fertilizations of N (1000), P (750) and K (750) and the combination of N-P-K (1000-750-750) g tree$^{-1}$ in 'Dusuhri' mango crop, statistically affected the level of total sugars, with the combination of fertilizers (N-P-K) achieving the maximum concentration with 20.48 g $100^{-1}$ g of pulp, with respect to the other individual fertilization treatments in which sugars ≤ 15.82 g $100^{-1}$ g of fruit pulp were obtained (Azam *et al*., 2021). The increase in $K^+$ and $Na^+$ exchange in soil colloids promotes the synthesis of solutes such as proline, betaine, polyols and soluble sugars (Casierra-Posada and Garcia, 2006). On the other hand, potassium is the main enzymatic activator for starch formation and sugar production (García-Gallegos *et al*., 2020).

**Table 5.** Reducing sugars and total sugars at physiological maturity (physiological) and maturity of consumption (M. consumption) in 'Ataulfo' mango fruit, by effect of production season (PS), fertilization dose (FD) and PS:FD combinations

| Factors and levels of study | Reducing sugars (g $100^{-1}$ g FP) | | Total sugar (g $100^{-1}$ g FP) | |
|---|---|---|---|---|
| | Physiological | M. Consumption | Physiological | M.Consumption |
| PS | | | | |
| Off-season (OS) | 0.8±0.1 a | 4.0±0.3 a | 1.22±0.2 a | 13.3±2.6 a |
| Main-season (MS) | 0.8±0.2 a | 3.7±0.6 a | 1.03±0.3 a | 10.4±4.3 b |
| HSD | 0.11 | 0.42 | 0.21 | 1.97 |
| FD | | | | |
| Proposed (PR) | 0.8±0.2 a | 4.2±0.6 a | 1.1±0.1 a | 13.7±2.2 a |
| Regional (RE) | 0.9±0.1 a | 3.6±0.4 a | 1.2±0.3 a | 12.6±2.8 a |
| No fertilization (NF) | 0.8±0.1 a | 3.9±0.5 a | 1.1±0.3 a | 9.4±4.5 b |
| HSD | 0.16 | 0.62 | 0.32 | 7.2 |
| Combinations PS:FD | | | | |
| OS:PR | 0.9±0.2 a | 4.2±0.2 a | 1.2±0.1 a | 14.5±2.4 a |
| OS:RE | 0.8±0.1 a | 3.8±0.3 a | 1.1±0.2 a | 11.6±3.2 a |
| OS:NF | 0.8±0.1 a | 4.0±0.6 a | 1.4±0.1 a | 13.4±2.1 a |
| MS:PR | 0.8±0.1 a | 4.1±0.8 a | 1.0±0.1 a | 12.9±2.0 a |
| MS:RE | 0.9±0.1 a | 3.3±0.4 a | 1.2±0.4 a | 13.6±2.4 a |
| MS:NF | 0.7±0.1 a | 3.9±0.4 a | 0.9±0.2 a | 5.4±0.3 b |
| HSD | 0.28 | 1.09 | 0.56 | 3.6 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, p ≤ 0.05); HSD: honest significant difference.

*Weight loss*

Between the at 5 and 10 day of storage, weight loss of the off-season fruit exceeded that of the main-season fruit by 200 and 52.4 %, respectively. The treatment with no fertilization suffered greater weight loss and was 16% greater than the proposed fertilization at 10 days. At 10 days, the OS:NF, OS:PR and OS:RE combinations showed a high weight loss and were statistically equal but superior to MS:PR, MS:NF and MS:RE, but the OS:NF combination exhibited the maximum weight loss with 79%, with respect to MS:PR; while, at 5 days the same trend was observed and the OS:NF combination reached up to 242% more weight loss than MS:PR (Table 6). In 'Kent' and 'Haden' mango fruits, production season induces variations in weight loss, since fruits harvested in July-August lost up to 4% of their weight, compared to the 2.5% recorded in May-July production (Siller-Cepeda *et al.*, 2009). On the one hand, in 'Kent' mango fertilizations with the doses (g tree$^{-1}$) of N-P-K, normal (381-367-296), high (normal + 50% of normal dose) and no fertilization, the weight loss at maturity of consumption was 6.4, 6.2 and 5.8%, respectively; while, on the other hand, the fruit weight loss increases in the course of its ripening process (Nolasco and Osuna, 2017). Fruit weight loss is related to transpiration and acceleration of metabolism when subjected to water stress and N and K deficiency (Vélez *et al.*, 2012; Martínez *et al.*, 2008).

*Nutraceutical properties*

The production seasons (PS) showed main effects on phenol content at physiological maturity and on β-carotene content at the two maturity levels studied. On the other hand, main effects on phenol, β-carotene and vitamin C content were obtained by fertilization dose (FD), but it was differential by fruit maturity. Meanwhile, by the interaction of both factors (PSxFD) simple effects were observed in the three nutraceutical attributes in the two maturity conditions, except for vitamin C at physiological maturity (Table 7).

**Table 6**. Weight loss at 5, 10 and 15 days of storage (13 ±2 °C at 55% RH for 10 days and subsequent transfer to 22 ±2 °C at 70% RH for 5 days) in 'Ataulfo' mango fruit, by effect of production season (PS), fertilization dose (FD) and PS:FD combinations

| Factors and levels of study | Weight loss (%) | | |
|---|---|---|---|
| | 5 d | 10 d | 15 d |
| PS | | | |
| Off-season (OS) | 6.0±0.5 a | 6.4±0.4 a | 7.4±0.6 a |
| Main-season (MS) | 2.0±0.3 b | 4.2±0.7 b | 7.0±0.8 a |
| HSD | 11.48 | 0.38 | 0.5548 |
| FD | | | |
| Proposed (PR) | 3.8±2.1 a | 5.0±1.4 b | 7.1±0.6 a |
| Regional (RE) | 3.9±2.0 a | 5.1±1.2 b | 7.0±0.5 a |
| No fertilization (NF) | 4.0±2.3 a | 5.8±1.2 a | 7.5±0.9 a |
| HSD | 7.64 | 0.56 | 0.83 |
| Combination PS:FD | | | |
| OS:PR | 5.8±0.5 a | 6.3±0.37 a | 7.3±0.3 a |
| OS:RE | 5.7±0.5 a | 6.1±0.3 a | 6.9±0.3 a |
| OS:NF | 6.5±0.4 a | 6.8±0.2 a | 8.0±0.3 a |
| MS:PR | 1.9±0.2 b | 3.8±0.4 b | 7.0±0.9 a |
| MS:RE | 2.1±0.5 b | 4.0±0.2 b | 7.1±0.7 a |
| MS:NF | 2.1±0.3 b | 4.8±0.8 b | 7.0±1.0 a |
| HSD | 3.79 | 0.99 | 1.4 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, $p \leq 0.05$); HSD: honest significant difference

**Table 7.** Effect (p-value) of production season (PS), fertilization dose (FD) and their interaction (PSxFD), on total phenols, β-carotene and vitamin C content of fruit at physiological maturity and maturity of consumption of 'Ataulfo' mango

| Variable | Maturity | Source of variation | | | CV (%) |
|---|---|---|---|---|---|
| | | Production season (PS) | Fertilization dose (FD) | PS×FD | |
| Total phenols | Consumption | <.0001 * | 0.0034 * | <.0001 * | 14.9 |
| | Physiological | 0.1562 ns | 0.0075 * | 0.02 * | 16.7 |
| β-carotene | Consumption | 0.0001 * | 0.0723 ns | 0.0018 * | 34.5 |
| | Physiological | 0.0228 * | 0.011 * | 0.0494 * | 12.0 |
| Vitamin C | Consumption | 0.443 ns | 0.8422 ns | 0.0571 ns | 11.3 |
| | Physiological | 0.6646 ns | <.0001 * | 0.0009 * | 16.4 |

*Significant ($p \leq 0.05$); CV: Coefficient of variation. ns: not significant.

*Total phenols*

At physiological maturity, the Off-season treatment improved phenol concentration by up to 70% compared to main-season. Likewise, at physiological maturity, the treatment no fertilization reduced the concentration of phenols 33% with respect to the proposed fertilization and 28% with respect to the regional fertilization; at maturity of consumption, a similar response was obtained, although the regional fertilization with the maximum value exceeded the treatment no fertilization by 43%. On the other hand, at physiological maturity, the combinations OS:PR, OS:RE and OS:NF were significantly superior to the other treatments, but OS:PR was 224% higher than MS:NF in phenol concentration; at maturity of consumption, the phenol concentration suffered a loss of 68% in the OS:NF combination, in relation to OS:RE, which statistically achieved the maximum phenol level (Table 7). The production seasons in 'Royal' mango does not influence phenol concentration where 0.81 mg $100^{-1}$ g pulp was recorded in Off-season and 0.653 mg $100^{-1}$ g pulp in main-season (Prasad *et al*., 2015). In 'Mamey' sapote fertilizations at low (1-1-1 kg tree$^{-1}$) and high (2-2-2 kg tree$^{-1}$) doses did not show significant difference having phenolic concentrations of 12.77 and 10.92 mg $100^{-1}$ g

(Vallejo-Pérez *et al*., 2009). The application of nitrogen fertilizer applied as calcium carbonate and ammonium nitrate from 75 (40-35) to 150 (80-70) kg $ha^{-1}$ favoured the application of nitrogen fertilizer. Phenolic compounds increase when there is stress by the presence of pathogens and by an increase in temperature during fruit development (Pérez *et al*., 2016). Low nitrogen concentrations reduce phenolic compounds in fruit (Farías *et al*., 2019).

*β -carotene*

On the one hand, the concentration of β-carotene was reduced 86% in mango Off-season with respect to the seasonal one at physiological maturity; but, on the other hand, at maturity of consumption, an opposite behavior was obtained, achieving 13% more β-carotene in off-season production than in main-season. At maturity of consumption, the concentration of β-carotene suffered a loss of 23% in fruits of the treatment no fertilization in relation to the regional fertilization that exhibited the maximum level of this carotenoid. At physiological maturity, the combinations MS:PR, MS:RE and MS:NF showed the highest concentration of β-carotene and were significantly higher than OS:PR, OS:RE and OS:NF, although MS:RE obtained the maximum level of β-carotene with 220% more than OS: NF with the lowest value; while, at maturity of consumption, the MS:NF combination had 51% less in β-carotene concentration than OS:PR, which was statistically similar OS:RE, OS:NF, MS:PR and MS:RE (Table 8). The concentration of β-carotene was affected by the production season, in which Off-season improved the level of this carotenoid with 4.47 mg $100^{-1}$ g, compared to the lowest level (2.33 mg $100^{-1}$ g) obtained in 'Royal' mango in main-season (Prasad *et al*., 2015). Fertilizations at low (1-1-1 kg $tree^{-1}$) and high (2-2-2 kg $tree^{-1}$) doses of N-P-K in the 'Mamey' sapote crop showed no significant difference maintaining the β-carotene concentration between 2.11 to 2.47 mg $100^{-1}$ g (Vallejo-Pérez *et al*., 2009). The increase of carotenoids in fruits is due to factors such as temperature, light and low nutrient competition (Prasad *et al*., 2015). N stress can alter enzymes involved in pigment biosynthesis (Martínes *et al*., 2017).

**Table 8.** Total phenols and β -carotene in fruits at physiological maturity (physiological) and maturity of consumption (M. consumption) in 'Ataulfo' mango, by effect of production season (PS), fertilization dose (FD) and PS:FD combination

| Factors and levels of study | Totals phenols (mg GAE $100^{-1}$ g FP) | | β-carotene (mg $100^{-1}$ g FP) | |
|---|---|---|---|---|
| | Physiological | M. Consumption | Physiological | M. Consumption |
| PS | | | | |
| Off-season (OS) | 129.2±19.0 a | 85.7±24.2 a | 0.7±0.3 b | 11.0±1.4 a |
| Main-season (MS) | 76.1±10.4 b | 61.7±16.5 a | 1.3±0.5 a | 9.7±1.9 b |
| HSD | 12.17 | 13.86 | 0.29 | 11.48 |
| FD | | | | |
| Proposed (PR) | 105.4±35.2 a | 88.2±10.6 a | 1.1±0.5 a | 10.6±1.5 ab |
| Regional (RE) | 101.7±39.3 a | 91.0±16.2 a | 1.2±0.5 a | 11.3±1.3 a |
| No fertilization (NF) | 79.3±40.9 b | 63.5±10.6 b | 0.8±0.5 a | 9.2±1.8 b |
| HSD | 18.11 | 20.79 | 0.44 | 7.64 |
| Combination PS:FD | | | | |
| OS:PR | 136.7±15.0 a | 96.3±6.7 ab | 0.8±0.3 bc | 11.9±0.6 a |
| OS:RE | 134.5±23.6 a | 100.9±13.7 a | 0.8±0.2 bc | 11.0±1.6 a |
| OS:NF | 116.4±14.5 a | 60.1±24.9 b | 0.5±0.2 c | 10.2±1.5 ab |
| MS:PR | 74.0±6.3 b | 80.1±6.5 ab | 1.4±0.4 ab | 9.3±0.9 ab |
| MS:RE | 68.9±12.8 bc | 81.2±13.5 ab | 1.6±0.3 a | 11.5±1.2 a |
| MS:NF | 42.1±3.9 c | 66.9±4.7 ab | 1.1±0.6 abc | 7.9±1.5 b |
| HSD | 31.90 | 37.01 | 0.77 | 3.79 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, p ≤ 0.05); HSD: honest significant difference GAE: gallic acid equivalents.

*Vitamin C*

At eating maturity, of season promoted 48% higher vitamin C synthesis than seasonal fruit. At the same maturity level, OS:PR and OS:NF combinations were significantly higher in vitamin C than MS:PR, MS:RE and MS:NF, however OS:PR reached the highest vitamin C concentration which was 59% higher than MS:RE with the lowest observed value (Table 9). The production seasons has shown effects on vitamin C concentration, in main-season in 'Tetapuri' mango, higher vitamin C concentration was recorded with 8.42 mg $100^{-1}$ g, than in off-season production with 6.59 mg $100^{-1}$g (Reddy *et al*., 2013); while, in 'Royal' mango, off-season production presented higher vitamin C concentration with 0.89 mg $100^{-1}$ g, than seasonal fruits with 0.67 mg $100^{-1}$ g (Prasad *et al*., 2015). A change in fertilization with normal dose of 381N-367$P_2O_5$-296$K_2O$ to high dose (normal + 50% of normal dose) non-significantly increased vitamin C concentration from 18 to 20 mg $100^{-1}$g, respectively (Garcia-Martínez *et al*., 2015). In 'Dusuhri' mango, fertilization dose influences vitamin C content, reporting that N-P-K fertilization (1000-750-750) achieved the maximum vitamin C concentration with 57.63 mg $100^{-1}$ g pulp, which was statistically higher than the levels of this vitamin (≤36.62 mg $100^{-1}$ g pulp) obtained with individual fertilizations of N (1000), P (750) and K (750) (Azam *et al*., 2021). It has been reported that vitamin C content changes during ripening, its content is higher in less ripe mango fruits compared to fully ripe fruits (Maldonado-Celis *et al*., 2019).

**Table 9.** Vitamin C in fruits at physiological maturity (physiological) and maturity of consumption (M. consumption) in 'Ataulfo' mango, by effect of production season (PS), fertilization dose (FD) and PS:FD combination

| Factors and levels of study | Vitamin C (mg AAE $100^{-1}$ g FP) | |
|---|---|---|
| | Physiological | M. Consumption |
| PS | | |
| Off-season (OS) | 58.6±7.2 a | 35.0±3.7 a |
| Main-season (MS) | 58.1±7.3 a | 23.6±5.1 b |
| HSD | 5.67 | 4.12 |
| FD | | |
| Proposed (PR) | 60.5±9.1 a | 30.2±7.6 a |
| Regional (RE) | 58.3±6.3 a | 28.1±8.3 a |
| No fertilization (NF) | 56.2±5.8 a | 29.7±6.6 a |
| HSD | 8.44 | 6.13 |
| Combination PS:FD | | |
| OS:PR | 61.2±8.5 a | 36.0±5.4 a |
| OS:RE | 62.6±4.6 a | 33.4±2.9 ab |
| OS:NF | 52.0±2.8 a | 35.6±2.6 a |
| MS:PR | 59.9±1.9 a | 24.4±3.9 b |
| MS:RE | 53.9±4.6 a | 22.7±8.8 b |
| MS:NF | 60.4±4.8 a | 23.8±1.4 b |
| HSD | 14.86 | 10.79 |

Averages with same letters in columns and each study factor indicate no significant difference (Tukey, $p \leq 0.05$); HSD: honest significant difference AAE: ascorbic equivalents acid.

## Conclusions

The dose of fertilization, production season and the interaction of both factors, modify the physicochemical quality depending on the maturity level of the mango. The off-season production gives benefits in a greater number of attributes such as colour (Hue), titratable acidity, total soluble solids and phenols in physiological maturity and in maturity of consumption in total sugars, colour (L), TSS/TA ratio, β-carotene and Vitamin C; whereas, fruits harvested in the normal seasonal period the benefits are limited only to firmness, colour (Chroma) and β-carotene at physiological maturity and colour (Hue) and total soluble solids at maturity of consumption. While, on the one hand, the regional fertilization dose of N-P-K 123-89-58 increases the level of TSS/TA ratio and phenols at physiological maturity, and at maturity of consumption it maintains this trend in total soluble solids, TSS/TA ratio, phenols, β-carotene and total sugars; but, on the other hand, the proposed fertilization dose 45-30-95 increases total soluble solids, phenols and TSS/TA ratio at physiological maturity and titratable acidity, total soluble solids, total sugars, phenols and β-carotene at maturity of consumption. In this work and others reported, it was found that the lack of fertilization offers fewer advantages in fruit quality than when fertilization is applied. However, even though comparable quality benefits are obtained in the regional dose (123-89-58) and the proposed dose (45-30-95), the fact of reducing the dose turns out to be more attractive to producers due to its low cost. Likewise, if at physiological maturity it is desired to privilege the best and highest quality in total soluble solids, titratable acidity, phenols, TSS/TA ratio, β-carotene, firmness, hue and chroma, one can choose those treatments resulting from the combinations of off-season (OS) or main-season (MS), plus the proposed fertilization (PR), regional fertilization (RE) or no fertilization (NF), which in this case were OS:PR and MS:PR. Although, in maturity of consumption the combinations OS:PR, OS:RE, OS:NF and MS:PR are the ones that offer the best performance (total sugars, β-carotene, total soluble solids, vitamin C, phenols, TSS/TA ratio, titratable acidity and colour in its three attributes) for the consumer and this cultivar has its particular attraction of great international acceptance.

## Authors' Contributions

Data curation: LBH; Formal analysis: LBH and CSMH; Funding acquisition: SHCF; Investigation: AML; Methodology: DJC, CGO, ALJ and CSMH; Resources: ALJ and SHCF; Supervision: LBH, CSMH, SHCF and DJC; Writing - original draft: LBH. Writing - review and editing: AML, CSMH and SHCF.

All authors read and approved the final manuscript.

## Ethical approval (for researches involving animals or humans)

Not applicable.

## Acknowledgements

This work was supported by the Consejo Nacional de Humanidades, Ciencias y Tecnologías (CONAHCYT) of Mexico through scholarship awarded to Liliana Baeza Herrera.

## Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

## References

Ali L, Svensson B, Alsanius BW, Olsson ME (2011). Late season harvest and storage of Rubus berries—Major antioxidant and sugar levels. Scientia Horticulturae 129(3):376-381. *https://doi.org/10.1016/j.scienta.2011.03.047*

Almanza-Merchán PJ, Velandia DJD, Tovar LYP (2016). Propiedades fisicoquímicas durante el crecimiento y desarrollo en dos variedades de frutos de lulo (*Solanum quitoense* Lam.) [Physicochemical properties during growth and development of fruits of two varieties of lulo (*Solanum quitoense* Lam)]. Revista Colombiana de Ciencias Hortícolas 10(2):222-231. *https://doi.org/10.17584/rcch.2016v10i2.5065*

AOAC (1990) Official Methods of Analysis. 15th ed. Vol. II. Association of Official Analytical Chemists. Washington, D.C.

AOAC (2002). Official Methods of Analysis of AOAC International. Association of Official Analytical Chemists (17th ed), Washington DC. *https://dof.gob.mx/nota_detalle.php?codigo=5280541&fecha=29/11/2012#gsc.tab=0*

Astudillo-Miller MX, Maldonado-Astudillo RI, Segura-Pacheco HR, Pallac MY (2020). Mango marketing chains and export potential in Costa Grande, Guerrero. Revista Mexicana de Ciencias Agrícolas 11(1):111-124. *https://doi.org/10.29312/remexca.v11i1.1769*

Azam M, Qadri R, Aslam A, Khan MI, Khan AS, Anwar R, … Chen J (2021). Effects of different combinations of N, P and K at different time interval on vegetative, reproductive, yield and quality traits of mango (*Mangifera indica*. L) cv. Dusehri. Brazilian Journal of Biology 82. *https://doi.org/10.1590/1519-6984.235612*

Cárdenas K, Rojas E (2003). Efecto del paclobutrazol y los nitratos de potasio y calcio sobre el desarrollo del mango 'Tommy Atkins' [Effect of paclobutrazol and potassium and calcium nitrates on 'Tommy Atkins' mango development]. Bioagro 15(2):83-90 *https://www.redalyc.org/articulo.oa?id=85715202*

Casierra-Posada F, García RN. (2006). Producción y calidad de fruta en cultivares producción y calidad de fruta en cultivares de fresa (*Fragaria* sp.) Afectados por estrés salino [Yield and fruit quality of salt-stressed strawberry cultivars (*Fragaria* sp.)]. Revista Facultad Nacional de Agronomía Medellín 59(2):3527-3542. *http://www.redalyc.org/articulo.oa?id=179914075009*

Conversa G, Lazzizera C, Bonasia A, Elia A (2020). Harvest season and genotype affect head quality and shelf-life of ready-to-use broccoli. Agronomy 10(4):527. *https://doi.org/10.3390/agronomy10040527*

Dubois M, Gilles KA, Hamilton JK, Rebers PA, Smith F (1956). Colorimetric method for the determination of sugars and related substances. Analytical Chemistry 28(3):350-356. *https://doi.org/10.1021/ac60111a017*

Farías TR, Olivas SMP, Flores MJP, Martínez RNR, Alvarez PE (2019). Efecto de la salinidad y nitrógeno inorgánico del suelo en los compuestos fenólicos y capacidad antioxidante de *Lycium berlandieri* [Effect of salinity and inorganic nitrogen of soils in phenols compounds and antioxidant capacity of *Lycium berlandieri*]. Terra Latinoamericana 37(1):81-90. *https://doi.org/10.28940/tl.v37i1.388*

Feng HD, Chen HY, Dang ZG, Ni B, He CC, Wei ZY, Chen YY (2020). Soil properties, leaf nutrients and fruit quality response to substituting chemical fertilizer with organic manure in a mango orchard. Applied Ecology & Environmental Research 18(3). *http://dx.doi.org/10.15666/aeer/1803_40254033*

García MR, López JA, Saucedo VC, Salazar-García S, Suárez EJ. (2015). Maduración y calidad de frutos de mango 'Kent' con tres niveles de fertilización [Ripening and fruit quality of mango 'Kent' with three levels of fertilization]. Revista Mexicana de Ciencias Agrícolas 6(4):665-678. *https://doi.org/10.29312/remexca.v6i4.610*

García-Gallegos E, Vázquez-Cuecuecha OG, Chávez-Gómez JA, Hernández-Acosta E, López-López A (2020). Relación entre parámetros edáficos y criterios de calidad postcosecha de frutos de *Prunus persica* (L.) Batsch por análisis multivariado [Relationship between edaphic parameters and postharvest quality criteria of *Prunus persica* (L.) Batsch fruits by multivariate analysis]. Scientia Agropecuaria 11(4):565-573. *https://doi.org/10.17268/sci.agropecu.2020.04.12*

Goykovic CV, Saavedra RG (2007). Algunos efectos de la salinidad en el cultivo del tomate y prácticas agronómicas de su manejo [Some effects of salinity on the tomato cultivars and agronomic practices in its managing]. IDESIA (Chile) 25(3):47-58. *http://dx.doi.org/10.4067/S0718-34292007000300006*

Guzmán-Camposeco F, Aguirre-Medina JF, Espinosa Zaragoza S, Villarreal-Fuentes JM, Villalobos-Villalobos V, Aguirre-Cadena JF (2021). Morphological and biochemical characteristics in fruits of *Mangifera indica* L. var. Ataulfo with and without conventional management. Agro Productividad. *https://doi.org/10.32854/agrop.v14i9.1888*

Harhash M, Ahmed M (2018). Effect of organic and mineral fertilization on yield and fruit quality of Ewaise mango cultivar. Alexandria Journal of Soil and Water Sciences 2(2):102-115. *https://doi.org/10.21608/ajsws.2018.225456*

Husen S, Ishartati E, Muhidin M, Siskawardani DD, Rizky A, Syaifudin A, Onthong, J (2021). Modified Off–Season Technology to the Flowering Time and Fruit Yield of Arumanis Mango (*Mangifera indica* L.). E3S Web of Conference. ***https://doi.org/10.1051/e3sconf/202122600045***

Jiménez-Maldonado MI, Tovar-Pedraza JM, León-Félix J, Muy-Rangel MD, Islas-Osuna MA (2022). Respuesta fisiológica y calidad de mango cv Ataulfo infectado por *Colletotrichum* spp [Physiological response and quality of mango cv Ataulfo infected with *Colletotrichum* spp]. Revista Mexicana de Ciencias Agrícolas 13(6):1103-1115 ***https://doi.org/10.29312/remexca.v13i6.3028***

Kaviarasu A, Balakrishnan S, Indirakumar K (2017). Environmental influence under off-season production on yield and quality attributes of mango. International Journal of Current Microbiology and Applied Sciences 6(2):494-502. ***http://dx.doi.org/10.20546/ijcmas.2017.602.056***

López MJD, Salas-Pérez L, Valenzuela SR, Borroel GVJ, Pablo PR, Ramírez SAR (2017). Efecto del potasio en el contenido fenólico y capacidad antioxidante de *Ocimum basilicum* L [Effect of potassium on the phenolic content and antioxidant capacity of *Ocimum basilicum* L]. Revista Mexicana de Ciencias Agrícolas 8(1):133-145. ***https://doi.org/10.29312/remexca.v8i1.77***

Luna EG, Arévalo GML, Anaya RS, Villegas MA, Acosta RM, Leyva RG (2006). Calidad de mango ´ataulfo´ sometido a tratamiento hidrotérmico [Quality of 'Ataulfo' mango after a hot water treatment]. Revista Fitotecnia Mexicana 29(Es2): 123-128. ***https://www.redalyc.org/articulo.oa?id=61009821***

Maldonado-Astudillo YI, Navarrete-García HA, Ortiz-Morales ÓD, 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 [Physical, chemical and antioxidant properties of mango varieties grown at the Guerrero Coast]. Revista Fitotecnia Mexicana 39(3): 207-214. ***https://doi.org/10.35196/rfm.2016.3.207-214***

Maldonado-Celis ME, Yahia EM, Bedoya R, Landázuri P, Loango N, Aguillón J, Guerrero OJC (2019). Chemical composition of mango (*Mangifera indica* L.) fruit: nutritional and phytochemical compounds. Frontiers in Plant Sciences 10:1073. ***https://doi.org/10.3389/fpls.2019.01073***

Maldonado-Peralta R, Maldonado-Peralta MA, Rojas-Garcia AR, Salinas-Vargas D (2021). Efecto del estrés hídrico en poblaciones nativas de tomate mexicano [Effect of water stress on tomato Mexican landraces]. Ecosistemas y Recursos Agropecuarios Núm. Esp. II: e2889. ***https://doi.org/10.19136/era.a8nII.2889***

Martínez FE, Sarmiento J, Fischer G, Jiménez F (2008). Efecto de la deficiencia de N, P, K, Ca, Mg y B en componentes de producción y calidad de la uchuva (*Physalis peruviana* L.) [Effect of N, P, K, Ca, Mg and B deficiency on production and quality components of cape gooseberry (*Physalis peruviana L.*)]. Agronomía Colombiana 26(3):389-398. ***https://revistas.unal.edu.co/index.php/agrocol/article/view/11470***

McGuire RG (1992). Reporting of objective color measurements. HortScience 27(2):1254–1255. ***https://doi.org/10.21273/HORTSCI.27.12.1254***

Mendoza-Hernández C, Rosas-Quijano R, Vázquez-Ovando A, Gálvez-López D (2020). Retos y controversias del mango Ataulfo [Challenges and controversies of the Ataulfo mango]. Revista Mexicana de Ciencias Agrícolas 11(7):1633-1645. ***https://doi.org/10.29312/remexca.v11i7.2199***

Miller G (1959). Use of dinitrosalicylic acid reagent for determination of reducing sugar. Analitycal Chemistry 31 (3):426-428. ***https://doi.org/10.1021/ac60147a030***

Morales-Martinez M, Moscoso-Ramírez PA, Castelán-Estrada M, Contreras-Oliva A (2020). Efecto de nitratos solos o con paclobutrazol en la inducción floral y producción en mango cv. Tommy Atkins [Effect of nitrates alone or with paclobutrazol on flowering induction and production in mango cv. Tommy Atkins]. Biotecnia 22(2):20-27. ***https://doi.org/10.7440/res64.2018.03***

Mosqueda-Lazcares G, Arévalo-Galarza M, Valdovinos-Ponce G, Rodríguez-Pérez JE, Colinas-León MT (2011). Época de corte y manejo poscosecha de ocho cultivares de rosa de corte [Time cutting and postharvest management of eight cut rose cultivars]. Revista Mexicana de Ciencias Agrícolas 2(SPE3):591-602. ***http://www.redalyc.org/articulo.oa?id=263122300015***

Nasreen S, Kamal AM, Siddiky MA, Rannu RP, Islam MS (2014). Effect of nitrogen, phosphorus, potassium and sulphur on the yield of mango. Bangladesh Journal of Agricultural Research 39(4):631-640. ***http://dx.doi.org/10.3329/bjar.v39i4.22542***

NMB (National Mango Board) (2019). Mango maturity and ripening guide. USA. Retrieved 2022 March 4 from ***https://www.mango.org/wp-content/uploads/2017/10/Maturity-poster_SP_hi.pdf***

NMX-FF-058-SCFI (2006). Non industrialized food products for human consumption – fresh fruit – mango (*Mangifera indica* L.) – specifications. Retrieved 2023 September 15 from *http://www.economia-nmx.gob.mx/normas/nmx/2006/nmx-ff-058-scfi-2006.pdf*

Nolasco-González Y, Osuna-García J (2017). Calidad poscosecha en mango 'Kent' con fertilización normal y alta [Postharvest quality in 'Kent' mango with normal and high fertilization]. Revista Mexicana de Ciencias Agrícolas 8(SPE19):4009-4022. *https://doi.org/10.29312/remexca.v0i19.669*

NOM-188-SCFI-2012. (2012). Mango Ataulfo del Soconusco Chiapas (*Mangifera caesia* Jack ex Wall) specifications and test methods. Diario Oficial de la Federación de México. Retrieved 2023 September 15 from *https://www.dof.gob.mx/nota_detalle.php?codigo=5280541&fecha=29/11/2012#gsc.tab=0*

Ornelas-Paz J, Gardea AA, Yahia EM, Failla ML (2010). Carotenoid composition in 'Ataulfo' mango and their bioavailability and bioconversion to vitamin A. Acta Horticulturae 877:1245-1252. *https://doi.org/10.17660/ActaHortic.2010.877.170*

Pérez LE, Rodríguez BD (2017). Estudio físico-químico para la formulación de un fertilizante líquido de composición completa [Physical-chemical study for the formulation of a full composition liquid fertilizer]. Universidad de Costa Rica. Pensamiento Actual 17(29):51-68. *https://doi.org/10.15517/pa.v17i29.31551*

Pérez MA., Vidal AY, Mulkay VT (2016). Contenido de fenoles totales en frutos de mango 'Super Haden' dañados por antracnosis y tratados en poscosecha [Total phenolic content in 'Super Haden' mango fruits damaged by anthracnose and treated in postharvest]. Cultivos Tropicales 37(1):71-77. *http://www.redalyc.org/articulo.oa?id=193245041010*

Prasad SR, Reddy YT, Upreti KK, Srilatha, V (2015). Chemical constituents during the main and off-season in mango (*Mangifera indica* L.) cv. Royal Special. Journal of Horticultural Sciences 10(2):229-232. *https://doi.org/10.24154/jhs.v10i2.135*

Quijada O, Herrero B, González R., Casanova A., Castellano G, Camacho R (2008). Influence of pruning and potassium nitrate and potassium tiosulphate application on the production of mango (*Mangifera indica* L.) varieties Irwin and Tommy Atkins in the Maracaibo plain, Venezuela. Revista Iberoamericana de Tecnología Postcosecha 9(2):121-130. *https://www.redalyc.org/articulo.oa?id=81315076005*

Reddy YT, Prasad SS, Upreti KK (2013). Effect of paclobutrazol on fruit quality attributes in mango (*Mangifera indica* L.) cv. Totapuri. Journal of Horticultural Sciences 8(2):236-239. *https://jhs.iihr.res.in/index.php/jhs/article/download/309/194*

Ríos-Velasco C, Ornelas-Paz JJ, Ruíz-Cisneros MF, Parra-Quezada RA, Pérez-Corral DA, González-Vigil MV, Berlanga Reyes DI (2023). Effect of the harvest date, calcium and other chemicals on the quality and storability of 'Golden Smoothie' apples. Agro Productividad 15(12):31-39. *https://doi.org/10.32854/agrop.v15i12.2296*

San-Martín-Hernández C, Muy-Rangel MD, Quintana-Obregón EA, Rivera-Vargas G, Volke-Haller VH (2023). Diagnóstico de la cadena productiva del mango en el estado de Guerrero [Diagnosis of the mango production chain in the state of Guerrero]. Centro de Investigación en Alimentación y Desarrollo, A. C. Coordinación, Culiacán, Sinaloa, México pp 79.

San Martín-Hernández C, Ordaz-Chaparro VM, Sánchez-García P, Beryl Colinas-Leon MT, Borges-Gómez L (2012). Calidad de tomate (*Solanum lycopersicum* L.) producido en hidroponia con diferentes granulometrías de tezontle [Tomato (*Solanum lycopersicum* L.) quality produced in hydroponics with different particle sizes of tezontle]. Agrociencia 46(3):243-254. *https://www.scielo.org.mx/pdf/agro/v46n3/v46n3a4.pdf*

Sarker BC, Rahim MA (2013). Yield and quality of mango (*Mangifera indica* L.) as influenced by foliar application of potassium nitrate and urea. Bangladesh Journal of Agricultural Research 38(1):145-154. *http://dx.doi.org/10.3329/bjar.v38i1.15201*

Servicio de Información Agroalimentaria y Pesquera (SIAP) (2021). Cierre de la producción agrícola: anuario estadístico de la producción agrícola (mango 'Ataulfo') [Closing of the agricultural production: Statistical yearbook of agricultural production ('Ataulfo' mango)]. Retrieved 2023 September 21 from *https://nube.siap.gob.mx/cierreagricola/*

Siller-Cepeda J, Muy-Rangel D, Báez-Sañudo M, Araiza-Lizarde E, Ireta-Ojeda A (2009). Calidad poscosecha de cultivares de mango de maduración temprana, intermedia y tardía [Postharvest quality of mango cultivars of early, middle and late seasons]. Revista Fitotecnia Mexicana 32(1):45-52. *https://www.redalyc.org/articulo.oa?id=61011105006*

Torres P, Aular J, Rengel M, Montaño J, Rodríguez Y (2009). Correlación entre la calidad de la fruta del naranjo y los macronutrimentos, considerando el balance de los nutrimentos a través de relaciones binarias [Correlation between orange fruit quality and micronutrients considering the nutrient balance trough binary relationships]. Revista Científica UDO Agricola 9(1):21-28. *https://dialnet.unirioja.es/descarga/articulo/3293685.pdf*

Vallejo-Pérez MR, Nieto-Ángel D, Martínez-Damián MT, Mora-Aguilera JA, Téliz-Ortiz D, Nava-Díaz C (2009). El riego y fertilización en la calidad postcosecha del zapote mamey [*Pouteria sapota* (Jacq.) H. E. Moore & Stearn]. The irrigation and fertilization on postharvest quality of sapote mamey [*Pouteria sapota* (Jacq.) HE Moore & Stearn]. Revista Chapingo Serie Horticultura 15(1):91-100. *https://www.redalyc.org/articulo.oa?id=60913518013*

Vélez JE, Álvarez-Herrera JG, Alvarado-Sanabria OH (2012). El Estrés Hídrico en Cítricos (*Citrus* spp.): Una revisión [Water stress on citric fruit (*Citrus* spp): a review]. Orinoquia 16(2):32-39. *https://doi.org/10.22579/20112629.245*

Venkatesan T, Tamilmani C (2011). Effect of ethrel on softening of off-season fruits of mango (*Mangifera indica* L. var. Neelum) during ripening. Current Botany 1(1). *http://dx.doi.org/10.18052/www.scipress.com/ILNS.7.1*

Venkateswarlu K, Krishna RPS (2014). Mango: Carotenoids. International Journal of Pharmamedix India 2(2):741-744.

Villamizar-Vargas R, Quiceno-Gómez C, Giraldo-Giraldo G (2019). Cambios fisicoquímicos durante la maduración del mango Tommy Atkins en la poscosecha [Physicochemical changes during the maturation of the Tommy Atkins mango in the post harvest]. Revista UDCA Actualidad & Divulgación Científica 22(1).

Zainuri Z, Sjah T, Nurrachman N, Ayu C (2019). Mango off-season technology (MOST): Innovative, applicable, adaptive to climate change, and brings many positive impacts. In AIP Conference Proceedings (Vol. 2199, No. 1) AIP Publishing. *http://dx.doi.org/10.1063/1.5141295car*