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Biochemical and physiological study of damages occurred during harvesting and transportation of Tommy Atkins mangoes

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ABSTRACT

In Roraima, the increasingly prominent production of mangoes cv. “Tommy Atkins”, with great prospects for the future, is becoming an economically viable option for cultivation in agroforestry systems, developed in small fields, generally in family farming production systems. Therefore, it is very important to have full knowledge of its production and, evidently, of its metabolism in the face of occurrences of damage to the fruits during production, harvesting, processing, transportation, marketing, and storage. So, the treatments performed on mangoes consisted of the execution of three of the main types of damage, according to the performance of pre-tests (presented in the methodology), namely: control (normal harvest at 90 DAA, without the incidence of damage), fruit fall (1 m), fruit compression (50 N), and application of ethylene (200 ml L^{-1}, for 24 h – simulation of acceleration of respiratory metabolism). At the end of the experimental period, it was found that the shelf life of the mangoes was impaired by all the damage caused, with the exogenous application of ethylene providing the greatest advance in ripening, with losses of 85% of their potential shelf life. Damage caused by compression and falling, on average, compromised them by 50% in terms of shelf life.

Keywords: *Mangifera indica* L., Waste, Prejudice.

Estudo bioquímico e fisiológico de danos ocorridos durante a colheita e transporte de mangas “Tommy Atkins”

RESUMO

Em Roraima, a produção de mangas cv. “Tommy Atkins”, que está cada vez mais acentuada, com grandes perceptivas de futuro, se transforma numa opção economicamente viável para o cultivo em sistemas agroflorestais, desenvolvidos em pequenas áreas, geralmente em sistemas agrofamiliares de produção. Portanto, é de suma importância o pleno conhecimento da sua produção e, evidentemente, do seu metabolismo frente as ocorrências de danos que acontecem aos frutos durante a produção, colheita, beneficiamento, transporte, comercialização e armazenamento. Sendo assim, os tratamentos realizados nas mangas consistiram na execução de 3 dos principais tipos de danos, segundo a realização de pré-ensaios (apresentado na metodologia), sendo eles: controle (colheita normal aos 90 DAA, sem a incidência de danos), queda do fruto (1 m), compressão do fruto (50 N) e aplicação de etileno (200ml L^{-1}, for 24 h – simulação da aceleração do metabolismo respiratório). Ao final do período experimental, verificou-se que ade vida útil das mangas foi prejudicado por todos os danos realizados, sendo que a aplicação exógena de etileno proporcionou o maior avanço do amadurecimento com perdas de potencial de vida na ordem de até 85%. Quanto aos danos por compressão e queda, ocorreu, em média, 50% de comprometimento quanto ao tempo de vida de prateleira.

Palavras-chave: *Mangifera indica* L., Desperdício, Prejuízo.

1. Introduction

Mango is a crop extensively cultivated in all regions of Brazil. However, like other fruits, due to its accelerated respiratory metabolism, it suffers rapid deterioration, making it difficult to sell far from production centers (Moreira et al., 2013). Brazil stands out among the largest mango producers in the world, since the climatic conditions allow the production of this fruit throughout the year and in all regions of the country (Carvalho et al., 2014). In the European Union, Brazil benefits from its ability to produce mangoes continuously, including varieties that are widely traded in the main European import markets, such as “Tommy Atkins” (FAO, 2022). In Brazil, mango ranks seventh in fruit production, with a total of 1,414,338 tons, generating values close to R$1.7 million during the year (Beling et al., 2021).

The Tommy Atkins variety, developed in Florida, USA, comes from a cross between two species, Haden and an unknown local variety. This fruit has great acceptability due to its attractive color, pleasant flavor, presence of few fibers, firm and juicy pulp, and a small seed (Xavier et al., 2009). It is the most produced variety in Brazil, being available on the Brazilian market throughout the year. Furthermore, the “Tommy Atkins” mango is considered by many researchers and fruit growers to be the most resistant to transportation and storage and is also well accepted by the consumer market. Mango is also considered a climacteric fruit, and during its maturation and ripening, due to intense respiratory activity, it is subject to numerous biochemical and physiological changes, such as changes in color, sugar, organic acid, and vitamin levels (Jongsri et al., 2016). Among the most common damages, those caused by impact, compression, and cutting stand out.

In this sense, the objective of carrying out this work was to evaluate the biochemical and physiological effects on the fruits resulting from damage occurring during the transport of “Tommy Atkins” mangoes grown in Boa Vista/RR and sold in Manaus/AM, which can compromise the final quality of the fruits and their potential shelf life during post-harvest storage, thus restricting the commercialization process of these fruits.

2. Material and Methods

The experiment was conducted with “Tommy Atkins” mangoes obtained from an agricultural property located in the rural area of Boa Vista/RR, latitude 2º50'06" N and longitude 60º40'28" W, and transported to the Food Technology Laboratory/UFRR (29 ± 2 ºC and 75 ± 3% R.H.). The samples were placed in 20 kg boxes, where they were selected based on the absence of damage and/or rot and standardized according to visual attributes (color and size). Harvested physiologically ripe, the mangoes had a greenish-purple color (1:1) and an average fresh mass of around 392 ± 25 g (according to previous experiments). The harvest point for the ‘Tommy Atkins’ mango was defined at 90 days after floral opening, with the fruits having a firmness of 12.2 ± 0.5 N and a solid content of 6.2 ± 0.3 Brix. Before carrying out the proposed treatments, the fruits were sanitized in a previously acidified solution (pH = 3.0) of sodium hypochlorite (NaOCl), at 10 mg L^{-1}, for 3 minutes. Fruits exposed to atmospheric air (29 ± 2 ºC and 75 ± 3% R.H.) were rinsed and dried. The experiment was conducted in a completely randomized design (DIC), in a factorial scheme (4 × 4) consisting of 7 analysis points and 4 post-harvest treatments, with 4 replications, each replication consisting of 10 fruits (sample units).

In this preliminary test, 25 visits were made at 3 different times, taking into consideration batches of mangoes that were destined for the most demanding markets, as well as batches that would be sold in open-air markets. It is estimated, on average, that more than 2,500 fruits were analyzed during 6 months of work. Afterwards, the fruits from all treatments were stored for 28 days under uncontrolled conditions of temperature and relative humidity, in a covered place free from direct exposure to light (29 ± 2 ºC and 75 ± 3% R.H.), with analyses carried out at 0, 4, 8, 12, 16, 20, 24, and 28 days.

After establishing the treatments and following the analysis timetable, the following analyses were carried out. The external appearance of the fruits was assessed using a visual color scale and was used to characterize the appearance of the fruits, following the method adapted from Braz et al. (2008), with the following equivalence: 4 = purple-green; 3 = yellowish-purple; 2 = orange-purple more than purple; 1 = withered orange-purple; and 0 = with notable dark and/or gray spots. Pulp firmness was measured using the Extralab TAXT Plus electronic texturometer (Stable Micro Systems, Surrey, United Kingdom), expressed in N (Latimer, 2012); and the loss of fresh fruit mass, where the fruits were weighed on a semi-analytical scale (Marte AD500, Brazil), according to Latimer (2012), where Mph is a mass after storage and FM is an average fresh mass when fruit were harvested.

$$\text{Loss of fresh fruit mass} = \frac{\text{Mph} \times 100}{\text{FM}}$$

The hydrogen potential (pH) was determined directly in the pulp with a digital potentiometer, according to Latimer (2012); soluble solids content (SS) and titratable acidity (TA) were measured in degrees Brix and in % citric acid, respectively, following the methodology described by Latimer (2012). The total and reducing sugars of fresh mass were evaluated according to Latimer (2012), with the results expressed in g 100 g^{-1}; and respiratory activity (CO_2 concentration) was performed according to the methodology described by Latimer (2012), with results presented in mL CO_2 kg^{-1} /h^{-1}.

Ethylene production was carried out according to the methodology described by Latimer (2012), with results presented in mL C_2H_4 kg^{-1} h^{-1}; the ascorbic acid (vitamin C) content was evaluated according to Latimer (2012), with results expressed in mg 100 g^{-1}; and the content of total phenolic compounds in fresh mass was expressed in mg of gallic acid·100 g^{-1} of sample using the Folin-Ciocalteu method, with some modifications. The absorbance of the sample was read against the blank at 725 nm using a spectrophotometer. The total phenolic content (TF) of the extracts was determined by comparison with a gallic acid calibration curve (Vieira et al., 2015) as a standard, with $R^2 = 0.9973$:

$$\text{Absorbance concentration} = 0.0628 \text{ x (Gallic Acid Conc, mg mL}^{-1}) - 0.0521$$

The total carotenoid content was measured using a UV-Vis spectrophotometer – FEMTO model 800 XI, according to analytical separation and extraction of compounds with organic solvents. For the determination of lycopene, absorbance was read at 470 nm, and for beta-carotene, absorbance was read at 450 nm. In this way, carotenoids were determined according to the equation below (Rodriguez-Amaya, 2001; Rodriguez-Amaya and Kimura, 2004), where A is the absorbance of the solution at a wavelength of 470 nm for lycopene and 450 nm for beta-carotene; V is the final volume of the solution; $A_{1cm}^{1\%}$ = extinction coefficient or molar absorptivity coefficient of a pigment in a specific solvent (3450 for lycopene and 2592 for beta-carotene); M is the mass of the sample taken for analysis.

$$\text{Carotenoid content (mg 100 g}^{-1}) = \frac{A \text{ x } V \text{ x } 10.000}{A_{1cm}^{1\%} \text{ x } M}$$

Antioxidant capacity using the DPPH method (1,1-diphenyl-2-picrylhydrazyl radical): methodology described by Vieira et al. (2015) and results expressed in molEq Trolox.100g^{-1} of sample; where Abs_{DPPH} is control absorbance and $Abs_{amostra}$ is sample absorbance.

$$\%DPPH = \frac{Abs_{DPPH} - Abs_{amostra}}{Abs_{DPPH}} \text{ x } 100$$

The Antioxidant capacity expressed in mmolEq Trolox.100g^{-1} of sample. using the ORAC method (Oxygen Radical Absorption Capacity) based on the method of Ou et al. (2001):

$$\text{Net AUC} = \text{AUC (Antioxidant)} - \text{AUC (blank)}$$

The variables evaluated were subjected to analysis of variance and polynomial regression, using the statistical programs R Core Team (2020) and SigmaPlot 14.0. Regression models were adjusted using the F statistical test, at a 5% probability level, to measure the significance of the proposed model.

3. Results and Discussion

From the collection and analysis of information pertinent to the preliminary test (Table 1), carried out between the months of May and October 2022, and from research conducted in various markets in the cities of Boa Vista – RR and Manaus – AM, the three types of mechanical, physical, and physiological damage that occur most frequently during transport and storage were identified, with the following treatments being carried out: control (harvest at 90 DAA), fruit drop (1 m), fruit compression (50 N), and application of ethylene (200 mL L^{-1} for 24 h).

Stored for 28 days under uncontrolled conditions of temperature and relative humidity, the "Tommy Atkins" mangoes subjected to falling and compression, as well as the fruits exposed to exogenous application of ethylene, had their appearance damaged in less than 16 days (Figure 1), which would supposedly affect their market value. The mangoes, which lost their turgidity from the first days of storage, also showed necrosis at the site of damage, compromising the appearance of the fruit and reducing the shelf life of these samples.

After harvest, the fresh mass of all "Tommy Atkins" mangoes gradually decreased over the experimental period (Figure 2A), occurring both in the fruits from the control group and those subjected to the proposed treatments. In this way, it was found that the fruits, which initially had an average mass of 392 g, after storage for 28 days, showed that the mangoes that were not damaged (control) lost, on average, 9% of their initial fresh mass.

However, the fruits subjected to the application of exogenous ethylene, falling, and compression showed, respectively, average losses of fresh mass in the order of 39%, 29%, and 28% in relation to their initial mass. Regarding the pulp firmness of the "Tommy Atkins" mangoes (Figure 2B), which, when harvested, had an average pulp firmness of approximately 12 N, after completing 16 days of storage under uncontrolled conditions of temperature and relative humidity, the fruits in the control group showed an average firmness of 9.45 N, representing average losses of 28% compared to the value observed at the beginning of the experiment.

On the other hand, fruits subjected to falling, compression, and exogenous ethylene presented, respectively, 6.96, 6.00, and 6.71 N of pulp firmness.

Table 1. Occurrence of mechanical, physical, and physiological damage between the production orchard located in Boa Vista – RR, transport via BR, between km 502 and 25, and distribution of the fruits in the city of Manaus – AM. Boa Vista – RR, 2022.

Damage	Percentage of Occurrence	Probable location of damage incidence
Fall	35	Field, harvest and packinhouse
Understanding	30	Harvest, packinhouse and transport
Superficial shocks	5	Field, harvest and packinhouse
Deep shocks	2	Field, harvest and packinhouse
Polite	1	Field, harvest and packinhouse
Healed wound	5	Field, harvest and packinhouse
Unhealed wound	≤ 1	Field, harvest and packinhouse
Sunburn	≤ 1	Field
Latex burn	≤ 1	Field and harvest
Early harvest	2	Harvest
Late harvest	15	Harvest
Bug bite	≤ 1	Field
Poorly formed fruits	≤ 1	Field

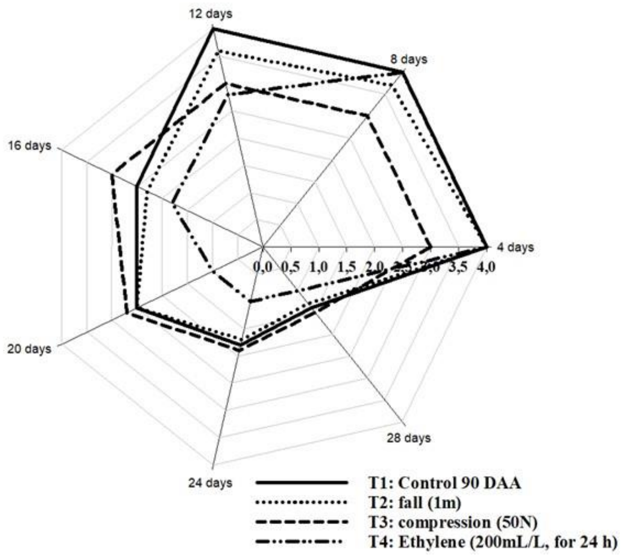

Figure 1. External appearance (subjective scale of values) of "Tommy Atkins" mangoes subjected to mechanical damage and exposure to exogenous ethylene. Boa Vista/RR - 2022.

In other words, the losses of pulp firmness of the fruits subjected to the three types of damage were, on average, 49%, 47%, and 54% greater, respectively, when compared to the pulp firmness of the fruits in the control group. Although fruits subjected to exogenous ethylene application had higher pH values (Figure 3A) when compared to fruits in the control group, there was no significant difference between treatments after 28 days of storage under uncontrolled conditions of temperature and relative humidity.

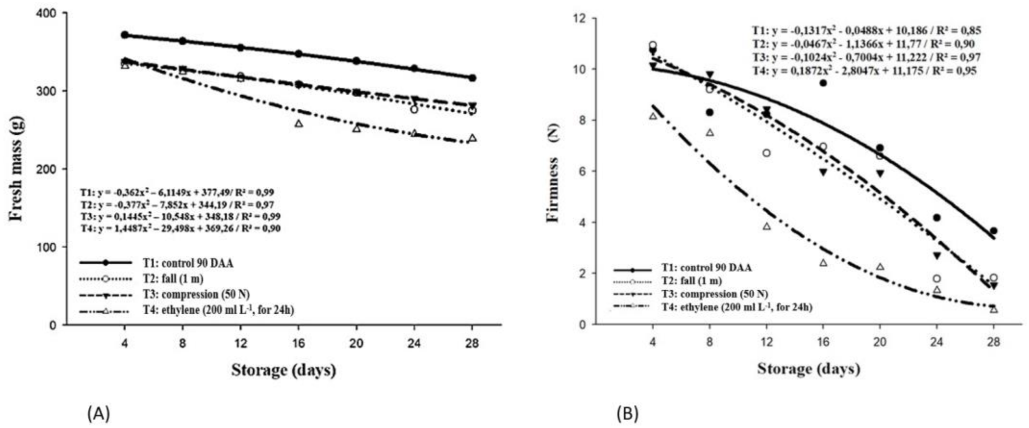

Figure 2. Loss of fresh mass, in grams, (A) and pulp firmness, in Newtons (N), (B), of "Tommy Atkins" mangoes subjected to mechanical damage and exposure to exogenous ethylene. Boa Vista/RR - 2022.

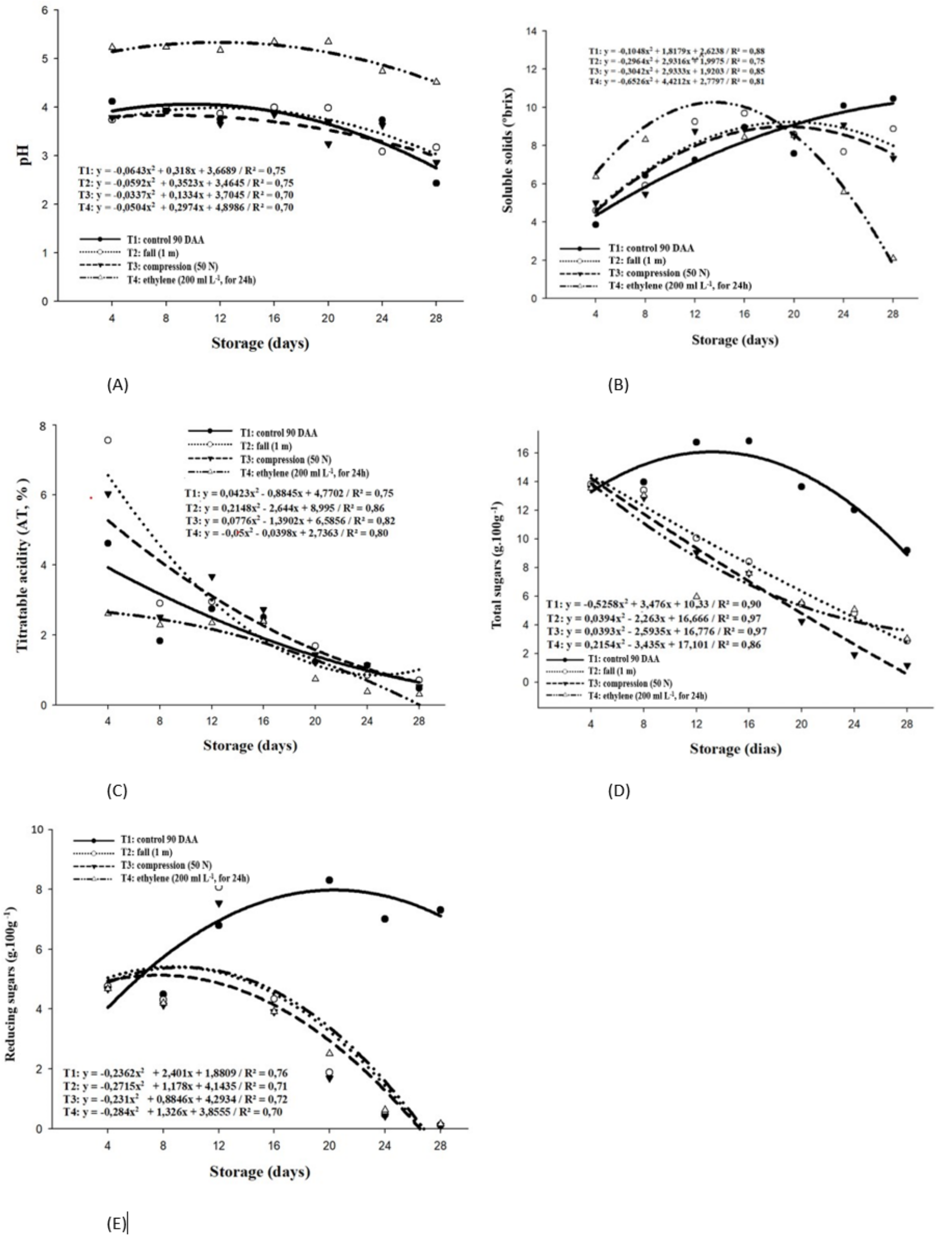

Figure 3. Potential hydrogen content – pH (A), soluble solids – Brix (B), titratable acidity – % citric acid (C), total (D) and reducing (E) sugars – g 100 g^{-1}, of "Tommy Atkins" mangoes subjected to mechanical damage and exposure to exogenous ethylene.

As for soluble solids (Figure 3B), the fruits subjected to falling, compression, and exogenous ethylene reached their maximum point between 12 and 16 days after the application of the treatments. In this sense, according to Guerra et al. (2017), "Tommy Atkins" mangoes can reach 12 to 13 Brix when ripe, that is, the fruits from these treatments ripened prematurely and, supposedly, entered senescence after 16 days of storage.

However, the fruits in the control group, not subjected to any type of damage, according to what was observed during the 28-day experimental period, did not even reach their maximum point in terms of soluble solids. Given this, it can be assumed that these fruits had not yet reached their climacteric peak, suggesting they were still in full ripeness. These data agree with the results presented in Figure 4A, where the evolution in CO_2 production of these samples can clearly be observed, while in the fruits of the other treatments, from 16 days onwards, a decline in respiration was already evident, characterizing them as senescent fruits.

Thus, it can be understood that the application of falling and compression damage, and even the application of exogenous ethylene, accelerated the biochemical metabolism of the fruits, exacerbating the respiratory rate as well as the consumption of their energy reserves (Dantas et al., 2016).

During the 28 days of storage, titratable acidity (Figure 3C) decreased considerably in the fruits. This reduction in titratable acidity occurred alongside the acceleration of respiratory metabolism (Figure 4A), induced by ethylene production (Figure 4B), during the storage of climacteric fruits such as mangoes (Souza et al., 2013). During the 28-day experimental period, the respiration of climacteric fruits was notably pronounced, particularly due to physical damage sustained by the mangoes. This led to an accelerated depletion of organic acids, following the typical curve of the climacteric peak in mangoes (Souza et al., 2013).

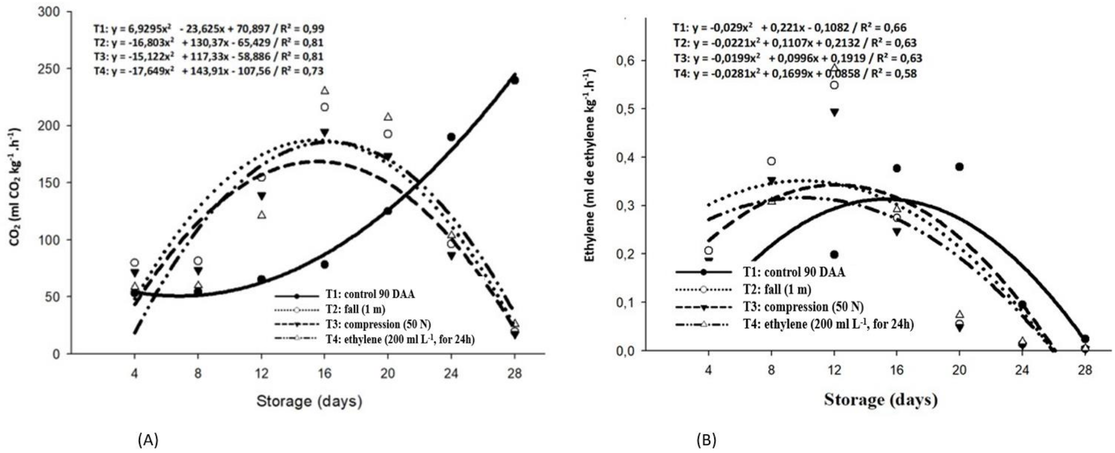

Figure 4. Production of CO_2, in mL of CO_2 kg^{-1} h^{-1} (A) and ethylene, in mL of ethylene kg^{-1} h^{-1} (B), of "Tommy Atkins" mangoes subjected to mechanical damage and exposure to exogenous ethylene. Boa Vista/RR – 2022.

Mangoes that were not subjected to the induced damage exhibited higher levels of total and reducing sugars (Figures 3D and 3E), indicating a less intensive use of reserve substrates. Consequently, these fruits were at a less advanced stage of ripening compared to those exposed to the other treatments (Leite and Crusciol, 2008).

According to Figures 5A and 5B, fruits subjected to mechanical damage - such as dropping, compression, and exposure to exogenous ethylene - reached their peak ethylene production and corresponding respiration peak (known as the climacteric peak) after 12 and 16 days of storage under uncontrolled temperature and relative humidity conditions (Dantas et al., 2016). In contrast, control group fruits, which were not damaged, reached their ethylene and respiration peaks after 20 and 28 days of storage, respectively. These findings suggest that physical damage accelerates respiration and ethylene production in "Tommy Atkins" mangoes, causing them to enter senescence 8 to 10 days earlier than undamaged fruits.

In mangoes subjected to falling, compression, and exogenous ethylene exposure, the biochemical-functional composition - represented by vitamin C content (Figure 5A), total phenolic compounds (Figure 5B), and carotenoids (Figure 5C) - declined progressively compared to the control group as storage time increased. Damaged mangoes exhibited vitamin C levels up to five times lower than those in the control group (Figure 5A), clearly demonstrating that the inflicted damage not only compromised sensory quality and respiratory metabolism but also significantly affected the fruits' biochemical and functional properties.

Similarly, it was observed that over the 28-day storage period, the concentration of phenolic compounds declined more sharply in fruits subjected to physical damage compared to those in the control group (Figure 5B). This reduction consequently impacted their antioxidant activity (Figures 5C and 5D). In this context, the decrease in total phenolic content was proportionally mirrored by a decline in antioxidant activity. However, this effect was notably more pronounced in fruits exposed to mechanical damage - particularly those subjected to falling and the exogenous application of ethylene.

Thus, the reduction in total phenolic content can be directly associated with the marked decrease in antioxidant activity observed in this study, consistent with findings reported by Jacobo-Velazquez and Cisneros-Zevallos (2012). The elevated antioxidant activity in fruits with high phenolic concentrations is primarily attributed to the reducing properties and chemical structure of these compounds. In addition to phenolics, a similar relationship can be inferred between total carotenoid content (Figure 5E) and the antioxidant capacity of "Tommy Atkins" mangoes.

Since fruit appearance plays a crucial role in consumer decision-making (Souza et al., 2008), the application of mechanical damage - such as dropping, compression, and exposure to exogenous ethylene - reduced the likelihood of consumer purchase by 90% compared to the control group, immediately following 16 days of storage under uncontrolled temperature and relative humidity conditions.

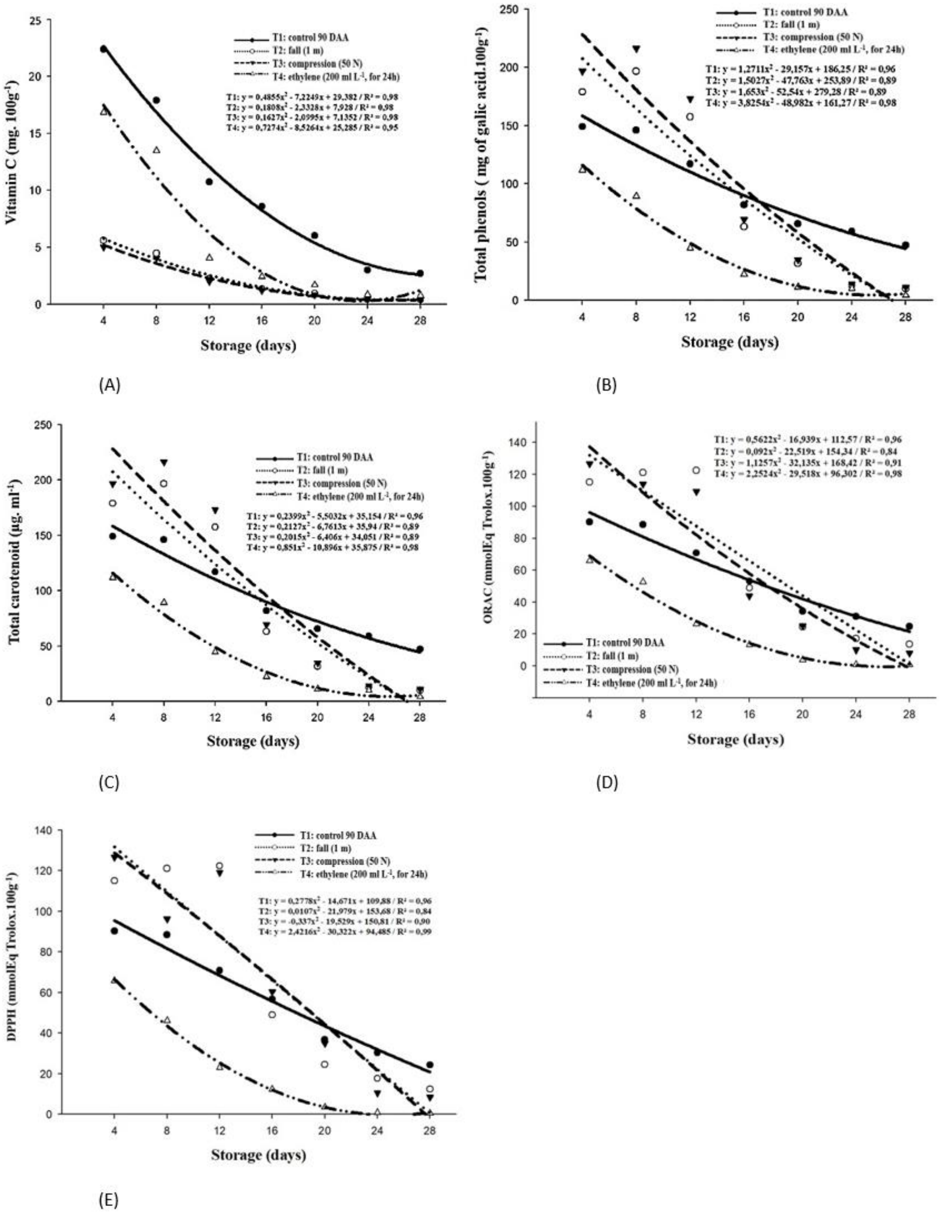

Figure 5. Vitamin C content, in mg $100g^{-1}$, (A), total phenolics, in mg of gallic acid 100 g^{-1} of sample, (B), carotenoids (C), in µg mL^{-1}, antioxidant capacity by the ORAC method (D) and by the DPPH method (E), in (mmolEq Trolox $100g^{-1}$) of sample, of "Tommy Atkins" mangoes subjected to mechanical damage and exposure to exogenous ethylene.

Similar findings regarding fresh mass loss were reported by Souza et al. (2013) in "Tommy Atkins" mangoes and by Godoy et al. (2010) in "Golden" papayas. These authors explain that fresh mass loss is an early symptom of water depletion, which is exacerbated by physical damage, leading to accelerated metabolic activity.

Loss of pulp firmness is considered a reliable indicator of ripening in "Tommy Atkins" mangoes (Lima et al., 2009; Neves et al., 2008). Fruits exposed to any form of damage may lose nearly half of their potential shelf life during storage, transport, and post-harvest handling. Vilar et al. (2019) confirmed similar results, noting that the reduction in pulp firmness is caused by structural changes in the cell wall due to enzymatic activity, which intensifies as the fruit matures and enters senescence (Dantas et al., 2017).

The pH values observed in this study fall within the acceptable range established by Benevides et al. (2008) for "Tommy Atkins" mangoes. Comparable results regarding titratable acidity were reported by Vélez-Rivera et al. (2013), Vasconcelos et al. (2019), and Costa et al. (2019), who emphasized that the high rate of acid degradation is a natural consequence of the ripening process, along with the low pH levels found in mango pulp. During the 28-day experimental period, respiration in climacteric fruits was notably pronounced, especially in damaged mangoes, resulting in accelerated acid consumption that followed the typical climacteric curve (Souza et al., 2013).

According to Finger et al. (2006), the onset of climacteric respiration does not always coincide with increased ethylene production. However, evidence suggests that ethylene acts as the primary trigger for elevated respiratory activity, making climacteric respiration an ethylene-regulated event (Grierson, 2013), as demonstrated in this study.

In summary, physical damage significantly impacted metabolic respiration, leading to excessive and accelerated sugar consumption, which ultimately shortened the post-harvest shelf life of the fruits (Henz et al., 2005). The correlation between phenolic compounds and antioxidant activity has been previously documented in various tropical fruits, including Indian jujube (Bastos et al., 2016), buriti (Tosin et al., 2016), camu-camu (Neves et al., 2015a-c; Neves et al., 2017), and murici (Neves et al., 2015b), among others (Neves et al., 2012).

These compounds play a vital role in neutralizing or scavenging free radicals and chelating transition metals, acting during both the initiation and propagation phases of oxidative stress (Ediriweera et al., 2016). In line with this, Braz et al. (2008) observed a positive correlation between mango ripening and the synthesis of carotenoids and phenolic compounds. While the antioxidant properties of total phenols against reactive oxygen species are well established, under certain conditions, they - like carotenoids - may also exhibit pro-oxidant behavior (Omoni and Aluko, 2005). According to Sousa (2007), carotenoids and phenols can neutralize free radicals without undergoing degradation, reacting with peroxyl, hydroxyl, and superoxide radicals.

4. Conclusions

Based on the results obtained, it can be concluded that the potential shelf life of "Tommy Atkins" mangoes subjected to compression and dropping, and stored under uncontrolled temperature and relative humidity conditions, is limited to just 4 to 8 days. This significantly restricts their transport and commercial distribution.

Mangoes exposed to high ethylene concentrations - likely due to late harvesting - demonstrated a shelf life of approximately 8 to 16 days under the same storage conditions.

In contrast, "Tommy Atkins" mangoes harvested at the optimal time (90 days after anthesis, as defined in this study) and stored without temperature and humidity control exhibited a post-harvest shelf life of at least 28 days.

Authors' Contribution

Oswald Renaud Koblam Ahouangbonou Conceptualization, Formal Analysis, Funding Acquisition, Research, Experimentation, Methodology, Writing, Data Curation. Leandro Timoni Buchdid Camargo Neves Conceptualization, Formal Analysis, Research, Experimentation, Methodology, Data Curation. Daniela Cavalcante dos Santos Campos Conceptualization, Formal Analysis, Methodology.

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