Acta Agronómica
ISSN: 0120-2812
actaagronomica@palmira.unal.edu.co
Universidad Nacional de Colombia
Colombia

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Acta Agronómica, vol. 66, núm. 3, 2017, pp. 331-337
Universidad Nacional de Colombia
Palmira, Colombia

Agroindustria y Ciencia de los Alimentos / Agroindustry and Food Science

Acta Agron. (2017) 66 (3) p 331-337 ISSN 0120-2812 | e-ISSN 2323-0118 https://doi.org/10.15446/acag.v66n3.54579

Potassium permanganate effects on the quality and post-harvest conservation of sapodilla (*Manilkara zapota* (L.) P.Royen) fruits under modified atmosphere

Efeitos do permanganato de potássio na qualidade e conservação pós-colheita de frutos de sapotizeiro (*Manilkara zapota* (L.) P.Royen) sob atmosfera modificada

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Rec.: 08.12.2015 Accep.: 14.06.2016

Abstract

Sapodilla (*Manilkara zapota* (L.) P. Royen) is a climacteric fruit, very perishable, with high metabolic activity, rapid ripening and reduced storage time at room temperature, thus making difficult its commercialization. However, this research aimed to evaluate the effect of potassium permanganate ($KMnO_4$) on the quality and post-harvest conservation of sapodilla fruit under modified atmosphere at room temperature. The sapodilla fruits were harvested when they reached physiological maturity and then accommodated in Styrofoam trays with PVC film coating. Within each package, $KMnO_4$ were placed at different concentrations (0, 0.250, 0.375, and 0.500 g of $KMnO_4$ per kg of fruit, respectively), impregnated in vermiculite. In addition, were kept in storage at room temperature (25 ± 1 °C and 54 ± 5% RU) for fifteen days, with fruit quality analysis every five days. The potassium permanganate doses influenced the sapodilla fruit quality, wherein the concentration of 0.375 g of $KMnO_4$ per kg of fruit was the most efficient, retarding the loss of firmness and vitamin C degradation of sapodilla fruits throughout five days storage under modified atmosphere at room temperature. The sapodilla fruit postharvest life stored under modified atmosphere with potassium permanganate 25 ± 1 °C and 54 ± 5% RU, is ten days.

Key words: Ethylene, fruit quality analysis, physiological maturity, postharvest conservation, storage time.

Resumo

O sapoti (*Manilkara zapota* (L.) P. Royen), é um fruto climatérico, muito perecível, com elevada atividade metabólica, rápido amadurecimento e tempo de conservação reduzido sob temperatura ambiente, dificultando assim a sua comercialização. No entanto, este trabalho teve como objetivo avaliar o efeito de sachês de permanganato de potássio ($KMnO_4$) sobre a qualidade e conservação pós-colheita do fruto de sapotizeiro sob atmosfera modificada em temperatura ambiente. Os sapotis foram colhidos ao atingirem a maturidade fisiológica e em seguida acomodados em bandejas de isopor com revestimento de filme PVC. No interior de cada embalagem, foram colocados sachês de $KMnO_4$ em diferentes concentrações (0, 0.250, 0.375 e 0.500 g de $KMnO_4$ por kg de fruto), impregnado em vermiculita. Em seguida realizou-se o armazenamento a temperatura ambiente (25 ± 1 ºC e 54 ± 5% UR) por um período de quinze dias, sendo realizadas análises de qualidade dos frutos a cada cinco dias. As doses de permanganato de potássio influenciaram na qualidade dos frutos de sapotizeiro, sendo que a concentração 0,375 g de $KMnO_4$ por kg de fruto foi a mais eficiente retardando a redução da firmeza e degradação da vitamina C dos frutos até cinco dias de armazenamento sob atmosfera modificada e temperatura ambiente. A vida útil pós-colheita de frutos de sapotizeiro armazenados sob atmosfera modificada com sachês de permanganato de potássio, sob condições ambientais de 25 ± 1 ºC e 54 ± 5% UR é de dez dias.

Palavras-chave: Análise de qualidade de frutos, conservação pós-colheita, etileno, maturidade fisiológica, tempo de armazenamento.

Introduction

Sapodilla (*Manilkara zapota* (L.) P. Royen), is a climacteric fruit, very perishable, with high metabolic activity, rapid ripening and reduced shelf life at room temperature (Oliveira *et al.*, 2011), due to substrates content favoring the proliferation of pathogenic organisms, moisture, organic acids and sugars, leading to a higher decay probability and limits the fruit conservation and marketing. Given these concerns, sapodilla is a fruit, which have the highest consumption in fresh form, it is necessary to establish post-harvest conservation techniques to extend the fruit shelf-life.

It is important to note that in postharvest, fruit conservation with a modified atmosphere is suggested as an important technology for reducing water loss, and provides other desirable effects such as firmness and color maintenance by changing the gas composition surrounding the fruit (Oshiro *et al.*, 2013).

Furthermore, the package under modified atmosphere, retards the growth of pathogenic and spoiling micro-organisms, from the decrease of the partial O_2 pressure and an increase in CO_2, which has an inhibitory effect on bacterial growth (Mantilla *et al.*, 2010).

However, even under these conditions, ripening or loss of quality can be accelerated due to the action of ethylene. Thus, for prolonged storage, other storage techniques such as the use of potassium permanganate can complement the effects of the modified atmosphere and maintain good fruit quality.

Control of ethylene and its effects on fruit ripening provides more accurate and reliable estimates of fruit harvest at the pre-climacteric stage and storing them in an environment which contains products able to remove this phytohormone (Amarante & Steffens, 2009). Potassium permanganate ($KMnO_4$), is an ethylene absorber being used in the form of sachets or impregnated in plastic containers or in chemical filters, which absorb and oxidize ethylene to water, carbon dioxide, manganese dioxide and potassium (Wills & Warton, 2004).

Alternatively, studies have shown the use of potassium permanganate for ethylene removal retards the ripening of various climacteric fruits such as banana (Prill *et al.*, 2012), papaya (Silva *et al.*, 2009b) and apple (Amarante & Steffens, 2009). Specifically, for sapodilla more studies are carry out only with modified atmosphere, inhibitor synthesis and ethylene action. Costa *et al.* (2011), observed the use of corn starch at 5%, reduced pulp loss and increased the shelf-life of sapodilla. Morais *et al.* (2008), studying with 1-MCP in the cell wall biochemistry of sapodilla found that 1-MCP, delayed the sapodilla softening for 11 days.

In the literature there is still little research with this species, related to the use of ethylene absorbers, such as potassium permanganate. Thus, this study aimed to evaluate the effect of potassium permanganate on the quality and post-harvest conservation of sapodilla fruit under modified atmosphere at room temperature.

Materials and methods

Sapodilla fruits used in this experiment were collected from a commercial plantation in the Norfruit Ltda. farm, located 7 km northeast of the km 36 of the BR 304 highway, Pau-Branco community, in Mossoró-RN, at south latitude 5º 11› and a west longitude 37º 20› and an altitude of 18 m.a.s.l. The cultivar used was 'Itapirema-31', whose seedlings for orchard installation were obtained from the Pernambuco Agricultural Research Company (IPA). The sapodilla with marketing standards (average weight of 120 g and an average size of 59 cm long and 63 cm in diameter) were harvested when reaching commercial maturity in May, 2010. Shortly after, they were transported to the laboratory of postharvest fruit physiology of the UFERSA- Universidade Federal Rural do Semi-Árido, Brazil. *in vitro* conditions, a selection of fruit was carried out by the degree of ripeness, shape and size. They were washed, dried and accommodated in Styrofoam trays with PVC film coating, four fruits per tray. Inside each package were put sachets of $KMnO_4$ impregnated in vermiculite. The $KMnO_4$ concentrations used were as follows: 0; 0.250; 0.375 and 0.500 g of $KMnO_4$ per kg of fruit, respectively. Sapodilla fruits were kept in storage at room temperature (25 ± 1 ºC and 54 ± 5% RU).

It was used a completely randomized design in a split plot design, with the treatments (doses of potassium permanganate) and the subplots were defined as storage time (0, 5, 10 and 15 days) in plots.

The evaluation of the external appearance was performed with a subjective scale according to Miranda *et al.* (2003), with some modifications taking into account the impact spots, fungal infection and wrinkling. The scores ranged from 1 to 5, based on the percentage of affected fruit as follows: 1) absence of symptoms; 2) 1 to 15%; 3)16 to 30%; 4) 31 to 45%; and 4) over 45% of fruits affected. Fruit with notes above 3.0, were considered unsuitable for marketing. In the evaluation of internal appearance, it was used a subjective scale, in which the scores ranged from 1 to 5, based on the percentage in the affected pulp area as follows: 1) no symptoms; 2) 1 to 15%; 3)

16 to 30%; 4) 31 to 45% and 5) over 45% of pulp affected, considering the stain incidence and mold attack. Therefore, analysis of color content in pulp fruit was carried out using a subjective scale of notes 1 to 4, where: 1) corresponds to light cream pulp; 2) dark cream; 3) light brown; and 4) dark brown. To determine the fruit firmness it was used a McCormick penetrometer, model FT 327, and the results were expressed in Newton (N). The weight loss was determined by the difference of the initial and final mass and expressed as a percentage. The electrolyte leakage was determined by using a blade to remove 2 cm disks from the bark of the median region of each sapodilla fruit for all replicates. Additionally, were transferred into test tubes containing distilled water at room conditions, where they remained for two hours. Once the resting time was over, the solution electrical conductivity was measured with a Schot conductivitymeter model CG 853. Subsequently, the test tubes containing the peeling discs were autoclaved (121 °C at 1.5 atm) for 30 minutes and the electrical conductivity measured again. The results were expressed in obtained percentage from the ratio between the first and second measurement values, multiplied by 100.

The amounts of vitamin C were determined immediately after fruit processing by means of titration with a DFI solution of (2,6-dichloro phenol indophenol 0.02%) until obtaining a permanent pink coloration. The titratable acidity (TA) was determined by pulp titration with solution of NaOH at 0.1 M, according to the AOAC method (2005), expressed in percentage of malic acid. The pH measurements were determined with the aid of a pHmeter with a measurement directly performed on processed pulp (AOAC, 2005). For the determination of soluble solids (SS, %), fruit pulp was filtered through filter paper and the soluble solids content measured in digital refractometer Atago® PR-101 Pallete model, according to the AOAC method (2005), with automatic temperature compensation. Determination of soluble sugars, readings in a spectrophotometer at 620 nm and results expressed as % of glucose.

The results were submitted to variance analysis using the Sisvar 4.6 software ®. For mean comparison, we used the Tukey and Kruskal Wallis test at 5% of significance ($p<= 0.05$) and regression analysis for the quantitative factor.

Results and discussion

There was interaction between the evaluated factors, potassium permanganate doses and storage time for vitamin C and fruit firmness. For external and internal appearance, pulp color, titratable acidity, pH, soluble solids, soluble solids/titratable acidity ratio, total soluble sugars, weight loss and electrolyte leakage variables, was observed significant effect only for storage.

The loss of fruit weight reached about 20% after 15 days of storage, which compromised the fruit appearance which became wrinkled (Table 1).

Table 1. Mean values for weight loss (WL), electrolyte leakage (EL), external appearance (EA), internal appearance (IA) and pulp color (COLOR) of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere permanganate and stored at room temperature (25 ± 1 °C and 54 ± 5% UR)

Storage (days)	WL¹ (%)	EL¹ (%)	EA²	IA²	COLOR²
0	-	-	1.0 b	1.0 b	1.0 b
5	7.0 c	61.5 b	1.1 b	1.4 b	1.6 b
10	15.6 b	85.4 a	2.4 a	2.6 a	2.9 a
15	19.3 a	83.7 a	3.3 a	3.7 a	3.3 a
CV 1 (%)	20.1	24.6	-	-	-
CV 2 (%)	16.9	33.8	-	-	-

* Means followed by the same letter in the column do not differ by ¹Tukey and ²Kruskal-Wallis test ($p<0.05$). CV= coefficient of variation.

The increase in mass loss is the result of an accelerated metabolism due to low relative humidity and high temperature at which, sapodilla fruits were submitted during storage.

Miranda *et al.* (2003), evaluating sapodilla storage for 12 days at room temperature (24 ± 2 °C and 90 ± 5% RU) obtained mass loss of approximately 9% lower than obtained in this research, presumably due to higher rate of relative humidity, which provided a reduction in fruit transpiration, which is the main factor and is associated with the difference in water vapor pressure, thereby reducing water loss from the fruit.

In addition, for electrolyte leakage variable, there was a significant increase in storage time (Table 1), which coincided with the climacteric rise, indicating a loss of integrity (selective permeability) of the cellular membrane system, possibly caused by the early senescence. The changes in the membrane functionality are the result of the decrease in lipid fluidity and structural change, and the decline of membrane proteins during senescence. The increase of electrolyte leakage in fruits during the storage time was also observed in banana peel at room temperature (Maia *et al.*, 2011) and papaya Sunrise Golden cultivar (Silva *et al.*, 2009b).

Sapodilla fruits, performed good appearance until 10 days of storage, but at 15 days in all treatments, the fruits were inadequate for marketing, reaching notes above 3.0 for external and internal appearance (Table 1). The Fruit appearance was compromised by fungus growth in some fruits, as well as the high mass loss and electrolyte leakage of cell wall, which have allowed the storage time decreased left them wrinkled finally.

The fruit acceptability by consumers is primarily determined by their appearance. Morais *et al.* (2006a), evaluating sapodilla fruits subjected to treatment with 1-methylcyclopropene, stored under modified atmosphere (25 ± 2 °C and 70 ± 5% UR), observed lifespan of 21 days, being higher than found in this research. This information is useful because provides more accurate and reliable estimates of treatment with 1-methylcyclopropene (ethylene action inhibitor) is more effective than potassium permanganate.

There was a significant development of pulp coloring with time of storage in which, went from pale cream to light brown (Table 1). The peel color change and fruit pulp after harvest may have an enzymatic origin, involving the participation of certain enzymes such as phenylalanine ammonia-lyase involved in anthocyanin synthesis and other phenolic (Edahiro *et al.*, 2005).

Throughout the storage, there was a clear decrease in fruit firmness, more pronounced for control treatment (Figure 1).

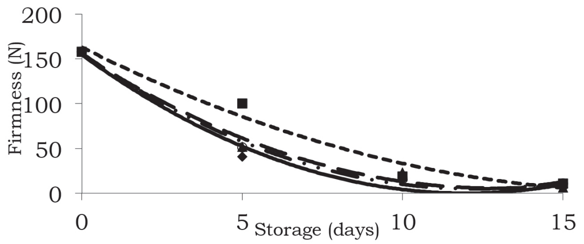

Figure 1. Firmness of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 °C and 54 ± 5% UR)

Although, for fruits treated with potassium permanganate, the firmness reduction was delayed, with an observed more efficient result for the dose of 0.375 g until the fifth day of storage (Table 2).

Table 2. Mean values of pulp firmness (N) of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 °C and 54 ± 5% UR)

Dose of $KMnO_4$	Storage (days)			
(g kg^{-1} fruit)	0	5	10	15
0.0	157.9 a	41.2 b	15.3 a	6.2 a
0.250	157.9 a	51.7 b	22.9 a	6.2 a
0.375	157.9 a	100.1 a	18.8 a	10.8 a
0.500	157.9 a	51.5 b	16.0 a	10.6 a
LSD	17.94			

* Means followed by the same letter in the column do not differ by Tukey test ($p<0.05$). LSD= least significant difference.

At the end of storage, treated fruits showed softening similar to the control, indicating that typically the fruit ripening was occurred as usual as effect treatment.

Accordingly to Vargas *et al.* (2006), the loss of fruit firmness during ripening is probably a result of the cell wall hydrolysis mechanism, which is related to increased activity of endogenous enzymes, which break down pectin material, or the reduction of turgor pressure, which diminishes with loss of water or dehydration caused by tissue perspiration during storage.

The fruit firmness is considered one of the key quality attributes which limit the fruit shelf-life, especially in the case of sapodilla, because when the fruit is suitable for consumption, it is very soft which makes it very susceptible to mechanical damage and pathogen attack. As observed in this research, the incidence of fungus (*Botrytis cinerea*) in some fruits at the end of storage.

In all treatments, vitamin C decreased over time of storage (Figure 2), the doses of 0.375 and 0.500 g of potassium permanganate providing larger retardation in vitamin C reduction during storage, and more effective to fifth day of evaluation (Table 3).

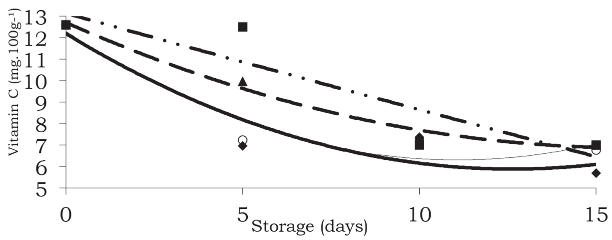

Figure 2. Vitamin C of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

Table 3. Contents of vitamin C (mg 100 g^{-1}) of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC e 54 ± 5% RU)

Dose of $KMnO_4$	Storage (days)			
(g kg^{-1} fruit)	0	5	10	15
0.0	12.6 a	6.9 b	7.4 a	5.7 a
0.250	12.6 a	7.2 b	7.2 a	6.8 a
0.375	12.6 a	9.9 a	7.4 a	7.0 a
0.500	12.6 a	12.5 a	7.0 a	7.0 a
LSD	2.57			

* Means followed by the same letter in the column do not differ by Tukey test ($p<0.05$). LSD= least significant difference.

It is important to note that vitamin C decreasing during the retention period is common in fruits and vegetables. This may be due to vitamin C, is an excellent antioxidant, acting on redox reactions as an electron transporter to the respiratory chain as well as regenerating different substrates from its oxidized form to the reduced form. In addition, vitamin C may have been used in interaction with ROS, in particular H_2O_2, which are produced during the oxidative stress, which must have occurred in the storage period. In concordance to Chitarra & Chitarra (2005), the vitamin C content tends to decrease with aging and storage, due to the action of ascorbic acid oxidase enzyme or by the action of oxidative enzymes such as peroxidase.

The titratable acidity was decreased until the eighth day of storage, but at the end of storage it was increased (Figure 3), probably due to the occurrence of fermentation, with the onset of senescence (Miranda *et al.*, 2003).

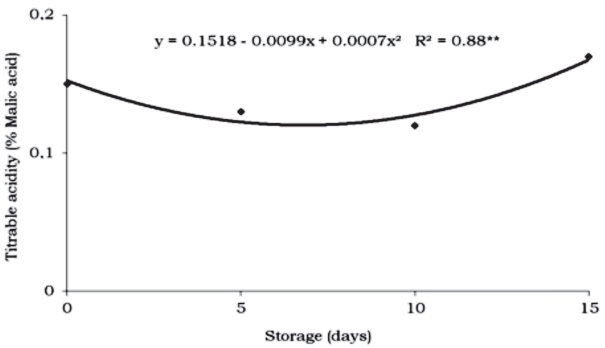

Figure 3. Titratable acidity of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

According to Silva *et al.* (2009a), the concentration of organic acids usually declines after harvest and during storage, due to its use as a substrate in breathing or their transformation into sugars, being influenced by temperature. These changes have important role in the characteristics of flavor and aroma, since some compounds are volatile.

The pH had a small change, increasing until the eighth day of storage, followed by a reduction by the end of the experiment (Figure 4), a variation which agreed with observed in the titratable acidity. Morais *et al.* (2006b), studying sapodilla cultivars storage at room temperature, also observed a slight variation of pH and the titratable acidity.

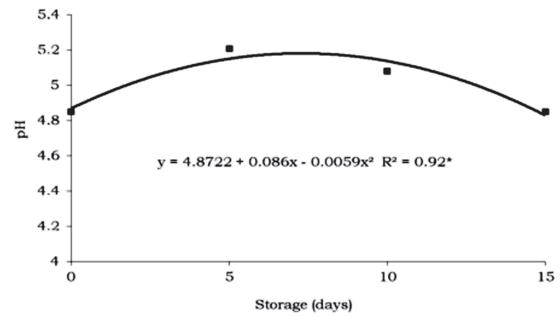

Figure 4. pH of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

The soluble solids had a small decrease over storage time (Figure 5). This reduction can be attributed, in part, to the mobilization of soluble solids for breathing, consisting mainly by sugars (glucose, fructose and sucrose), organic acids and soluble pectins (Atta-Aly, 2003; Pelayo-Zaldívar *et al.*, 2005).

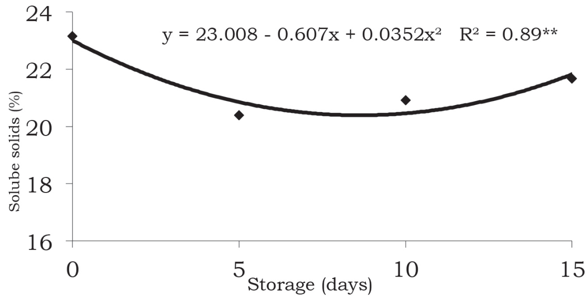

Figure 5. Soluble solids of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

The soluble sugars increased until ten days of storage. After this period, there was a decrease (Figure 6).

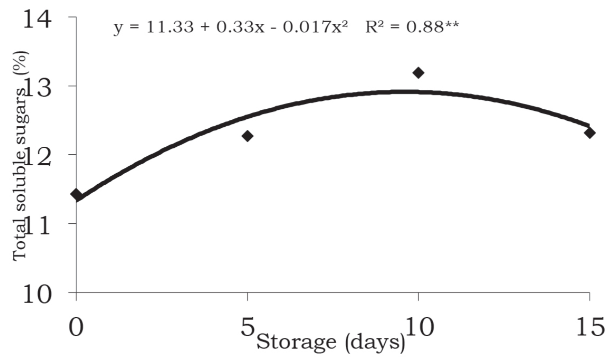

Figure 6. Total soluble sugars of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

Similar results were found by Morais *et al.* (2006b), evaluating the storage of two sapodilla cultivars. Accordingly to Miranda *et al.* (2003), sapodilla fruit can reach ripening with a full sugar content of 21.3%, this research found lower values ranging from 11.5 to 13%, similar to the values found by Oliveira *et al.* (2011), whose found approximately 11.2%.

The total soluble solids content is an important quality factor to the taste of products. In concordance to Chitarra & Chitarra (2005), it is used as an indirect measure of sugar content because the large percentage of soluble solids in sapodilla fruit is made up of sugars.

In this research, the soluble solids values and total soluble sugars were inversely proportional. This probably happened because the sugars correspond only partially to soluble solids, this correlation ranging from 60 to 80% depending on the fruit. During storage other solid constituents such as soluble organic acids, primarily ascorbic acid, experienced a heavy reduction, which may have influenced the soluble solids content.

There was an increase in the SS/TA from the fifth day of storage reaching a maximum on the tenth day, followed by a sharp reduction up to the end of the storage (Figure 7) due to the observed increase in titratable acidity coinciding with the start of senescence. This relationship is one of the best ways to evaluate the flavor, more representative than the isolated measuring of sugar or acidity, providing a good idea of the balance between these two components (Chitarra & Chitarra, 2005).

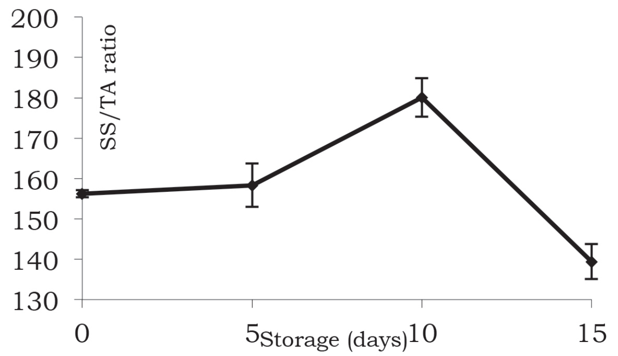

Figure 7. Ratio soluble solids/titrable acidity of sapodilla (*Manilkara zapota* (L.) P. Royen) subjected to treatment with potassium permanganate under modified atmosphere and stored at room temperature (25 ± 1 ºC and 54 ± 5% RU)

Conclusion

The potassium permanganate dose influenced the fruit quality, wherein the concentration of 0.375 g of $KMnO_4$ per kg of fruit was the most efficient in retarding the loss of firmness and vitamin C degradation of sapodilla fruits up to five days in storage under modified atmosphere at room temperature.

This information is useful and have allowed to determine the sapodilla fruit postharvest life stored under modified atmosphere with potassium permanganate under modified atmosphere conditions of 25 ± 1 °C and 54 ± 5% UR, is ten days.

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