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Full Length Research Paper

Effect of chitosan coating on some characteristics of mango (*Mangifera indica* L.) "Ataulfo" subjected to hydrothermal process

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Because of the possible presence of immature stages of the Mexican fruit fly, *Anastrepha ludens* (Loew), the mango fruits cv. Ataulfo are most often treated by immersion in hot water (46.1°C during 90 min. This hydrothermal process has been shown to accelerate the ripening of fruit, but undesirable effect can be reversed with the use of coatings of various compositions. The objective for this study was to determine the effect of chitosan coating on physicochemical and biochemical parameters of Ataulfo mango subjected to hydrothermal process. Using mature green fruit, free from both physical and biological damage, the following treatments were established: 1) Fruits with hydrothermal process not coated with chitosan (HCh^-), 2) fruits with hydrothermal process coated with chitosan (HCh^+), 3) fruits without hydrothermal process not coated with chitosan (Ch^-) and 4) fruits without hydrothermal process coated with chitosan (Ch^+). All fruits were stored for 21 days at 22°C and 80 to 85% RH. At the end of their storage, fruits of HCh^+ treatment had higher values of firmness, but weight loss, pH, PG and PME activity, production of CO_2, tone and chromaticity, lower than those shown by the fruits of HCh^- treatment. The results obtained in treatments Ch^- and Ch^+, together with those reported by other authors who used chitosan as a coating, suggests a hypothesis: that the attenuation in the physiology of the fruits are due to changes in gas transfer.

Key words: Gas transfer, postharvest quality, biocoating, ripening.

INTRODUCTION

Because of its large consumer market, the fruits of Ataulfo mango (*Mangifera indica* L.) denominated "Soconusco Ataulfo Mango from Chiapas" (IMPI, 2003) is widely produced in the coastal plain of Chiapas, Mexico, and represents an important source of income for farmers in this area of production. Over 80% of total production is exported to countries in Europe, Asia and United States (SAGARPA, 2010), the latter being the main consumer of the fruit. One of the more rigorous requirements for successful marketing is the treatment of the fruit with hot water immersion (46.1°C during 90 min), in order to eliminate the presence of immature stages of the Mexican fruit fly *Anastrepha ludens* Loew (USDA, 2009). Although the hydrothermal process is effective in destroying the immature stages of flies and inducing the generation of uniform color of the fruit, it also removes the wax that covers the fruit (with consequent loss brightness), accelerates the physiological processes of ripening, and thus reduces the shelf life of fruit (Yahia

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Abbreviations: **HCh^-,** Fruits with hydrothermal treatment not coated with chitosan; **HCh^+,** fruits with hydrothermal treatment coated with chitosan; **Ch^-,** fruits without hydrothermal process not coated with chitosan; **Ch^+,** fruits without hydrothermal process coated with chitosan.

and Campos, 2000; Luna et al., 2006; Dea et al., 2010). Therefore, several studies have been conducted to develop procedures which permit an increase in the shelf life of fruits of different varieties of mango (Kent, Tommy Atkins, Lirfa, Haden, Manila, Kesar, cat Hoa loc, Tainong, Bocado, Alphonso, among others). The use of films and coatings of various types has been the most studied alternative, but many of the studies use mangos without the prior hydrothermal process (Hoa and Ducamp, 2008; Rathore et al., 2007; Wang et al., 2007; Zhu et al., 2008; Muy et al., 2009).

When the mangoes are subjected to the hydrothermal process, the application of wax-based coating (bee, carnauba or candelilla) has been the most commonly used method for reducing the negative effects of such treatment (Dhemre and Waskar, 2003; Pérez et al., 2003; 2005; Castrillo and Bermudez, 2007). The application of such coatings has been shown to reduce, among other things, the moisture loss, respiration rate and generation of color, while at the same time reduces the firmness loss of mango fruits (Muy et al., 2004; Pérez et al., 2005; Luna et al., 2006).

Another coating that has been recently used is that made from chitosan. This is a material used, among other purposes, as a supplement for human consumption, as a coagulant in wastewater treatment, and seed coating. Chitosan is a nontoxic polysaccharide, biocompatible, biodegradable (Shigemasa et al., 1994), which forms films, and has antifungal (Hernandez et al., 2007) and antibacterial (Gil et al., 2004) properties. When used on fruits, the coatings based on this polymer have significantly improved shelf life (Salvador et al., 1999; Bautista et al., 2005). For mango fruits coated or packaged with this biopolymer, ripening is delayed up to 9 days (Srinivasa et al., 2002), while the presence of pathogenic microorganisms is diminished (Wang et al., 2007; Zhu, 2008), there is less moisture loss, the firmness of this fruit is longer preserved, the amount of soluble solids is reduced and acidity is lower (Srinivasa et al., 2002; Salvador et al., 2003; Bautista et al., 2006). However, the work carried out with mango fruits has been performed with fruits that were not subjected to the hydrothermal process.

Since, as noted earlier, mango Ataulfo must necessarily be subjected to hydrothermal process for marketing, the application of a coating of chitosan was thought to reduce the negative effects of this process. Therefore, the objective of this study was to determine the effect of chitosan coating on some physicochemical and biochemical parameters of Ataulfo mango fruits when subjected to the hydrothermal process.

MATERIALS AND METHODS

Fruits and treatments

One hundred fruits mature green of Ataulfo mango, free of physical and biological damage, were harvested in the groves of “Productora y Comercializadora Cabello” (Cabello Producer and Marketing Company) in Tapachula, Chiapas (Mexico). After harvest, fruits were sanitized with chlorinated water (200 mg L^{-1}) and divided into four groups (treatments) in accordance with a factorial design 2^2: Treatment 1: fruits with hydrothermal treatment not coated with chitosan (HCh^-). Treatment 2: fruits with hydrothermal treatment coated with chitosan (HCh^+). Treatment 3: fruits without hydrothermal process not coated with chitosan (Ch^-). Treatment 4: fruits without hydrothermal process coated with chitosan (Ch^+). The hydrothermal treatment was performed at 46.1°C during 90 min in a pilot scale system [1.96 × 0.7 × 0.83 m (L×W×H) made in steel stainless (Industrial Uruapan. Michoacán, México)] with time and temperature automatic control. Subsequently, the fruits were cooled with water at 23 to 25°C for 30 min. After air dry, the fruits were chitosan coating by individual immersion in a 2% solution of low viscosity material (Chitosan from crab shells Fluka ®, Germany) dissolved in 0.1 M ascorbic acid. All fruits were stored at 22±1°C and 80±5% RH for three weeks according to the recommendations by Luna et al. (2006). All treatments were followed by sampling three fruits every 3 days for a period of 21 days (seven samples in total).

Physicochemical characteristics

Weight loss

Weight loss of fruits was determined using a digital scale (OHAUS CS model 5000), referencing to the initial and final weights of the fruit. The result was reported in percentage of weight loss (%WL) (AOAC, 1994).

Firmness

The firmness of the fruit was determined to be the force needed, in Newtons (N), to penetrate the pericarp of the fruit after removing the peel from the middle part of the fruit, and using a digital penetrometer TR ® (Italy) for fruit provided with a conical plunger of 10 mm diameter (AOAC, 1994).

Total soluble solids

The total soluble solids (°Bx) were determined at 22°C, with a digital refractometer ATAGO, Model PAL-α (Japan) using 2 to 3 drops of juice obtained by squeezing the fruits (AOAC, 1994).

Titratable acidity

To determine the titratable acidity of the fruit, 10 g of pulp of each fruit were first diluted with sterile distilled water to achieve 50 ml. 10 ml of the dilution were then titrated with 0.1 N NaOH according to the process reported by the AOAC (1999). The results were expressed as a percentage of citric acid present in the samples.

pH

The determination of pH was made directly in the solution used for the determination of titratable acidity, using a potentiometer model Corning Pinacle ® 530 pH meter.

Color

The color of the peel and pulp was determined with a colorimeter Chroma Meter model CR-410® (Konica-Minolta, Japan). Measurements in the peel were made near the peduncle, in the middle of the fruit and in the pedicel. Measurements in the pulp were made near the seed. Both determinations were performed using the system of CIEL, a*, b *, and the color tone was estimated [° Hue = arctg ($b^* \cdot a^{*-1}$)] and chromaticity ($C = \sqrt{a^{*2}+b^{*2}}$) according to the CIE (1986).

Biochemical characteristics

Polygalacturonase activity (PG)

PG activity was determined for both the pulp and peel, using a method proposed by Miller (1959). For this, 100 mg of tissue was macerated in liquid nitrogen and suspended in 1 ml of 0.1 M acetate buffer pH 4.5. After centrifugation at 10 000 × g for 5 min at 4°C, 50 µl of supernatant was mixed with 350 µl of a solution 0.1% polygalacturonic acid (Fluka®) and incubated at 30°C. After 30 min, 600 µl of 1% DNS (3, 5-dinitrosalicylate) reagent (Fluka®) was added and, boiled for 15 min. After cooling, absorbance was measured at 575 nm. Enzyme activity was expressed as nmoles of galacturonic acid liberated per second per gram of fresh tissue ($nkatal \cdot g_{fresh\ tissue}^{-1}$).

Pectinmethylesterase activity (PME)

PME activity was carried out following the method of Sawamura et al. (1978). A 100 mg of tissue was homogenized at 2°C with 1 ml mixture of 10% NaCl, 1% EDTA-disodium salt and 1% PVP (polyvinylpyrrolidone). The homogenate was adjusted to pH 7.0, allowed to stand for 30 min (2 °C) and centrifuged (20,000 *x* g) for 10 min. The supernatant was filtered through a filter paper and used directly for the PME activity assay. The reaction mixture, containing 2 ml 1% pectin solution, 0.5 ml 1 M NaCl, 0.1 ml extract and 1 ml distilled water was warmed over a water-bath (30°C) and adjusted to pH 7.5 with constant stirring. The amount of 0.1 N NaOH required to maintain the pH strictly at 7.5 after every 15 min indicates the enzyme activity. Enzyme activity was expressed in $pkatal \cdot g_{fresh\ tissue}^{-1}$.

Respiration

The fruit respiration was assessed by the collection of CO_2 according to a methodology described by Wills et al. (1999) and Angueira et al. (2003). A kilogram of mangoes from each group was placed in hermetically sealed containers (three per treatment) of 3.5 L capacity, in which air fluxed ($3.5\ L \cdot min^{-1}$) during the entire period of the determination. Exhaust air was bubbled into a 5 N NaOH solution, which was then changed daily. Twenty milliliters of this solution was titrated with 1 N HCl, using phenolphthalein as indicator. The results were expressed in mg CO_2 produced/kg.

Data analysis

All determinations were performed in triplicate. The data obtained were analyzed by ANOVA and subsequent comparison of means by the Tukey test (alpha = 0.05), using the statistical software JMP® (The Statistical Discovery Software).

RESULTS

Physicochemical characteristics

The physicochemical characteristics of different treatments on Ataulfo mango fruits are shown in Table 1. It can be seen that after 18 days of storage, fruits of HCh^+ treatment had less weight loss, maintenance firmness, lower pH, and higher acidity than fruits of HCh^- treatment, with significant differences ($p < 0.05$) encountered. Throughout the study treatment, HCh^- had the highest physiological weight loss, different than other treatments ($p < 0.05$), and from day 9, the lowest pulp firmness, even when on the third day of treatment it had the highest strength (165.6 N).

Furthermore, the physicochemical characteristics of fruits in treatment HCh^+ were similar to fruits that were not subjected to hydrothermal treatment (Treatment Ch^-) although, both were exceeded by the fruits coated with chitosan and not subjected to hydrothermal process (Treatment Ch^+).

Enzymatic activity

PG activity

After hydrothermal process, in both tissue of fruits, peel and pulp to which the chitosan coating was applied, the PG activity was lower ($p < 0.05$) than in the fruits subjected only with the hydrothermal process (HCh^-), as shown in Table 2. Thus, after 21 days of storage, the fruits of HCh^- treatment had, in peel and pulp, respectively, 1.43 and 1.32 times more activity of PG than the HCh^+ treatment fruits.

Meanwhile, PG activity in the peel and pulp of fruits HCh^+ treatment was, respectively, 11 and 13% lower than Ch^- treatment fruits, and 8 and 23% higher than the fruits of treatment Ch^+.

PME activity

During storage of the Ataulfo mango, the activity of PME in their peel and pulp was similar (data not shown). Moreover, after 21 days of storage, the fruits coated with chitosan after hydrothermal treatment (Treatment HCh^+) showed 35.7% lower PME activity in relation to the activity observed in chitosan coated fruits subjected to hydrothermal process (Table 3). The observed difference was statistically significant ($p < 0.05$).

Moreover, PME activity in fruits of HCh^+ treatment, after 21 days of storage, was 13.1% lower than in the fruits of Ch^- treatment and 19% higher than in the fruits of treatment Ch^+.

Peel color

As storage time elapsed, the chromaticity of the fruits

Table 1. Physicochemical characteristics of mango fruits "Ataulfo" variety, stored for 21 days at 22 ± 1°C and 80 ± 5% RH.

Time (days)	Treatment	Weight loss (%)	Firmness (N)	Soluble solids (°Bx)	pH	Acidity as citric acid (%)
3	HCh^-	4.4±0.30^a	165.6±7.8^a	10.7±0.2^a	2.99±0.04^{ab}	0.53±0.02^a
	HCh^+	3.2±0.10^b	134.3±5.3^b	10.9±0.5^a	2.94±0.01^b	0.50±0.01^a
	Ch^-	3.7±0.24^b	159.4±6.5^a	9.13±0.5^b	3.05±0.01^a	0.52±0.03^a
	Ch^+	3.4±0.11^b	164.4±7.5^a	10.2±0.1^a	2.92±0.06^b	0.46±0.02^b
6	HCh^-	6.4±0.05^a	35.6±8.3^c	12.5±0.4^{ab}	3.35±0.01^b	0.46±0.01^a
	HCh^+	5.7±0.22^{ab}	53.0±1.8^b	12.1±0.3^b	3.48±0.06^a	0.45±0.01^{ab}
	Ch^-	5.5±0.17^b	32.8±4.7^c	13.0±0.4^a	3.40±0.04^{ab}	0.42±0.01^b
	Ch^+	5.2±0.26^b	69.4±6.7^a	10.2±0.3^c	2.98±0.06^c	0.42±0.02^{ab}
9	HCh^-	9.0±0.70^a	14.4±2.0^d	15.3±0.3^b	4.05±0.11^a	0.14±0.01^c
	HCh^+	8.2±0.01^{ab}	42.5±1.3^b	12.5±0.6^c	3.09±0.08^b	0.45±0.01^{ab}
	Ch^-	7.2±0.17^{bc}	26.8±1.0^c	16.0±0.2^a	4.19±0.07^a	0.13±0.01^c
	Ch^+	6.2±0.38^c	55.0±7.9^a	15.0±0.2^b	3.09±0.09^b	0.37±0.03^b
12	HCh^-	11.7±0.64^a	10.4±1.1^d	18.2±0.2^a	4.76±0.04^a	0.06±0.01^c
	HCh^+	8.5±0.14^c	21.6±2.1^c	17.4±0.1^{ab}	3.50±0.04^c	0.25±0.03^b
	Ch^-	10.2±0.49^b	25.2±1.6^b	18.3±0.9^a	4.32±0.18^b	0.06±0.01^c
	Ch^+	8.5±0.82^c	45.6±10.1^a	15.8±0.3^b	3.34±0.06^d	0.31±0.01^a
15	HCh^-	14.1±0.58^a	8.2±2.5^c	19.1±0.5^a	4.92±0.04^a	0.05±0.01^b
	HCh^+	12.9±0.39^{ab}	17.3±1.2^b	19.5±0.5^a	3.33±0.23^c	0.20±0.03^a
	Ch^-	11.4±0.71^{bc}	16.4±1.1^b	18.0±0.3^b	4.53±0.19^b	0.06±0.01^b
	Ch^+	10.1±0.10^c	35.6±6.7^a	16.3±0.2^c	3.44±0.22^c	0.20±0.04^a
18	HCh^-	21.9±0.20^a	5.2±1.3^c	19.2±0.6^a	5.33±0.04^a	0.05±0.01^b
	HCh^+	13.6±0.45^{bc}	9.9±0.8^b	19.5±0.3^a	3.89±0.20^c	0.17±0.03^a
	Ch^-	15.0±0.34^b	11.0±0.7^b	18.5±0.3^b	5.02±0.06^b	0.05±0.01^b
	Ch^+	12.1±0.71^c	33.3±8.8^a	17.4±0.5^c	3.55±0.07^d	0.19±0.04^a
21	HCh^-	22.5±0.64^a	5.0±0.8^d	21.5±0.2^a	5.47±0.04^a	0.04±0.01^b
	HCh^+	15.0±0.16^{bc}	8.13±0.6^b	20.6±0.1^a	5.30±0.02^b	0.04±0.01^b
	Ch^-	16.7±0.18^b	6.5±0.4^c	20.3±0.3^{ab}	5.25±0.11^b	0.04±0.01^b
	Ch^+	14.3±0.31^c	22.5±3.5^a	18.2±0.5^b	4.04±0.21^c	0.17±0.05^a

Statistical analysis was conducted independently for each variable and for each sampling day. Values with the same letters within the column and sampling day are statistically equal.

were in the quadrants -a*+b* and +a*+b*, indicating that they went from a green to a yellow color tone, typical of Ataulfo mango. After 21 days of storage, the C value of the fruits of HCh^+ treatment was lower and statistically different ($p < 0.05$) than the fruits of HCh^- treatment (Table 4A). Also, the C value of the fruits of treatment HCh^+ was statistically similar ($p > 0.05$) to that in the fruits of treatment Ch^+, and the C value of the fruits of treatment HCh^- were similar ($p > 0.05$) to that in treatment Ch^-. In these latter were found, on average, 9.42 units more of chromaticity than in the first.

Also, the color tone in all treated fruits decreased according to storage time (Table 4B). At the end of the storage period (21 days), the fruit color tone of HCh^+ treatment was higher than the fruits of HCh^- treatment. The difference was statistically significant ($p < 0.05$). Similarly, the tone of the HCh^+ treatment fruits was 4.23°Hue less than the Ch^+ treatment fruits, and 4.51°Hue greater than the Ch^- treatment fruits.

Pulp color

The color components, tone and chromaticity, of the pulp

Table 2. Polygalacturonase activity in the peel and pulp (nKatal $g_{fresh\ tissue}^{-1}$) in mango fruit "Ataulfo", stored for 21 days at 22 ± 1°C and 80 ± 5% RH.

Tissue	Treatment	Storage days						
		3	6	9	12	15	18	21
Peel	HCh-	2.74±0.04^{a}	3.50±0.10^{a}	5.16±0.12^{a}	5.03±0.13^{a}	5.86±0.10^{a}	6.25±0.12^{a}	6.32±0.12^{a}
	HCh+	2.47±0.05^{c}	2.94±.07^{c}	4.10±0.11^{c}	4.47±0.09^{c}	4.56±0.11^{c}	4.52±0.15^{c}	4.41±0.12^{c}
	Ch-	2.66±0.02^{b}	3.14±0.05^{b}	4.36±0.14^{b}	4.66±0.08^{b}	4.74±0.11^{b}	5.62±0.13^{b}	4.97±0.11^{b}
	Ch+	2.37±0.03^{d}	2.40±0.03^{d}	3.60±0.15^{d}	3.62±0.21^{d}	4.18±0.12^{d}	3.66±0.11^{d}	4.04±0.14^{d}
Pulp	HCh-	1.56±0.05^{a}	1.91±0.01^{a}	4.19±0.05^{a}	4.25±0.10^{a}	4.74±0.11^{a}	4.97±0.12^{a}	5.09±0.21^{a}
	HCh+	1.30±0.02^{c}	1.79±0.01^{c}	3.27±0.11^{c}	3.56±0.12^{c}	3.68±0.13^{c}	3.97±0.11^{c}	3.86±0.14^{c}
	Ch-	1.45±0.03^{b}	1.85±0.02^{b}	3.61±0.02^{b}	4.00±0.08^{b}	4.21±0.14^{b}	4.43±0.12^{b}	4.44±0.11^{b}
	Ch+	1.21±0.05^{d}	1.39±0.09^{d}	2.73±0.15^{d}	3.20±0.10^{d}	3.01±0.20^{d}	2.98±0.13^{d}	2.94±0.15^{d}

Statistical analysis was conducted independently for each tissue type and for each sampling day. Values with the same letters within the column and tissue type are statistically equal.

Table 3. Pectinmethylesterase activity (pKatal $g_{fresh\ tissue}^{-1}$) in mango fruit "Ataulfo" variety, stored for 21 days at 22 ± 1°C and 80 ± 5 RH.

Treatment	Storage days						
	3	6	9	12	15	18	21
HCh^{-}	316.0±2.1^{a}	626.0±6.7^{a}	865.0±5.3^{a}	1294.0±7.4^{a}	1434.5±9.9^{a}	1333.3±13.8^{a}	1392.3±12.9^{a}
HCh^{+}	201.5±1.2^{d}	357.0±8.6^{c}	644.0±2.8^{c}	888.5±8.9^{c}	801.0±5.2^{c}	899.0±8.5^{c}	895.0±7.3^{c}
Ch^{-}	312.0±1.7^{b}	535.0±10.1^{b}	831.0±9.3^{b}	1070.0±6.8^{b}	1044.5±10.2^{b}	1050.5±12.8^{b}	1160.8±12.5^{b}
Ch^{+}	205.0±1.5^{c}	334.0±3.3^{d}	637.0±3.0^{d}	791.8±5.3^{d}	787.5±6.6^{d}	733.0±9.4^{d}	725.0±9.1^{d}

Statistical analysis was conducted independently for each sampling day. Values with the same letters within the column are statistically equal.

Table 4. Peel color of fruits mango "Ataulfo" variety, stored for 21 days at 22 ± 1°C and 80 ± 5% RH. I) C values. II) °Hue values.

Treatment	Storage days						
	3	6	9	12	15	18	21
				I			
HCh^{-}	45.4±0.2^{a}	49.3±3.1^{a}	57.8±0.1^{a}	55.7±0.1^{a}	57.5±0.1^{a}	59.4±0.6^{a}	59.8±0.9^{a}
HCh^{+}	43.6±0.1^{ab}	44.7±0.9^{a}	44.3±0.6^{b}	42.8±0.2^{c}	43.3±0.1^{b}	46.4±0.6^{c}	49.1±0.9^{b}
Ch^{-}	41.9±1.0^{b}	46.1±2.1^{a}	53.7±0.8^{a}	57.2±0.3^{a}	56.6±0.7^{a}	57.3±0.5^{b}	57.4±0.5^{ab}
Ch^{+}	42.0±1.4^{ab}	43.5±1.3^{a}	44.0±2.1^{b}	45.1±1.2^{b}	45.1±1.2^{b}	45.3±0.1^{c}	49.0±0.9^{b}
				II			
HCh^{-}	104.1±1.0^{a}	91.2±0.1^{b}	79.0±0.7^{c}	77.1±0.1^{d}	74.7±0.1^{c}	71.4±0.3^{d}	71.0±0.4^{d}
HCh^{+}	104.1±0.8^{a}	102.1±1.3^{a}	98.5±1.0^{a}	90.4±1.0^{b}	86.1±0.1^{b}	84.0±1.2^{b}	80.2±0.1^{b}
Ch^{-}	106.6±1.8^{a}	93.6±0.5^{b}	82.5±0.5^{b}	79.1±0.1^{c}	76.1±0.7^{c}	74.3±0.3^{c}	75.7±0.3^{c}
Ch^{+}	105.5±2.0^{a}	103.2±0.7^{a}	101.0±1.7^{a}	98.8±0.3^{a}	96.4±0.4^{a}	86.8±0.1^{a}	84.4±1.9^{a}

Statistical analysis was conducted independently for each sampling day. Values with the same letters within the column are statistically equal.

showed a similar behavior to that of the peel, that is, the °Hue decreased and the C value increased, although the changes were less pronounced. This way, during the time of storage, the ºHue of the pulp in the fruits of the treatment HCh^{+} diminished from 92.1 to 79.1 while, in the fruits of the treatment HCh^{-} it diminished from 92.8 to

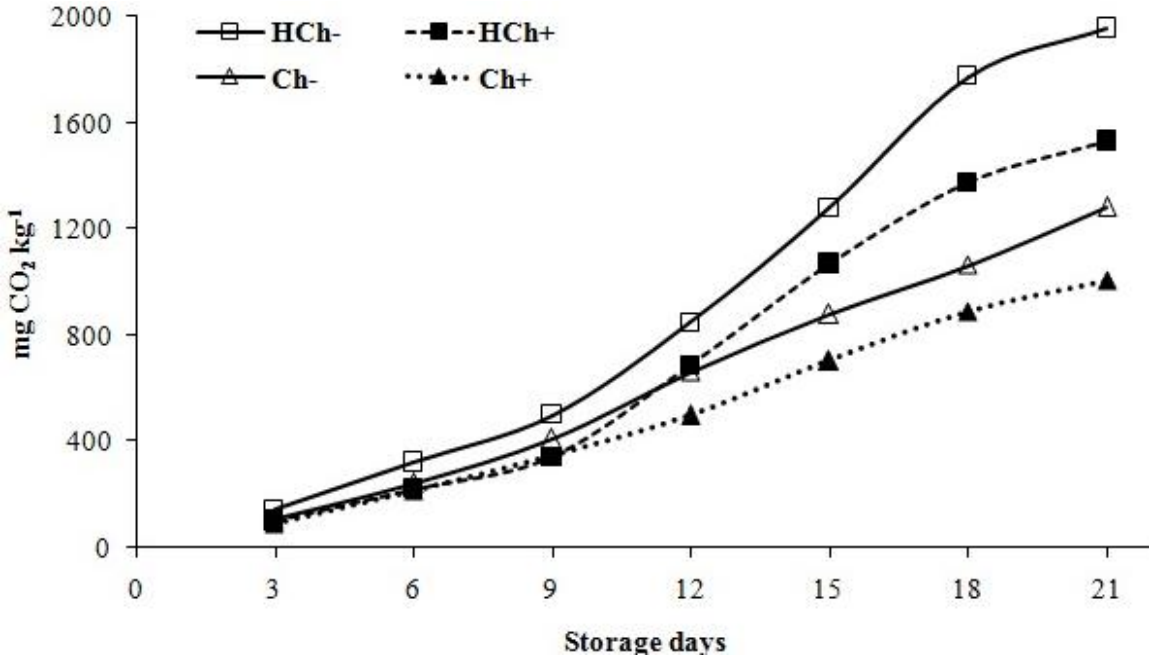

Figure 1. Accumulation of CO_2 from mango fruits "Ataulfo" variety stored at 22 ± 1ºC, and 80 ± 5% RH.

70.9. On the other hand, the value C of the fruits of those treatments increased from 52.0 to 69.3 and of 53.0 at 67.3, respectively.

In turn, the tone value of treatments Ch^- and Ch^+ fruits decreased from 91.6 to 73.6 and 92.4 to 82.7ºHue, respectively, while the C value increased from 57.1 to 70.0 and from 57.1 to 65.6, respectively.

Accumulated CO_2 (respiration)

The CO_2 produced during the 21-day storage of Ataulfo fruits in the different treatments of this study is shown in Figure 1. At the end of storage, the fruits of HCh^+ treatment produced 423.23 mg kg^{-1} (21.6%) less CO_2 than the fruits of HCh^- treatment.

On the other hand, the fruits of treatment HCh^+ produced 249.71 (16.3%) and 527.17 (34.4%) mg kg^{-1} more CO_2 than the fruits of treatment Ch^- and Ch^+, respectively, resulting in statistically different values ($p < 0.05$).

DISCUSSION

To commercialize the Ataulfo mango, hydrothermal treatment is an essential requirement, however, this treatment accelerated the ripening process of the fruit, as evidenced by weight loss and firmness (Table 1) and CO_2 produced (Figure 1). Osuna et al. (2002) reported similar effect of hydrothermal treatment on the firmness (decrease from 15 to 2 kgf in 4 days) of fruits of the same variety stored at 25°C. Like Perez et al. (2003), Osuna et al. (2002) understand that the greatest fruit softening subject to hydrothermal process was due to changes in the activity of enzymes that hydrolyze the cell wall. In this sense, we found that activities of PME and PG were higher in the fruits of the HCh^- treatment (Tables 2 and 3) and has a high logarithmic correlation (R = 0.84) between PME and PG activities to fruit firmness (data no shown). Therefore, the enzymatic complexes participation or other structural polymer-degrading enzymes as hemicelluloses and pectin (glucanases and galactosidases) that cause chemical changes (pH) and structural wall cell (Ali et al., 2004) and to a lesser degree of amylolytic enzymes (Chien et al., 2007) could explain the softening of fruits and other ripening processes associated as TSS increase, pH increased, lower titratable acidity, color changes, and respiration observed in fruits subjected to hydrothermal process (Tables 1, 2, 3, 4 and Figure 1).

Another factor that may help explain the observed is the structure destabilization of the cuticle cells may be involved in greater moisture loss (Table 1) and increased rate of gas exchange. This argument was used by Luna et al. (2006) to explain the results found in the same variety of mango cultivated in the Mexican state of Colima, subjected to hydrothermal process and stored for 9 days at 20ºC and 60% RH.

Moreover, the results of this study show that application of chitosan-based coating to fruits subjected to hydrothermal process reduces both metabolic processes and damage to the cellular structure of the cuticle (compare the values of the different variables between the fruits of HCh^+ treatment and HCh^- treatment in Tables

1, 2, 3, 4 and Figure 1). However, the decrease in the activity enzymatic involved in pectin degradation (Tables 2 and 3), the minor loss firmness (Table 1), the slower rate of transition to the typical color range of Ataulfo variety (Table 4) and reduced CO_2 production observed in the fruits without hydrothermal process coated with chitosan, suggest that these effects are due to changes in gas exchange processes, rather than the attenuation of damage to the cellular structure of the cuticle. In this sense, several authors demonstrated that chitosan films function as a barrier to O_2 (Casariego et al., 2009; Sathivel et al., 2007; Miranda et al., 2004) and that property is not evident with CO_2 (Casaringo et al., 2009). Also, it has been reported that O_2 permeability of the films of chitosan depends on water content (Despond et al., 2001), temperature (Liu et al., 2008, El-Azzami and Grulke, 2007) and acid that was dissolved (Casariego et al., 2009, Park et al., 2002; Caner et al., 1998). From what has been said, in chitosan films has been reported selectivity coefficients (CO_2/O_2) ranging from 1.25 (Despond et al., 2001) to 16.97 (Miranda et al., 2004). Considering this, the chitosan film applied to both the fruits without hydrothermal process as fruits with hydrothermal process reduced the transfer of O_2 in 27.4% (selectivity coefficient of 1.274 ± 0.002). On the other hand, the application of hydrothermal treatment increased the production of CO_2 in 52.3% (Figure 1). Considering the selectivity of chitosan films, the observed delay in the generation of color in the fruits coated with chitosan may be the result of the decrease in ethylene synthesis because its production depends on the presence of O_2 (Taiz and Zeiger, 2007).

The results reported by Wang et al. (2007), who found lower decrease in the firmness of the fruits of Tainong mango without hydrothermal process and coated with chitosan, by Zhu et al. (2008), who reported that chitosan coated Tainong mangoes without hydrothermal process had lower color tone after 16 days of storage and Bégin et al. (2004), who found between 30 and 50% lower rate of respiration in mango fruits coated with chitosan, seem to support the hypothesis that gas exchange is the factor that attenuates the process of fruit ripening.

Preliminary data obtained in our laboratory (unpublished) show that indeed chitosan coating decreases oxygen transfer, so that as well as reducing the ripening process of mango fruits, this coating could prevent the development of the immature stages of the fruit fly since these results demonstrate that indeed mangos coated with chitosan and artificially infested do not develop symptoms of the presence of immature stages of fruit fly.

Based on the results presented in this work, we can conclude that the application of a chitosan-based coating on the fruits of mango Ataulfo variety put through hydro-thermal process will reduce the metabolic processes induced by the increase in temperature, and that this coating could be an alternative to increase its shelf life

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