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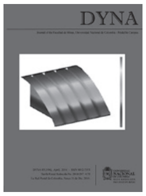

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Viscoelastic behavior of yellow pitahaya treated with 1-MCP

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Abstract
Foods may have both solid and liquid properties, and are described as viscoelastic products. Knowledge on such viscoelastic features is very useful for quality control and/or food stability. The purpose of this work was to evaluate the effect of the application of 1-MCP on the viscoelastic properties of minimally processed yellow pitahaya during refrigeration storage, by using a stress relaxation test. Viscoelastic parameters were determined through Generalized Maxwell and Peleg's rheologic models. Both rheological models proved suitable to predict viscoelastic behavior; however, Peleg's model better described this behavior. Samples of treated and non-treated pitahaya with 1-MCP decreased their elastic behavior (firmness decrease) during storage. Fruit treated with 1-MCP showed a greater elastic component than non-treated samples during storage. These two rheological models were suitable for predicting the viscoelastic behavior, however

Keywords: Stress relaxation; Generalized Maxwell; Peleg; *Selenicereus megalanthus.*

Comportamiento viscoelástico de pitahaya amarilla tratada con 1-MCP

Resumen
Los alimentos pueden exhibir características de sólido y de líquido y se describen como productos viscoelásticos. El conocimiento de las propiedades viscoelasticas es muy útil para el control de la calidad y/o estabilidad de los alimentos. El objetivo de este trabajo fue evaluar el efecto de la aplicación de 1-MCP sobre propiedades viscoelásticas de muestras de pitahaya amarilla mínimamente procesada durante el almacenamiento en refrigeración, empleando la prueba de esfuerzo de relajación. Los parámetros viscoelásticos se determinaron mediante los modelos reológicos de Maxwell Generalizado y Peleg. Estos dos modelos reológicos fueron apropiados para predecir el comportamiento viscoelástico, sin embargo, el modelo de Peleg describió mejor este comportamiento. Las muestras de pitahaya tratada y no tratadas con 1-MCP disminuyeron su comportamiento elástico (disminución de firmeza) durante el almacenamiento. La fruta tratada con 1-MCP presentó mayor componente elástico que las muestras no tratadas durante el almacenamiento.

Palabras clave: Esfuerzo de relajación; Maxwell generalizado; Peleg, *Selenicereus megalanthus*.

1. Introduction

Yellow pitahaya is a cactus from tropical and sub-tropical America, that belongs to the group of promising fruit for plantation [1]. It is included in the ten most promising fruits for exportation from Colombia [2,3].

Before 1989, Japan was the main destination of yellow pitahaya; exports were suspended due to the presence of Mediterranean fruit fly (*Ceratitis capitata*) larva, resulting in a reduction in production [4]. In order to mitigate the impact of this suspension, Protocol T106 was signed in January 2008, this protocol allows for the importation of minimally processed pitahaya into the United States, taking into account that this process removes the risk of the presence of Mediterranean fruit fly in the fruit.

Minimally processed products are one of the fastest growing areas in the food industry. However, cutting fruit results in a decrease in shelf life [5], changes to texture and a reduced firmness of the cell wall[6,7]. These changes set limits to storage time resulting in a shorter shelf life [8].

The mechanical and / or textural properties of foods are important for quality control and consumer acceptance [9-11]; these properties are one of the four main quality features of foods [12]. Foods, which exhibit both liquid and solid properties, are described as viscoelastic products [13]. Most foods behave as a viscoelastic material under given levels of applied stress and

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within certain time scales [14]. In order to study the viscoelastic behavior of foods it is important to learn about rheological properties, which study the science of flow and deformation of matter [15]. Various rheologic models are used to represent materials and predict their viscoelastic behavior [16]. Such models include various combinations of Hookean solid elements (springs), and elements of Newtonian flow (dashpot) [17]. One of the tests used to establish a foods viscoelastic behavior is stress relaxation [16,18]. This test consists of subjecting a piece of food to a constant load for a determined period of time, in which such stress significantly decreases [19,20]. In addition, it allows for the definition of parameters such as relaxation time, elasticity and viscosity modules [21]. Results of stress relaxation analysis are important because they provide information on firmness, acceptation and processing of fruit [12], and predict changes of material during manipulation [16]. This test is widely used to establish foods viscoelastic properties, and their experimental values are mainly adjusted by Maxwell and Peleg's models [13,16,20].

1-Methylcyclopropene (1-MCP) is a compound that inhibits ethylene action both on whole fruit and cut fruit; it has been demonstrated to have the potential to reduce the softening of minimally processed products such as pineapple [22], melon 'Galia' [23], kiwi fruit [24,25], mango 'Kent' and 'Keitt', marmalade fruit 'Fuyu' [24], and pear 'Blanquilla' [25]. Application of 1-MCP on minimally-processed yellow pitahaya, may represent an alternative to reduce changes to texture during storage [25].

The purpose of this work is to evaluate the effect of applying 200 µgL-1 of 1-MCP on the viscoelastic properties of minimally-processed yellow pitahaya samples during refrigerated storage, by using a stress relaxation test.

2. Methodology

2.1. Raw Material

Yellow pitahaya at ripeness stage 3 [26], from the municipality of Roldanillo, Valle del Cauca, Colombia was used. Harvested fruit pieces were classified, washed with current water, hygenized with chlorated water (200 µgL^{-1}), washed with distillate water and dried at room air.

2.2. Preparation and application of 1-MCP

A powder formulation of 1-MCP (3.8% w / w) supplied by Rohm and Haas Chemical Ltd. (Philadelphia, Pennsylvania) was used. Solutions of 40 L of 1-MCP at a concentration of 200 µgL^{-1} were prepared using distillate water. Selected fruit pieces were submerged for 10 min into the solution, then they were washed in distillate water for 5 min (to remove excess of 1-MCP), and dried at room air.

2.3. Minimal processing, packaging and storage

Previously 1-MCP treated and non-treated (control) fruit pieces were transversely cut at a thickness of 1.0 ± 0.1 and a diameter of 6 cm, using a mechanical cutting machine Javar (model GE 250, Cali, Colombia). They were vacuum packed, in a low density polyamide and polyethylene coextruded flexible packaging, 70-micra thick and permeability at O_2 39 cm^3 m-^{2} day-1 Atm-1 at 23°C permeability at CO2 of 107 cm3 m-2 day-^{1} Atm-^{1} at 23°C and permeability at water vapor of 10.2 g cm^3 m-^{2} day-^{1} Atm-^{1} at 38°C. Bags were sealed using a sealing strength of 1.5 Kg cm^{-1} at 160°C per 3 s. The packed fruits were stored for 16 days in an environmental chamber (1000 L Dies, Colombia) at 10 ± 1°C and 85% relative humidity.

2.4. Stress relaxation

At each storage period of time, samples were removed from the climate chamber. Disks 4 cm in diameter were then cut out from the slices by using a cork borer. Such slices were tested for stress-relaxation by using a texturemeter (EZ-Test, Shimadzu, USA), adapted to a 6-cm cylindrical plate. The samples were placed on an aluminum base lubricated with liquid paraffin to prevent effects from friction[20], and compressed at 0.8 mm (8% initial height), at a compression velocity of 10 mm/min. This stress compression was kept constant for 600 s.

2.5. Relaxation modeling

Stress-relaxation experimental values (stress-time) were adjusted to generalized Maxwell (Ec. 1) and Peleg (Ec.2) models. For Ec. 1 three elements were used, where ε_i is the elastic module of element i, θ_i is the time relaxation of element i and $\sigma(t)$ is the stress for one time t.

$$\sigma(t) = \varepsilon_0 + \varepsilon_1 * e^{\left(\frac{-t}{\theta 1}\right)} + \varepsilon_2 * e^{\left(\frac{-t}{\theta 2}\right)} \quad (1)$$

The model is composed of two Maxwell elements and a spring in parallel. Each Maxwell element consists of a Newtonian dashpot in series with a Hookean spring [13]. Constants of a generalized Maxwell model were obtained by non-linear regression (Levenberg-Marquard), using an SPSS 11.5 program for Windows (SPSS Inc, Chicago, 2002).

Peleg and Normand proposed Ec 2, which may be adjusted through linear regression, were σ_0 is the initial stress, σ the stress of each time t during relaxation process, k1 is the reciprocal of initial decrease of velocity and k2 is an hypothetic value of normalized asymptotic force [15] [16].

$$\frac{\sigma_0 t}{\sigma_0 - \sigma} = k1 + k2t \quad (2)$$

These non-dimension constants are related to the elasticity of material subject to stress relaxation, and were obtained through linear regression with Microsoft® Office Excel 2007.

2.6. Experimental design

A completely randomized factorial design 2x4 was used, with two factors: Concentration of 1-MCP solution with two levels: 0 and 200 µgL^{-1}, where 0 is the control treatment (without 1-MCP application), and storage time with 4 levels

0, 4, 12, and 16 days. The effect of 1-MCP concentration and storage time was determined by analyzing the variance (ANOVA) at 5% probability using the Statgraphics software version Demo (Minitab Inc., State College, PA, 2007). All determinations were performed in triplicate.

3. Results

3.1. Analysis of relaxation

Fig. 1 shows typical curves of stress relaxation of pitahaya samples at various days of storage. In all treatments the relaxation curve decreased in function of storage time.

3.2. Relaxation modeling

Maxwell model constants for treated and non-treated samples during storage are shown in Table 1.

A good adjustment of experimental values is seen, showing an R^2 variation between 0.989 and 0.996, which shows that the Maxwell model is suitable for predicting experimental results. Elasticity constants of module ε_o, ε1 and ε_2 associated to the 3 springs of Maxwell, did not show any pattern of trend in the viscoelastic analysis of pitahaya samples during storage. On day 4 treated samples showed lower values in elastic models compared to the control, indicating minor elastic behavior, or minor firmness, but on day 12 it was inverse showing more elastic component than the control. On day 16 only the elastic module ε_2 showed a higher value in samples treated with 1-MCP. Significant differences between the control and 200 $\mu g.L^{-1}$ 1-MCP application were observed in all the elastic module (ε_i) and the first time relaxation (θ_1) ($p < 0.05$); the second time relaxation was not affected ($p > 0.05$).

In terms of relaxation time constants, (θ_1 and θ_2), associated to viscous behavior or liquid phase of foods [13], it was observed that control treatment showed minor values (except for θ1 on day 4). This fact means that at less relaxation time, the material dissipates faster due to the imposed load, indicating a behavior more similar to liquid (less firmness) than to solid [27]. Therefore, according to these relaxation times, samples treated with 1-MCP showed higher values of solidity, perhaps due to minor degradation of pectins and hemicellulose by the effect of decreasing enzymatic activity [28].

This behavior is the same as behavior reported in uniaxial compression tests of yellow pitahaya treated with 200 μgL^{-1} of 1-MCP during storage [29,30].

Table 1.
Maxwell generalized model constants for samples treated with 200 μgL^{-1} of 1-MCP and control during storage

Treatment	**ε_0 (Pa)**	**ε_1 (Pa)**	**θ1 (s)**	**ε_2 (Pa)**	**θ2 (s)**	**R^2**
Day 0 200	2988.74	1280.10	11.62	789.10	220.85	0.995
Control	2988.74	1280.10	11.62	789.10	220.85	0.995
Day 4 200	2782.78	1566.15	9.68	912.39	230.10	0.996
Control	4428.79	2180.89	10.88	1295.50	214.97	0.995
Day 12 200	2737.15	1578.93	10.01	923.59	219.34	0.995
Control	2425.97	1357.80	9.64	597.35	189.73	0.993
Day 16 200	2087.04	1177.47	11.37	699.51	588.61	0.989
Control	2425.97	1357.72	9.65	597.34	189.74	0.993

Source: The authors.

Table 2.
Constants of Peleg's model for fruit treated with 200 μgL^{-1} of 1-MCP and control during storage

Time	Control			200 $\mu g\ L^{-1}$		
(Days)	k_1	k_2	R_2	k_1	k_2	R2
0	68,8	2,27	0,999	68,8	2,27	0,999
4	68,8	2,16	0,999	70,2	2,07	0,999
12	54,7	2,16	0,999	62,6	2,06	0,999
16	53,9	2,16	0,999	72,9	2,08	0,997

Source: The authors.

According to the above results relaxation time parameter is more suitable than elasticity modules εo, ε1 and ε2 to describe viscoelastic behavior of pitahaya samples treated and non-treated with 1-MCP during storage. Table 2 shows rheological constants (k1 and k2) of Peleg's model. Correlation coefficients (R_2) for control samples varied between 0,9987 and 0,9993 and for treated samples between 0,9984 and 0,9993. These values show that Peleg´s model fits the experimental values better than Maxwell´s model.

It can be seen that k1 parameter decreases in control treatment from 68.8 to 53.9 during storage, while in the samples treated with 1-MCP no trend is seen. The reciprocal of K1 constant of Peleg's model depicts the initial decay rate during relaxation time [13]; therefore a decrease of this parameter is an indication of stress relaxation decline, associated with minor firmness. This table shows that the application of 1-MCP

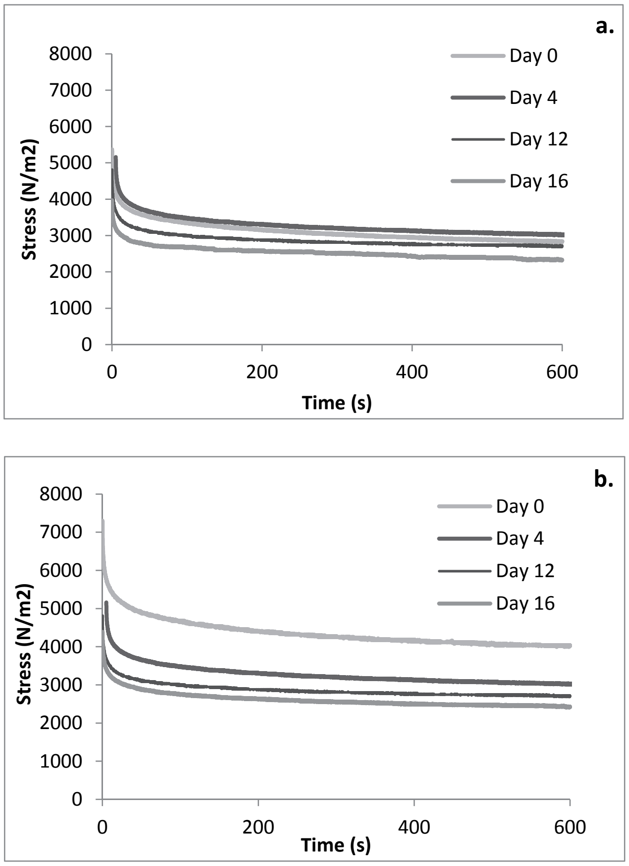

Figure 1. Relaxation curve of pitahaya slices (a) treated with 1-MCP and (b) control in function of storage time.
Source: The authors.

increased k1 values compared to the control during storage ($p<0.05$), which means that the application of 1-MCP decreased stress relaxation reduction, associated with a more elastic or solid material. This behavior may be attributed to the fact that 1-MCP impacted enzymatic activity decrease, and consequently a lower degradation of fruit pectins and hemicelluloses is achieved [28].

Parameter k2 represents material solidity degree when $k_2 \rightarrow \infty$ is considered an ideal elastic solid [16]. A slight decrease of this parameter during storage may be seen in both treatments, associated with a mild loss of solidity or firm,ess of samples. This result may be due to a low weight loss because of dehydration of the fruit [31]. However, the ANOVA did not show any significant difference ($p>0.05$). No significant difference was observed, ($p>0.05$) when comparing control treatment and samples with an application of 1-MCP, with values relatively close varying between 2.06 and 2.27. This result indicates that parameter k2 was not suitable to describe fruit viscoelastic properties.

The results demonstrate that during storage of slices of yellow pitahaya, the viscoelastic properties were more sensitive to the viscous component (relaxation times and K1), than to the elastic component (elastic modules and K2). This behavior may be explained by using minimally processed fruit with the characteristics of fresh fruit, therefore its viscous component was predominant.

4. Conclusion

Yellow pitahaya samples treated and non-treated by applying 200 μgL-1 of 1-MCP decreased their elastic behavior (firmness decrease), due to the effect of storage time in refrigeration, perhaps due to natural and irreversible degradation of pectins and hemicelluloses. The application of

200 μgL-1 of 1-MCP positively impacted fruit elastic behavior, showing more elasticity or solidity than non-treated samples (control) during storage, in relation to increasing relaxation time in the Maxwell model, and higher k1 values in the Peleg model. It was shown that Maxwell's and Peleg's rheologic models are suitable to predict the viscoelastic behavior of minimally processed yellow pitahaya samples; however, Peleg's model showed the best adjustments of experimental values. The stress relaxation test may become a useful tool to evaluate the viscoelastic behavior of yellow pitahaya samples during storage in refrigeration.

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