Research

The use of active modified atmosphere for the conservation of minimally processed eggplant

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ABSTRACT

The aim of this work was to evaluate effects of different gas concentrations (O_2 and CO_2) on conservation of minimally processed eggplants. The eggplants were sanitized, processed and packed in nylon + transparent polyethylene. The vegetables were submitted to modified atmospheres (T1= atmospheric air; T2= vacuum; T3= 4% O_2 and 5% CO_2; T4= 4% O_2 and 6% CO_2; T5= 4% O_2 and 7% CO_2; T6= 4% O_2 and 8% CO_2). The minimally processed eggplants were kept at 5±1°C and 90±1% RH, for 10 days. After 0, 2, 4, 6, 8 and 10 days of storage, fresh weight loss, respiratory rate, color, soluble solids (SS), titratable acidity (TA), pH, SS/TA ratio, visual analysis and purchase intent were determined. We used completely randomized experimental design, in a factorial scheme 6x6 (atmosphere x days of conservation). The atmosphere with higher CO_2 concentration (8%) reduced the respiratory rate more intensely. The minimally processed eggplant maintained at 4% O_2 + 6% CO_2 obtained better grades on the visual analysis and purchase intention, with 10-day storage period. The vacuum was not recommended to keep minimally processed eggplant refrigerated under the studied conditions.

Keywords: *Solanum melongena*, quality, storage.

RESUMO

Atmosfera modificada ativa na conservação de berinjela minimamente processada

Objetivou-se estudar o efeito de diferentes concentrações de gases (O_2 e CO_2) na conservação de berinjela minimamente processada. As berinjelas foram higienizadas, processadas e embaladas em nylon + polietileno transparente. Foram submetidas a atmosfera modificada (T1= ar atmosférico; T2= vácuo; T3= 4% O_2 e 5% de CO_2; T4= 4% O_2 e 6% de CO_2; T5= 4% O_2 e 7% de CO_2; T6= 4% O_2 e 8% de CO_2). As berinjelas minimamente processadas foram mantidas a 5±1°C e 90±1% de UR, por 10 dias. Aos 0, 2, 4, 6, 8 e 10 dias de conservação foram determinadas perda de massa fresca, taxa respiratória, coloração, sólidos solúveis (SS), acidez titulável (AT), pH, relação SS/AT, análise visual e intenção de compra. O delineamento experimental utilizado foi inteiramente casualizado, em esquema fatorial 6x6 (atmosfera x dias de conservação). A atmosfera com maior concentração de CO_2 (8%) reduziu mais intensamente a taxa respiratória. A berinjela minimamente processada mantida a 4% O_2 + 6% CO_2 obteve melhores notas na análise visual e intenção de compra no período de 10 dias. O vácuo não foi recomendado para manter refrigerada berinjela minimamente processada nas condições estudadas.

Palavras-chave: *Solanum melongena*, qualidade, conservação.

Eggplant (*Solanum melongena*) is an important non-climacteric vegetable largely consumed fresh and wholesome. About 30 millions of tons are produced worldwide (Li *et al*., 2014). It is considered a low-calorie and low-fat vegetable, a good source of minerals, vitamin B-complex, and phenolic compounds, being also consumed due to its medicinal properties (Shukla & Naik, 1993). As most fresh products, a growing interest in this vegetable, minimally processed, has been noticed, due to practicality and convenience in meal preparation, product uniformity and reduced post-harvest losses (Russo *et al*., 2012).

Minimally processed vegetables of fresh fruits, ready to be cooked, show to be convenient and do not have their nutritional and functional properties changed, when compared to fresh product. Despite the advantages in terms of convenience and freshness, cutting and slicing vegetables may lead to quality losses, resulting in water loss, softening, microbiological contamination, changes in chemical composition and production of secondary metabolites. Moreover, increasing respiration and enzymatic activity can be verified, reducing the product shelf life. The main limiting factor which reduces eggplant life is the oxidation of phenolic compounds

by polyphenol oxidases (PPOs), which causes browning and, consequently, the depreciation of the final product quality (Ghidelli *et al*., 2014).

The fast discoloration immediately after cutting is an impediment in its minimal processing. One of the main methods in order to delay these physiological, biochemical and microbiological reduction processes on the crop is the use of modified atmosphere (Fonseca *et al*., 2002; Li *et al*., 2014; Steffens *et al*., 2009; Vieites *et al*., 2014).

Active modified atmosphere aims to decrease the metabolism of the product, consequently its senescence, through

partial oxygen reduction and an increase in carbon dioxide concentration; allied with refrigerated storage, this technique is considered a less costly alternative, resulting in an extended shelf life (Steffens *et al.*, 2009; Vieites *et al.*, 2014). It also seems to be a convenient alternative to delay physiological, biochemical and microbiological reduction processes (Arruda *et al.*, 2011). The effect of low O_2 concentration and high CO_2 concentration to control enzymatic browning and make shelf life longer has been positively reported for several minimally processed fruits and vegetables (Rojas-Grau *et al.*, 2009), including eggplants (Moretti & Pineli, 2005). According to the reports, 2% of O_2 is the critical concentration to possibly cause anaerobic respiration, considering that this limit depends on the product used. However, for fresh eggplants, Catalano *et al.* (2007) reported that, although the modified atmosphere improves quality preservation during conservation at 4°C, an increase in CO_2 and a decrease in O_2 inside the packaging can stimulate PPO activity of the product. Responses for different atmospheres depend mainly on the product used, temperature and storage time. For eggplants, the results found in literature are still scarce. Thus, the aim of this study was to evaluate the effect of different O_2 and CO_2 concentrations in minimally processed eggplant.

MATERIAL AND METHODS

Eggplant cv. Ciça was grown on a property in Campinas, São Paulo State, taken to the laboratory of Faculdade de Ciências Agronômicas, UNESP, and selected. The authors eliminated samples showing physical and biological damages aiming to obtain a uniform lot.

After washed in running water in order to take off dirt from harvest and transport, the samples were immersed into sodium hypochlorite solution (200 mg L^{-1}) for 20 minutes. Then, the eggplants were sliced in 1.5-cm thick pieces, eliminating inedible parts. After cutting, the samples were placed in a solution containing 50 mg L^{-1} of sodium hypochlorite for 20 minutes; afterwards, they were drained, rinsed under running

water and immersed into citric acid solution (2%) for 10 minutes, in order to prevent browning.

Slices were drained using a colander for 3 minutes and placed in a centrifuge (Consul), for 40 seconds at 2800 rpm. Right after, portions of 150 grams were packed in plastic containers (vacuum) of nylon + transparent polyethylene of high oxygen barrier (10 cm^3 day^{-1}) and water vapor (5 m^2 day^{-1}), afterwards submitted to modified atmosphere, with application of gases provided by White Martins Gases. Each cylinder was purchased with the appropriate gas mixture for each treatment: T1= atmospheric air, T2= vaccum, T3= 4% O_2 + 5% CO_2, T4= 4% O_2 + 6% O_2, T5= 4% O_2 + 7% CO_2 and T6= 4% O_2 + 8% CO_2. The process consisted of formation of vacuum followed by gas injection and sealing using a vacuum packaging machine (Tec Maq). Control treatment was sealed with ambient air, and then the packages were stored in a cold chamber at 5±1°C temperature and 90±1% relative humidity, for 10 days. At 0, 2, 4, 6, 8 and 10 days, three replicates were taken from each treatment and analysed: fresh weight loss, respiratory rate, color, soluble solids (SS), titratable acidity (TA), pH, SS/TA ratio, visual analysis and purchase intent.

Fresh weight loss was calculated using the mass differences of experimental units, being the initial weight of packaging of the minimally processed eggplants used as reference, with the aid of an analytical scale, with 5 replicates and the results expressed in percentage (%).

Respiratory curve was obtained by titration. Respiratory rate was determined indirectly in a respirometer, measuring CO_2 released, following the methodology adapted by Bleinroth *et al.* (1976). Respiratory rate was calculated using the equation:

$$TCO_2 = \frac{2.2x(A-B)xV1}{PxTxV2} \quad \text{(Equation 1)}$$

where TCO_2= respiratory rate in mL of CO_2 kg of fruit^{-1} hour^{-1}; A= the amount of volume of standardized HCl used as a tritant of standard potassium hydroxide, before CO_2 absorption (white); B= the amount of volume of

standardized HCl used as a tritant of potassium hydroxide after respiration CO_2 absorption; V1= the amount of volume of potassium hydroxide used in CO_2 absorption (mL); P= mass of minimally processed eggplants (kg); T= metabolic reaction time (hour); V2= the amount of volume of potassium hydroxide used as tritant (mL); 2.2= related to the equivalent to CO_2 (44/2), multiplied by the concentration of 0.1 N hydrochloric acid.

Soluble solids were determined by direct reading using a table refractometer, type Palette PR–32, with temperature correction to 20°C, and results expressed in %. Titratable acidity was determined in eggplant pulp through titration with 0.01N NaOH solution and phenolphthalein indicator and results expressed in g citric acid 100 g^{-1} pulp according to the recommendation of Instituto Adolfo Lutz (Brasil, 2008). The hydrogenion potential (pH) was obtained using the digital potentiometer model DMPH-2 Digimed.

Color was determined at two points, peel and pulp, using Konica Minolta colorimeter model CR400, to determine values (L*, Croma and *Hue*) (Minolta, 1998).

Visual analysis of minimally processed eggplant was done by 32 non-selected and untrained panelists, using subjective scoring scale taking into consideration the product appearance, where 1= very bad, showing fungi (rot); 2= bad, dark and fungus-free; 3= regular, opaque color and fungus-free (suitable for market); 4=- good, dull and fungus-free; 5= excellent, firm and normal color, being 3 the market acceptance limit. In order to evaluate purchase intent, the authors used 5-point scale according to Meilgaard *et al.* (1999), where 5= definitely would buy; 4= may buy; 3= maybe would buy/maybe wouldn't buy; 2= probably wouldn't buy and 1= definitely would not buy.

The experiment was carried out in a completely randomized design, in a factorial scheme 6x6 (atmosphere x days of storage). Percentage values for fresh mass loss were transformed to arcsin square root values (x/100); in order to make the table, original values

were presented, though. The data were submitted to analysis of variance and means compared using Tukey test, at 5% probability. Regression analysis was done for storage time.

RESULTS AND DISCUSSION

Respiratory rate at 6-day post-harvest storage for eggplants stored in air was higher than in other atmospheric conditions, reaching 288.5 mL CO_2 kg^{-1} h^{-1}(Figure 1). On day 10, the authors verified low respiratory rate for all treatments. Decreasing in respiratory activity after climacteric peak is a result of reaction inactivation of enzymes present in the cells on the cut surface with respiratory substrates (Kluge *et al*., 2014), or due to the change in glycolysis route, synthesis, degradation, inactivation or inhibition of certain enzymes which take part in this metabolic route (Araújo *et al*., 2005). Similar behavior was reported by Kluge

et al. (2014) for minimally processed yellow bell pepper. Vacuum and higher oxygen atmospheric (8%) treatments showed the lowest respiratory rate, with maximum values close to 107.8 mL CO_2 kg^{-1} h^{-1}. In overall means for mass loss, the values were significantly lower than in 6 and 7% CO_2 treatments (Table 1), which anticipated the climacteric peak in relation to the control (at 2-day storage). Theoretically, the use of higher CO_2 concentrations decreases respiratory rate, controls physiological changes and, concomitantly, reduces weight loss of the product (Toivonen & Dedell, 2002), which corroborates the results found in this study.

Regardless of the atmosphere used in this study, mass loss of minimally processed eggplant was only influenced in storage. A linear increasing was verified (Figure 1), possibly in response to the stress caused by the cut during processing, resulting in an increase in respiratory activity (carbohydrate consumption via glycolysis). This

increasing mass loss in minimally processed vegetables was also verified for other crops, such as pumpkin (Russo *et al*., 2012) and beet (Kluge *et al*., 2006) stored under active modified atmosphere.

A decrease in soluble solids (SS) was verified, overall mean of 4.37%. This reduction may be related to resource consumption for metabolic reactions as well as respiration of minimally processed eggplant. In relation to titratable acidity, a decrease in all treatments was observed (30 to 43%) (Table 2). The authors observed pH changes along the days (Figure 2). However, a small increase was observed at the end of storage period, mainly for the control which showed, in overall mean, significantly higher value comparing to the other treatments (under active modified atmosphere) (Table 1). The pH values are used as an indicator of the microbiota in food for preserving. Thus, pH values lower or equal to 4.5 do not favor the presence of *Clostridium botulinum* and other pathogenic bacteria (Hoffmann, 2001). Rinaldi *et al*. (2009) and Kluge *et al*. (2014) cited that some studies report that pH value can increase in response to an increase in microbiota during storage. This phenomenon is characteristic in vegetables deteriorated by Gram-negative bacteria, since protein breakdown results in a release of basic compounds (Jacxsens *et al*., 2013). Maturation index, obtained by SS/AT ratio, is a variable which indicates maturation and quality of the material to be analyzed during post-harvest (Chitarra & Chitarra, 2005). Using the results of regression in table 2, the authors noticed that on day 6 of storage the values reached higher level and then this level tends to fall. Nevertheless, control treatment showed higher values of maturation index since day 4 of storage. In the same conditions, opposite behavior was reported by Russo *et al*. (2012), who verified a decrease in SS/AT ratio in all treatments throughout storage, working with minimally processed pumpkin during 12-day storage.

For peel luminosity (Table 3), significant regression was noticed only for the vacuum treatment, considering

Table 1. Means of mass loss (%) and pH values among treatments of minimally processed eggplants packed under active modified atmosphere during a 10-day storage. Botucatu, UNESP, 2015.

Treatments	Mass loss (%)						
	Days of storage						
	0	2	4	6	8	10	Mean
Control	0	0.05	0.05	0.09	0.11	0.07	0.06 ab
Vacuum	0	0.00	0.00	0.01	0.05	0.09	0.02 b
4% O_2 + 5% CO_2	0	0.03	0.02	0.06	0.12	0.16	0.06 ab
4% O_2 + 6% CO_2	0	0.07	0.06	0.10	0.16	0.22	0.10 a
4% O_2 + 7% CO_2	0	0.04	0.27	0.12	0.12	0.17	0.12 a
4% O_2 + 8% CO_2	0	0.02	0.00	0.01	0.06	0.10	0.03 b
CV (%)	-	-	-	-	-	-	67.0

Treatments	pH						
	Days of storage						
	0	2	4	6	8	10	Mean
Control	4.38	4.88	5.02	5.25	5.18	5.12	4.97 a
Vacuum	4.38	4.56	4.71	4.77	4.57	4.57	4.59 bc
4% O_2 + 5% CO_2	4.38	4.44	4.54	4.88	4.60	4.89	4.62 bc
4% O_2 + 6% CO_2	4.38	4.59	4.70	4.96	4.85	4.78	4.71 b
4% O_2 + 7% CO_2	4.38	4.63	4.62	4.72	5.02	4.70	4.68 bc
4% O_2 + 8% CO_2	4.38	4.53	4.57	4.60	4.48	4.58	4.52 c
CV (%)	-	-	-	-	-	-	3.6

*Means followed by same lowercase letter in column do not differ significantly by Tukey test (p <0.05).
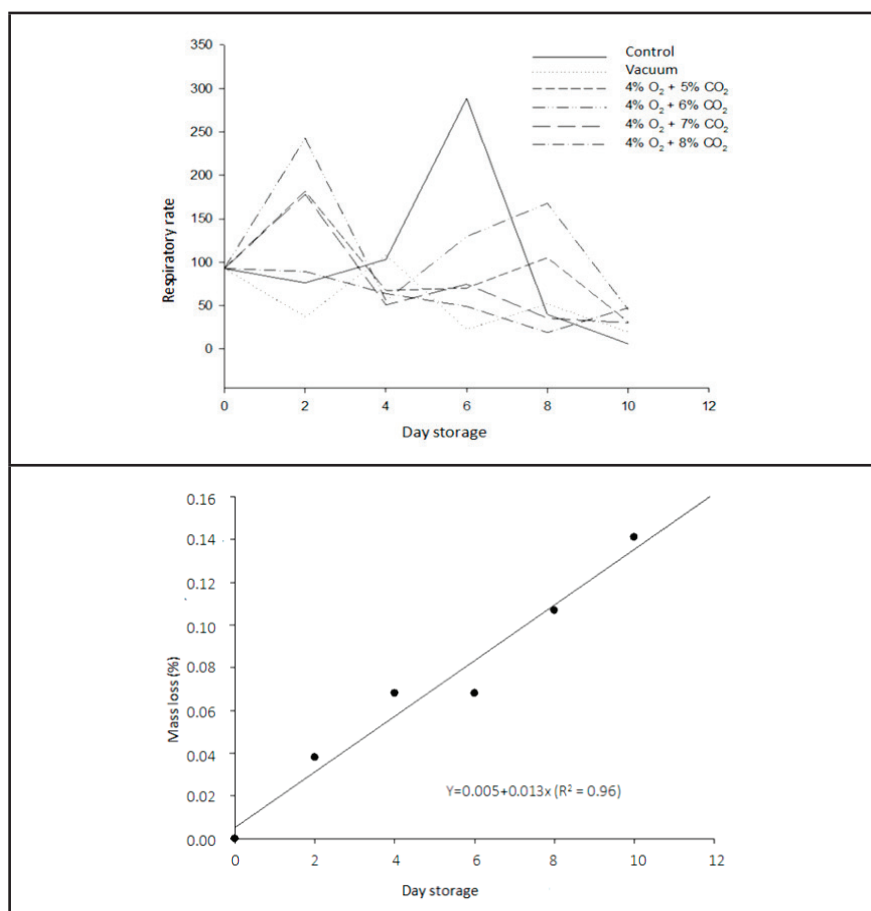
Figure 1. Respiratory rate (mL CO_2 kg^{-1} h^{-1}) among the treatments of minimally processed eggplant packed under active modified atmosphere and mass loss (%) during a 10-day storage. Botucatu, UNESP, 2015.

that from processing up to the end of storage period, it ranged from 27.2 to 45.4, making the peel brighter. This increase may be the result of cellular juice accumulated into the vacuum packaging, since this treatment was the one which the most depreciate vegetable quality during storage. According to Arruda *et al.* (2003), luminosity distinguishes light from dark colors. This attribute ranges from zero for dark colors to 100 for light colors. The lower this value, the greater the degree of depreciation of the product appearance.

For pulp, the authors noticed effect only in storage, with values decreasing for luminosity (Figure 2), ranged from 87.8 to 80.2, resulting in a loss of 8.7% at 10-day storage. This loss in brightness is a consequence of product depreciation, highlighting pulp darkening, corroborating Rinaldi *et al.* (2009), who working with cabbage and modified atmospheres cited reduction of 8.13% in luminosity during 16-day storage. On the other hand, Russo *et al.* (2012), in minimally processed pumpkin in active modified atmosphere, did not observe significant differences for pulp luminosity.

Regression of peel chroma (Table

Table 2. Regression equations for soluble solids (%), titratable acidity (g citric acid 100 g pulp^{-1}), and maturation index between treatments of minimally processed eggplant packed under active modified atmosphere during a 10-day storage. Botucatu, UNESP, 2015.

Variable	Treatment	Equation (x= storage)	R²
Soluble solids (%)	Control	Y= 5.13 - 0.224x + 0.013x²	0.49
	Vacuum	Y= 5.13 - 0.519x + 0.092x²- 0.005x³	0.84
	4% O_2 + 5% CO_2	Y= 5.06 - 0.249x + 0.015x²	0.89
	4% O_2 + 6% CO_2	Y= 5.04 - 0.553x + 0.117x²- 0.007x³	0.75
	4% O_2 + 7% CO_2	Y= 5.06 - 0.638x + 0.121x²- 0.007x³	0.87
	4% O_2 + 8% CO_2	Y= 4.91 - 0.119x	0.82
Titratable acidity (g of citric acid 100 g^{-1})	Control	Y= 0.33 - 0.08x + 0.011x² - 0.0005x³	0.91
	Vacuum	Y= 0.34 - 0.08x + 0.012x² - 0.0006x³	0.66
	4% O_2 + 5% CO_2	Y= 0.34 - 0.04x + 0.002x²	0.70
	4% O_2 + 6% CO_2	Y= 0.33 - 0.05x + 0.003x²	0.86
	4% O_2 + 7% CO_2	Y= 0.33 - 0.05x + 0.004x²	0.83
	4% O_2 + 8% CO_2	Y= 0.33 - 0.05x + 0.003x²	0.83
Maturation index	Control	Y= 15.95 + 3.92x - 0.22x²	0.88
	Vacuum	Y= 15.21 + 3.28x - 0.27x²	0.42
	4% O_2 + 5% CO_2	Y= 15.63 + 1.18x	0.48
	4% O_2 + 6% CO_2	Y= 14.26 + 4.43x - 0.31x²	0.69
	4% O_2 + 7% CO_2	Y= 14.23 + 4.07x - 0.28x²	0.62
	4% O_2 + 8% CO_2	Y= 14.71 + 3.66x - 0.31x²	0.69

Table 3. Regression for peel luminosity, chroma of peel and pulp and peel color (*Hue* values) among treatments of minimally processed eggplant packed under active modified atmosphere during a 10-day storage. Botucatu, UNESP, 2015.

Variable	Treatment	Equation (x= storage)	R^2
Peel luminosity	Control	ns	ns
	Vacuum	Y= 26.42 - 0.367x + 0.162x²	0.89
	4% O_2 + 5% CO_2	ns	ns
	4% O_2 + 6% CO_2	ns	ns
	4% O_2 + 7% CO_2	ns	ns
	4% O_2 + 8% CO_2	ns	ns
Peel chroma	Control	ns	ns
	Vacuum	Y= 5.96 + 0.154x + 0.181x²	0.92
	4% O_2 + 5% CO_2	ns	ns
	4% O_2 + 6% CO_2	ns	ns
	4% O_2 + 7% CO_2	ns	ns
	4% O_2 + 8% CO_2	ns	ns
Pulp chroma	Control	ns	ns
	Vacuum	Y= 24.79 - 0.959x + 0.590x²- 0.05x³	0.94
	4% O_2 + 5% CO_2	ns	ns
	4% O_2 + 6% CO_2	ns	ns
	4% O_2 + 7% CO_2	ns	ns
	4% O_2 + 8% CO_2	ns	ns
Peel color	Control	ns	ns
	Vacuum	Y= 2.72 - 1.151x + 2.841x² - 0.200x³	0.86
	4% O_2 + 5% CO_2	Y= 4.30 + 3.597x - 0.347x²	0.78
	4% O_2 + 6% CO_2	ns	ns
	4% O_2 + 7% CO_2	Y= 0.587 + 7.939x - 0.745x²	0.42
	4% O_2 + 8% CO_2	Y= 0.683 + 6.599x – 0.579x²	0.41

3) was significant only in vacuum treatment. The eggplants stored in this system showed higher color saturation, with values ranging from 6.4 to 25.3. Hue angle (peel) in vacuum treatment ranged from 2.76 to 78.3, changing from red-violet to orange. However, using joint analysis for chroma and luminosity values and according to Minolta (1998), a color change from a very dark violet red to dirty orange was noticed. The other treatments kept the color during shelf life. In relation to pulp chroma (Table 3), the vacuum treatment lost color saturation, making the color lighter. Pale yellow color (*hue* pulp) of the eggplant slices was kept during the shelf life (103.2 to 93.3), regardless the treatment (Figure 2). Contrary, in a study with minimally processed pumpkin, the vacuum treatment kept the best color for the product (Silva *et al.*, 2009). Given the above, the authors concluded that the vacuum treatment showed a darker pulp color and that the peel of those slices lost the purple color typical of this cultivar, making it reddish. This statement was confirmed by the results of visual analysis and purchase intention (Table 4), the slices stored in vacuum packaging obtained the worst grades for visual analysis (1.5) and the lowest purchase intention (1.1), being classified as terrible and certainly would not buy.

Color is the most attractive quality attribute when buying eggplant.

Table 4. Regression for visual analysis (grades) and purchase intention (grades), among treatments of minimally processed eggplant packed under active modified atmosphere during a 10-day storage. Botucatu, UNESP, 2015.

| Variable	Treatment	Equation (x= storage)	R^2
Visual analysis (grades)	Control	Y= 5.00 - 1.129x + 0.217x² - 0.013x³	0.99
	Vacuum	Y= 4.99 - 1.37x + 0.182x² - 0.007x³	0.99
	4% O_2 + 5% CO_2	Y= 4.99 - 0.996x + 0.142x² - 0.007x³	0.95
	4% O_2 + 6% CO_2	Y= 5.00 - 0.821x + 0.141x² - 0.007x³	0.99
	4% O_2 + 7% CO_2	Y= 5.00 - 0.800x +0.151x² - 0.009x³	0.99
	4% O_2 + 8% CO_2	Y= 4.89 - 0.323x + 0.016x²	0.95
Purchase intention (grades)	Testemunha	Y= 5.00 + 1.196x - 0.232x² + 0.014x³	0.99
	Vácuo	Y= 5.00 + 1.374x - 0.185x² - 0.009x³	0.99
	4% O_2 + 5% CO_2	Y= 4.94 - 0.666x + 0.041x²	0.96
	4% O_2 + 6% CO_2	Y= 4.95 - 0.504x + 0.038x²	0.85
	4% O_2 + 7% CO_2	Y= 4.94 - 0.370x + 0.018x²	0.94
	4% O_2 + 8% CO_2	Y= 5.00 - 0.811x + 0.145x² - 0.009x³	0.99
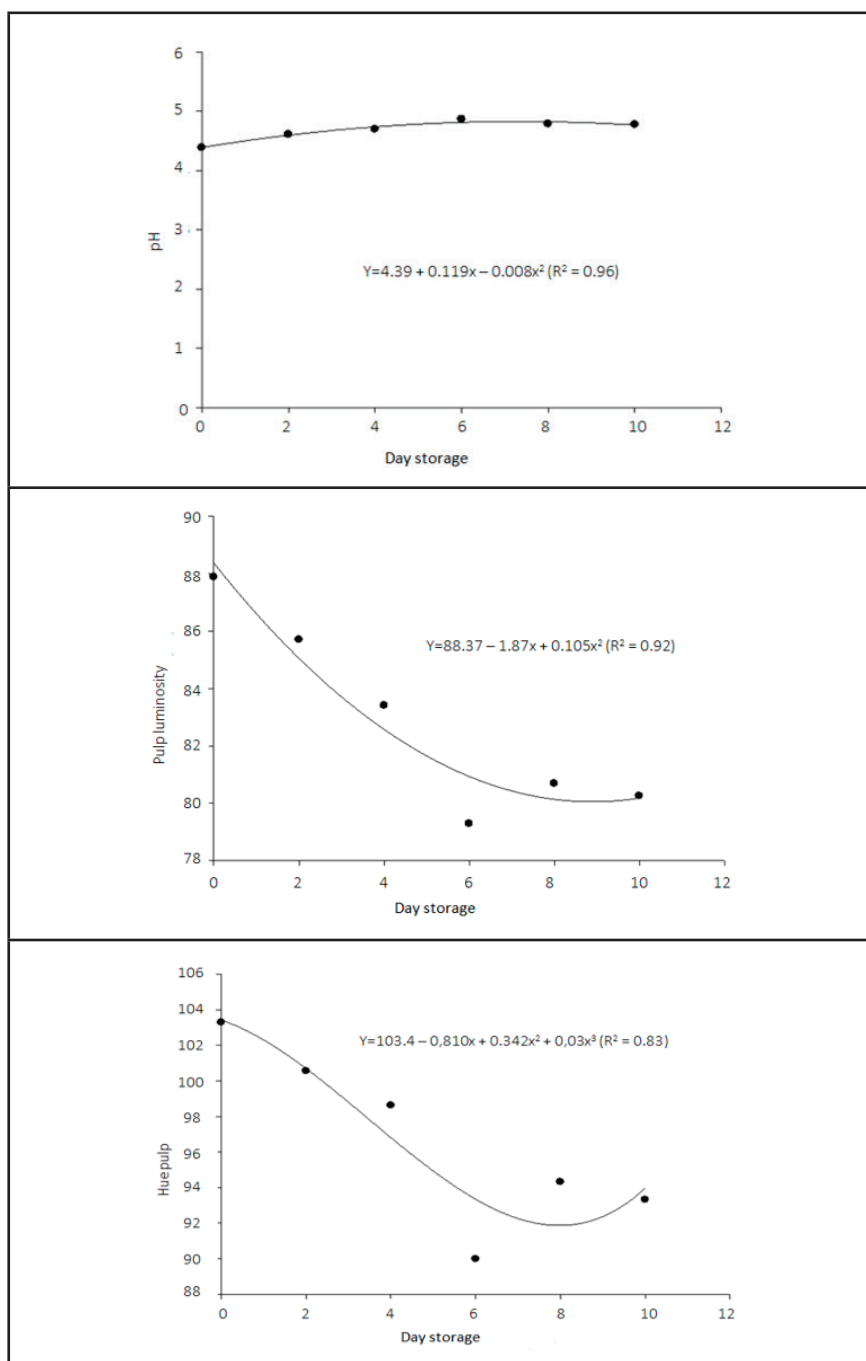
Figure 2. Values of pH, luminosity, hue of pulp for treatments of minimally processed eggplant packed under active modified atmosphere during a 10-day storage. Botucatu, UNESP, 2015.

Colorful and shining products are the most preferred, being an important characteristic in processed products (Chitarra & Chitarra, 2005; Miguel *et al.*, 2010). In visual analysis (Table 4), the eggplant packed in 6% CO_2 packaging obtained the best grades, reaching grade 3.9 (good) on day 10. The worst storage was observed in vacuum packaging, since it was classified as bad (1.9) on day 4, reaching a terrible grade, 1.5. For the other modified atmospheres, grades ranged from 2.5 to 3.1 (bad to regular). Miguel *et al.* (2010) stated that product preference test should be applied in order to know the taste and meet the demands of the consumer. Purchase intention showed the same behavior. The lowest purchase intention was related to the vacuum-packed product, from day 4 on, grade 1.9 (probably would not buy). Eggplants in active modified atmosphere, 6% CO_2, at the end of shelf life, obtained grade 3.5 (classified between probably would buy to maybe would buy). Dantas *et al.* (2005) mentioned the importance of market surveys before developing products or even improving existing products, aiming to identify market segments making it possible to improve marketing strategies.

Minimally processed eggplant, stored at 5°C temperature and 90% UR, kept in modified atmosphere (4% O_2 + 6% CO_2), obtained better grades in visual analysis and purchase intention during a 10-day storage period.

Vacuum packaging is not recommended to keep minimally processed eggplant. The eggplants were probably under anaerobic conditions.

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