EFFECT OF COMPOSITE EDIBLE COATING FROM *AMARANTHUS CRUENTUS* FLOUR AND STEARIC ACID ON REFRIGERATED STRAWBERRY (*FRAGARIA ANANASSA*) QUALITY

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***Abstract*— A composite coating from *Amaranthus cruentus* flour and stearic acid (10 g stearic acid/100 g flour, 26 g glycerol/100 g flour and stirring speed at 12000 rpm) was applied on fresh strawberries in order to verify the effect on its quality. Other treatments were effected to comparison: PVC film, bilayer coating of the optimized formulation, optimized formulation without stearic acid and a control group of fruits (not coated). Fruit quality was evaluated by weight loss, mold spoilage, firmness retention and surface color development. The weight loss increased with the storage time for all treatments and the firmness decreased, however, the optimized coating was the most effective for the firmness retention of fruits among the edible coatings studied (excepting PVC film). The same trend was observed for the surface color development; the optimized coating resulted in a minor increase in the ratio of chromaticity parameters (*a/b*) as a function of storage time.**

***Keywords*— edible coating, *Amaranthus cruentus* flour, stearic acid, strawberry quality.**

I. INTRODUCTION

Edible coatings have long been known to protect perishable food products from deterioration by retarding dehydration, suppressing respiration, improving the textural quality, helping retain the volatile flavor compounds and reducing the microbial growth (Debeaufort *et al.*, 1998). In this way, the application of edible coatings on fresh fruits like strawberries can provide an alternative method to extend the post-harvest life, reducing quality changes and quantity losses, and can also result in the same effect as modified atmosphere storage in modifying the internal gas composition (Park, 1999).

The types of materials used to elaborate edible coatings include lipids, resins, polysaccharides and proteins (Krochta and Mulder-Johnston, 1997). Each group of material has certain advantages and disadvantages and, for this reason, many coatings are actually formulations of any or all of the above (Baldwin *et al.*, 1997). The use of natural mixtures of protein, polysaccharides and lipids from agricultural sources, to take advantage of each of these components in a ready system, appears as a new opportunity of material in the area of edible films. Amaranth (*Amaranthus* spp.) is a tiny grain (~1 mm diameter) typical from South America. The *Amaranthus cruentus* specie presents a composition of 15-22% protein, 3.0-11.5% fat and 9-16% dietary fiber, depending on cultivation technique and environmental effects. The main constituent is starch, 48-62%, with small granule size (< 1μm), which can be easily dispersed and hence it may yield good properties of resultant films and coatings (Tosi *et al.*, 2001). These characteristics of composition makes the *Amaranthus cruentus* flour an interesting source of raw material for the edible film technology (Tapia *et al.*, 2005).

The aim of this work was to study the effect of a composite coating from *Amaranthus cruentus* flour and stearic acid on the quality maintenance of fresh strawberries under refrigeration.

II. METHODS

A. Raw material

Amaranth flour was prepared using the mature seeds of *Amaranthus Cruentus* cultivar "BRS Alegria", provided by Embrapa Cerrados (Brazilian Company of Agropecuary Research - Federal District - Brazil). After harvest the seeds were cleaned and stored at 20 ºC in sealed containers until tested. Flour was obtained using the modification of the alkaline wet milling method of Perez *et al.* (1993), such as proposed by Tapia *et al.* (2005). Glycerol and all chemicals used were reagent grade and were purchased from Synth (São Paulo, Brazil).

B. Preparation of Coating Formulation

The composite coating from *Amaranthus cruentus* flour and stearic acid studied in this work was prepared from an optimized formulation defined previously by Colla *et al.* (2006), using an experimental design (Central Composite Rotatable Design - 2^3 with 6 axial and 3 central points, resulting in a sum of 17 experiments). The optimized parameters of this formulation were stearic acid concentration (10g/100g of amaranth flour), glycerol concentration (26 g/100g of flour) and stirring speed in the step of stearic acid incorporation on the amaranth flour suspension (12000 rpm). The coating suspension was prepared using the following procedure: amaranth flour and distilled water (4.0 g/100 mL solution) was mixed until the temperature reached 50 ºC; then, the pH was adjusted for proteins solubilization (10.7 adjusted with NaOH 1.0 N) and the heating process continued until 80 ºC, when glycerol and stearic acid were added; after the lipid melting, the hot solution was immediately emulsified with an Ultra-Turrax homogenizer (IKA Works Brazil, model T18-Basic, Jacarepaguá, Brazil) for 3 min at 12000 rpm; the solution was cooled with an ice bath and kept under vacuum in order to remove air bubbles or any dissolved air, during approximately 3 h, before the application in the fresh strawberries.

C. Fresh Strawberries Preparation and Treatments

Strawberries (*Fragaria ananassa*) at commercial ripening stage, grown in greenhouses of a local farm, were harvested and immediately treated. Fruits of uniform size, free of physical damage and fungal infection were used. Strawberries were dipped in chlorinated water (0.25 g Cl_2/L), dried, dipped in the formulated suspensions (coatings) at room temperature and dried again with air (20 ºC and 85% RH). Five treatments were performed to coat fresh strawberries and to compare with the optimized coating formulation: 1 (control), the strawberries were dipped into distilled water for 1 min; 2 (PVC), fruits were individually covered with a thin PVC film (synthetic); 3 (optimized), the fresh strawberries were held with pliers and dipped into the optimized amaranth flour film-forming solution at room temperature for 1 min; 4 (bilayer of optimized), the fruits were dipped twice in the optimised formulation, in order to form a bilayer film over the strawberries (the first layer was dried for 1 h at 20 ºC before the application of the second layer); 5 (optimized without stearic acid), the fruits were dipped into an optimized formulation suspension elaborated without the stearic acid addition, in order to assess the global effect of the lipid in the coating. Then, the strawberries were stored in a chamber with air renewal and circulation with temperature and relative humidity controls (Marconi, model MA 415UR, Piracicaba, Brazil) at 7 ºC and 80% RH for 21 days.

D. Mold Spoilage

The loss of fruit due to mold growth was established by visual inspection on 3, 6, 9, 11, 14 and 18 days of storage and were considered infected when a visible lesion was observed. For each treatment, a group of 10 fruits was observed. The decay incidence was expressed as percentage of infected fruits (Han *et al.*, 2004).

E. Weight Loss

The same fruits used to verify the mold spoilage were weighed at the beginning of the experiment and at 3, 6, 9, 11, 14 and 18 days of storage. Weight loss was expressed as percentage loss of the initial total weight.

F. Firmness

Texture analysis was performed using a TA-XT2i Texture analyser (Stable Micro Systems, Surrey, England). The system was equipped with a compression cell of 5 kg and a cylindrical probe of 4.5 cm in diameter, moving at 1 mm/s until 80% of samples deformation. The probe with 4.5 cm in diameter was used to avoid the appearance of shearing forces during the test. Firmness was measured as the maximum penetration force (N) reached during tissue breakage. Strawberries of uniform size from which the calyces had been removed to obtain even surfaces, were used to determine the break force. A number of 7 strawberries per treatment were used for each storage time, which were 1, 3, 6, 10, 13, 16 and 18 days.

G. Surface Color Development

Strawberry surface color was evaluated with a Hunter Labscan colorimeter equipped with an optical sensor (ColorQuest II, Hunter Associates Laboratory, Fairfax, VA, USA) calibrated with an appropriate device to reduce sampling area. L^* (lightness), a^* (redness), and b^* (yellowness) values were registered after 1, 3, 6, 10, 13, 16 and 18 days of storage. For each fruit, three different sites were measured. As the ratio of chromaticity parameters (a/b) has been commonly accepted for describing color changes on post-harvest fruits and vegetables (McGuire, 1992), it was also calculated and reported in this study.

III. RESULTS AND DISCUSSION

A. Visual Coating Characterization

The coatings were well adhered to the strawberry surfaces. Regarding the transparency, the coating elaborated without stearic acid addition was transparent (treatment 5), but the coating elaborated with the optimized formulation (treatment 3) and the bilayer coating (treatment 4) was opaque yellowish. Comparing the control and coated strawberries at 1 and 21 days of storage (Fig. 1 - 5), all the strawberries shrank and lost their brightness. The control fruits (Fig. 1) and those coated with the bilayer treatment (Fig. 4) presented the greater shrinking. For the strawberries coated with the optimized formulation (Fig. 3), the original initial size was kept by a longer time in comparison to the other treatments, exception for the PVC treatment (Fig. 2), which resulted in the minor strawberry shrinking. By the visual analysis was possible to verify that the best quality was maintained until the day 16, for the strawberries coated with the optimized formulation, what it can be an indicative of its efficiency to delay the senescence process of the strawberries. According to Han *et al.* (2004), the shelf-life of fresh strawberries at cold temperatures (0 - 4 ºC) is usually less than 5 days.

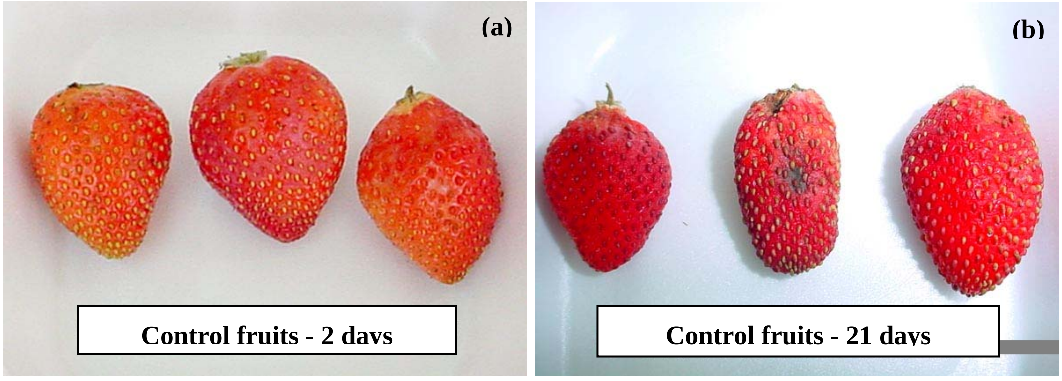

Figure 1. Strawberries not coated (Control) at 2 (a) and 21 days (b) of storage at 7 ºC and 80% RH.

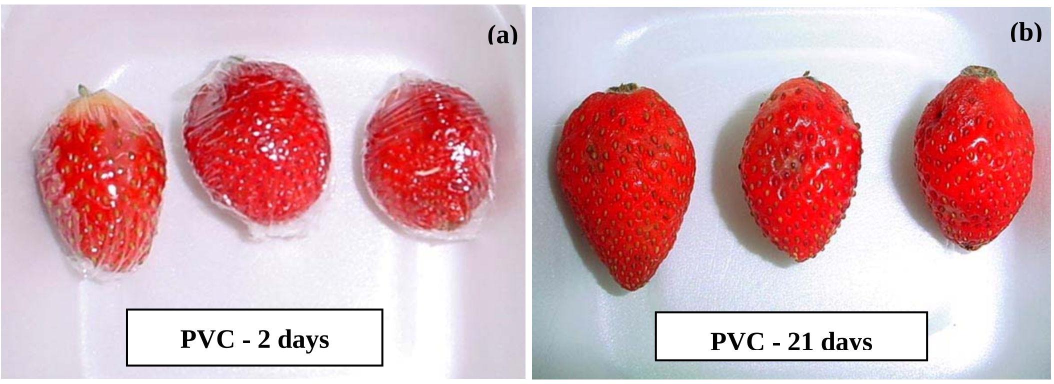

Figure 2. Strawberries coated whit PVC film at 2 (a) and 21 days (b) of storage at 7 ºC and 80% RH.

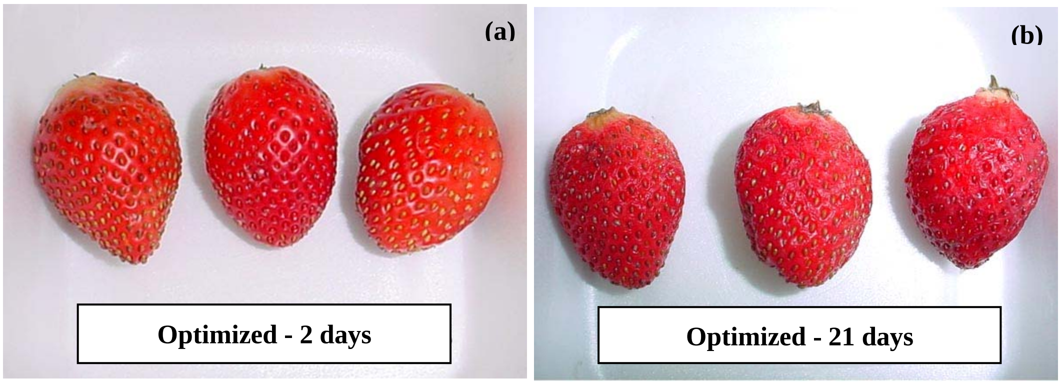

Figure 3. Strawberries coated whit the Optimized formulation at 2 (a) and 21 days (b) of storage at 7 ºC and 80% RH.

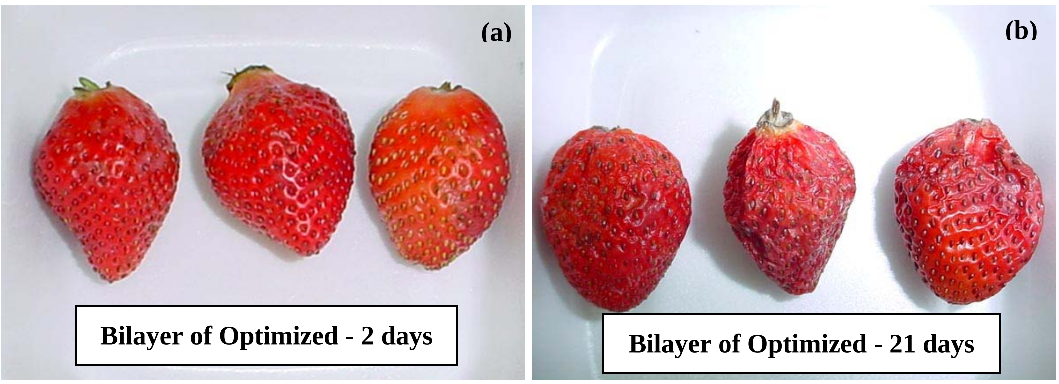

Figure 4. Strawberries coated whit the Bilayer of Optimized formulation at 2 (a) and 21 days (b) of storage at 7 ºC and 80% RH.

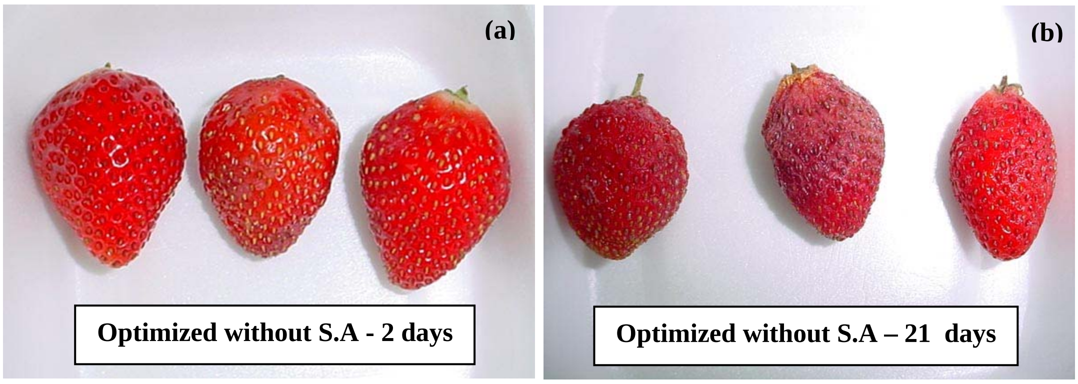

Figure 5. Strawberries coated whit the Optimized without stearic acid formulation at 2 (a) and 21 days (b) of storage at 7 ºC and 80% RH.

B. Mold Spoilage of Fresh Fruits

The results observed for the mold spoilage of the strawberries stored at 7 ºC and 80% RH are shown in Fig. 6. Strawberries are highly perishable fruit and have high physiological post-harvest activities, presenting short time of useful life after the harvest, due to the fungal attack, that promotes the appearance of dark points and texture loss (softening) in the attacked zones (García *et al.*, 1998; Ghaout *et al.*, 1991). Strawberries are also susceptible to water loss, bruising and mechanical injuries due to their soft texture and lack of a protective rind (Hernández-Muñoz *et al.*, 2006).

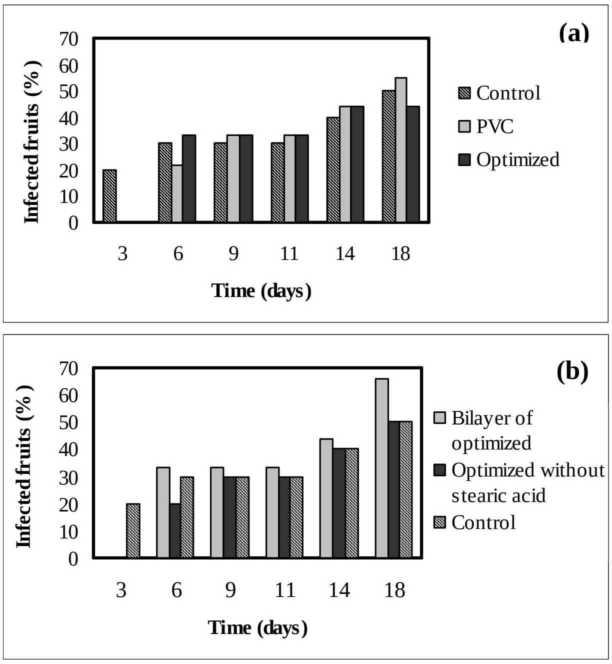

Figure 6. Effect of coatings on mold spoilage of fresh strawberries stored at 7 ºC and 80% RH: (a) Control group of fruits and treatments 2 and 3; (b) Control group and treatments 4 and 5.

It can be seen in Figure 6 that all treatments protected fruits against mold until 3 days of storage. However, the better protection against mold during the total storage time was observed for the coating elaborated with the optimized formulation, which presented 44% of infected fruits. After 18 days of storage, the fruits coated with the without stearic acid treatment presented 50% of infected fruits, as well as the group of fruits not coated (control). The fruits coated with the bilayer treatment had 66% of contaminated fruits. These results were statistically different (Tukey test, $p<0.05$). The better efficiency of the optimized coating against the strawberries spoilage was probably due to its low permeability to the O_2 (2.36×10^{-13} cm^3/m.s.Pa), determined in a previous work (Colla *et al.*, 2006).

According to Baldwin *et al.* (1995), the coating could affect the respiratory process of the fruits and water loss, through the reduction of the O_2 and CO_2 permeabilities (increase of the CO_2 concentration and reduction of the O_2 concentration) and consequent formation of an internal atmosphere in the fruits. Thus, the high rate of breath and production of ethylene of the fruits as the strawberries can be reduced by the application of half-permeable coatings. The half-permeability is an important characteristic that unable the formation of anaerobic conditions and development of capable microorganisms that grows in these conditions.

The application of the bilayer of optimized coating could have resulted in better conditions for mold growth (possible formation of cracks, increasing the contamination process); this could explain the greater percentage of infection for the fruits coated with this treatment.

C. Weight Loss

Normally, the weight loss occurs during the fruits storage due to its respiratory process, the transference of humidity and some processes of oxidation (Ayranci and Tunc, 2003). It can be observed in Fig. 7 that the weight loss increased with the storage time, for all treatments. However, the PVC and the optimized formulation coating significantly reduced the weight loss of strawberries during the storage period, compared to the control

($p<0.05$). In this way, the film formed on the surface of fruits delayed moisture migration from the fruits into the environment, thus reducing weight loss during the storage. The maximum weight loss observed for the strawberries coated with the optimized formulation was ~23%, after 18 days of storage. García *et al.* (1998) observed a similar result (~21% of weight loss) for strawberries coated with high amylose corn-based coating, after 30 days of storage at 0ºC.

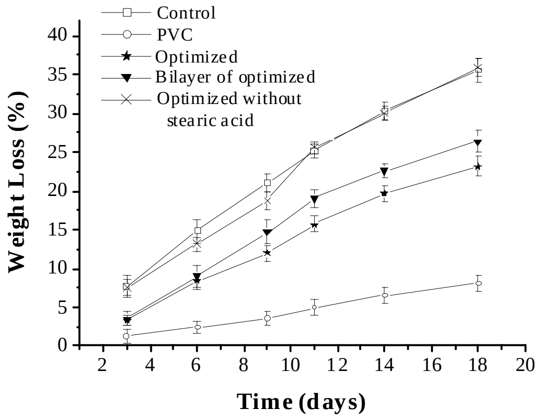

Figure 7. Effect of coatings studied on weight loss of fresh strawberries stored at 7 ºC and 80% RH. Vertical bars indicate standard deviation.

The bilayer coating treatment resulted in higher weight loss in comparison to the fruits coated with a single layer of the optimized formulation, after 11 days of storage (means statistically different, $p<0.05$). This result was unexpected, but could be explained by the possible formation of cracks in the coating, increasing the water vapor transference. The fruits coated without stearic acid presented similar weight loss compared with the control fruits ($p>0.05$) (~35% after 18 days of storage). Based on this result it can be suggested that the stearic acid had an important function in the coating, improving the barrier properties, especially the water vapor barrier, which can be confirmed by the results obtained with the optimized coating (~23% of weight loss after 18 days of storage). It must be pointed out that the water vapor permeability of the optimized films, determined in a previous work (Colla *et al.*, 2006), was 0.32 g.mm/m^2.h.kPa, which can be considered effectively as low, and could explain the better effect of the optimized coating in reducing the weight loss of the strawberries.

D. Firmness

Loss of texture is one of the main factors limiting quality and the postharvest shelf-life of fruit and vegetables. Strawberries soften considerably during ripening which mainly occurs as a result of degradation of the middle lamella of the cell was of cortical parenchyma cells (Hernández-Muñoz *et al.*, 2006). Changes in the firmness between control and treated fruits during the storage time at 7 ºC are shown in Fig. 8. Initial firmness values were similar for control and treated samples ($p>0.05$). Increasing the storage time, the firmness decreased for both control and coated fruits, but in a higher degree for the fruits treated with the optimized without stearic acid coating and for the control group. As can be seen in Fig. 8, the optimized and bilayer coatings were efficient to promote the firmness retention of the strawberries during the storage time; the results at the end of storage time (18 days) were similar to those obtained for the PVC treatment ($p>0.05$).

The rate and extension of firmness loss during ripening of soft fruits like strawberries is the main factor to determine fruit quality and post-harvest shelf life. According to García *et al.* (1998), the texture modifications in fruits and vegetables are related to the composition of cell wall, enzyme activity, metabolic changes and water content.

In the same way for the weight loss, the strawberries coated without stearic was not effective in retaining the firmness, in comparison to the control fruits, as can be seen in Fig. 8. This behavior was expected, since it was observed a high weight loss for this treatment, what is an indicative of the water loss of the fruit and consequently texture modification. The break forces of the strawberries coated with PVC remained almost constant until 16 days of storage ($p>0.05$). The optimized coating, as well as observed for weight loss results, was more effective in retaining the firmness of the strawberries, among the coatings studied. This result proved that the coating prepared from optimized conditions controlled the migration of moisture from the fruits, thus controlling the integrity and texture of the strawberries during cold storage.

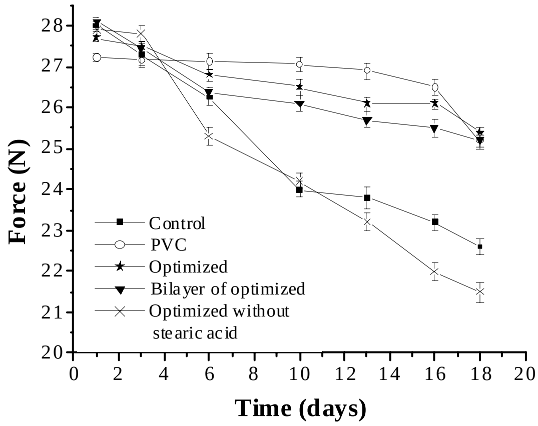

Figure 8. Effect of coatings studied on the firmness (peak force) of fresh strawberries stored at 7 ºC and 80% RH. Vertical bars indicate standard deviation.

E. Surface Color Development

The modification of the color occurs during the post-harvest ripening and the fruits becomes redder and darker along the storage time, due to the synthesis of anthocyanins, a pigment contributing to the red color in strawberries (Han *et al.*, 2004; Holcroft and Kader, 1999).The color changes of the coated strawberries and control fruits were evaluated by the chromaticity parameters (*a/b*) ratio in function of storage time. As can be seen in Figure 9, the control fruits presented higher values of *a/b* than the coated fruits. The optimized coating was the most efficient to avoid de *a/b* ratio increase, between the coatings studied. Thus, the senescence delay, evidenced by the decrease in color changes, demonstrates the effectiveness of this coating.

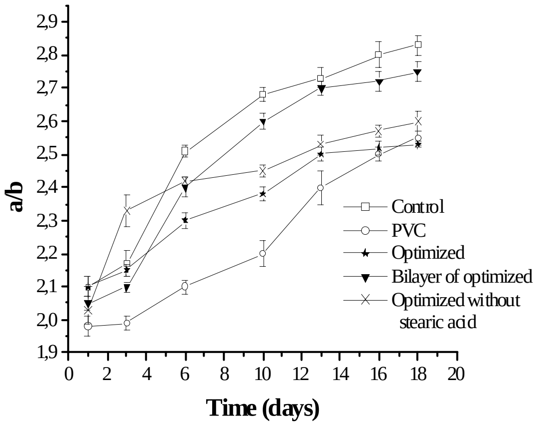

Figure 9. Effect of coatings on the surface color development (*a/b* ratio) of fresh strawberries stored at 7 ºC and 80% RH. Vertical bars indicate standard deviation.

IV. CONCLUSIONS

The application of the optimized formulation coating elaborated from *Amaranthus cruentus* flour and stearic acid to strawberry fruits were shown to be beneficial in retarding the senescence process. This coating reduced the weight loss and the external color changes, and was effective in retaining the firmness of the refrigerated strawberries. In this way, Amaranth flour seems to be a very interesting source of raw material for coatings formulation, following the actual trends in to use natural mixtures of protein, starch and lipids, to reach the desired properties for edible films.

V. ACKNOWLEDGMENTS

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