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ORIGINAL PAPER

Enhancement of Quality and Stability of Dried Papaya by Pectin-Based Coatings as Air-Drying Pretreatment

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Abstract Edible coatings have rarely been studied as a pretreatment for air-drying process. Hydrocolloid-based coatings possess good barrier properties to gases, are soluble in water, and can incorporate additives such as ascorbic acid. The aim of the present study was to improve the physical and nutritional characteristics of dehydrated fruits and vegetables by edible coating application. For this, the drying kinetics and the vitamin C and color retention in papaya (*Carica papaya* L.) with and without edible coatings were evaluated. Color and vitamin C were analyzed after 3, 9, and 30 days of storage. Papaya slices were immersed in a 2 % pectin solution (*w*/*w*) or in a 2 % pectin solution with vitamin C (1 % *w*/*w*). The pectin coating was gelled by immersion in calcium lactate solution (2.8 % *w*/*w*). The pectin-coated and non-coated slices were air-dried at temperatures of 60 and 70 °C. Vitamin C, color, and water content were analyzed in fresh papaya and in coated papaya before and after drying and during storage. All drying experiments were repeated four times. Analysis of variance was applied to the experimental data to identify differences at a 5 % significance level. The drying kinetics of coated and non-coated samples were very similar, only changing with temperature. Even though the highest vitamin C retention has been found in pectin-coated samples during drying at 60 °C and during 30 days of storage, considerable levels of vitamin C were obtained in samples with pectin+vitamin C coating, after drying and storage. Sensory analysis presented positive results for encouraging the use of dried pectin+vitamin C-coated papaya commercially.

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Introduction

Papaya (*Carica papaya* L.) is a popular inexpensive fruit, largely produced in several tropical and subtropical countries. The annual world production of papaya reached more than 11.5 million tonnes in 2011 with India producing most (36 %) followed by Brazil, with 16 % (FAO 2010). Papaya is an important source of vitamins because it is available all year round and widely accepted (Rodriguez-Amaya et al. 2008). Varieties of papaya species contain considerable amounts of lycopene and β-criptoxanthin as major carotenoids (Rodriguez-Amaya 2010), as well as β-carotene (Rodriguez-Amaya et al. 2008), vitamin C, fibers, and mineral salts (USDA 2012). Papayas of the Formosa cultivar presented 3.7±2.7 μg/g β-carotene, 7.0±2.4 μg/g β-cryptoxanthin, and 22.8±5.7 μg/g lycopene (Kimura et al. 1991).

Investigating methods for increasing the shelf life of fruits and vegetables is a challenge for researchers aiming to help minimize production losses and consequently guarantee food security. Several treatments and processes have been used to improve quality, reduce nutrient loss, and increase the shelf life of food products, such as osmotic dehydration (Ferrari et al. 2013), blanching (Garcia et al. 2012), edible coating (Díaz-Mula et al. 2012), encapsulation (Pérez-Chabela et al. 2013), microencapsulation (Malmo et al. 2013), convective drying (Garcia et al. 2012; Kurozawa et al. 2012), and foam-mat drying of pulp fruits (Raharitsifa and Ratti 2010; Kadam et al. 2011).

Edible coatings have been used successfully to improve the quality and storage time of minimally processed foods, because they decrease moisture loss, gas exchange, respiration, and oxidative reaction (Vargas et al. 2008; Díaz-Mula et al. 2012; Ferrari et al. 2013). For example, minimally processed sweet cherry fruits treated with an edible coating based on sodium alginate (1, 3, or 5 % *w/v*) achieved a maximum storage period of 16 days at 2 °C plus 2 days at 20 °C, while samples without treatment could be stored for only 8 days at 2 °C plus 2 days at 20 °C (Díaz-Mula et al. 2012). Ferrari et al. (2013) observed that treatment with a pectin coating promoted a significant decrease in the respiration rate of fresh-cut melon during storage. However, even with an edible coating, the maximum period of storage for minimally processed food is still relatively short.

Dehydration by convective air-drying of food products is widely used for different purposes: to increase the shelf life; reduce packaging costs, transport, and storage; and to modify sensory attributes. However, the degradation of food quality during drying is a major concern regarding the selection, design, and operation of dryers because of the physical, chemical, and biochemical changes resulting from this process (Mujumdar 1997). Research on maintaining the quality of dried fruit with respect to its texture, appearance, and preservation of nutrients has led to studies on drying pretreatments such as osmotic dehydration (Garcia et al. 2007) and the application of edible coatings (Lago-Vanzela et al. 2013) and methods combined with the application of inert gases (Hawlader et al. 2006) or vacuum (Shi et al. 1999) during the drying process.

Edible coatings based on polysaccharides possess good barrier properties to oxygen, are soluble in water, and can easily incorporate additives because of their polymeric structure. The low solubility of oxygen in aqueous compounds like polysaccharide-based edible coating and its capacity to reduce moisture loss from the product acting as a sacrificial agent (Kester and Fennema 1986; Wong et al. 1994; Cuq et al. 1995; Avena-Bustillos et al. 1997; Ferrari et al. 2013) suggests its suitability for application as a pretreatment before drying. This could minimize the damaging effects of the long exposure time of the product to oxygen at drying temperatures. This innovative technique, reported in only a few studies (Zhao and Chang 1995; Eik 2008; Gonçalves 2010; Lago-Vanzela et al. 2013; Garcia et al. 2014), has shown promise in improving the retention of nutrients and characteristics of the food during the convective drying process. The coating can also incorporate food additives, to improve the color, flavor, texture, and nutritional quality of food or even to control microbial growth (Cuppett 1994; Donhowe and Fennema 1994).

Vitamin C is an important antioxidant but is easily degraded by thermal action (Wawire et al. 2011) and enzymes (ascorbate peroxidase and ascorbate oxidase), as well as by the presence of light, oxygen, and metal catalysts. Being susceptible to these many variables, it is often used as an indicator of the quality of processed foods (Santos and Silva 2008; Frias et al. 2010). Ascorbic acid has been used as an additive for methyl cellulose- and polyethylene glycol-based coating for minimally processed apricots and green peppers, reducing the vitamin C loss during storage (Ayranci and Tunc 2004). Vitamin C occurs in three forms: L-ascorbate anion (L-AA), monodehydroascorbate (MDHA) radical, and dehydroascorbic (DHA). In plant cells, the L-ascorbate anion is predominant. L-AA is oxidized to MDHA and two molecules of MDHA can spontaneously disproportionate to L-AA and DHA, where DHA is the uncharged form of vitamin C (Davey et al. 2000). Ascorbate anion's ability to donate one electron and the relative stability of this oxidation product (MDHA) are the basis of its biological role as an antioxidant (Buettner and Schafer 2004).

The aim of this work was to improve the physical and nutritional characteristics of dehydrated papayas. For this, the present study investigated the influence of edible coatings applied before drying on process efficiency, color retention, the retention of vitamin C, and the sensory acceptability of these products.

Materials and Methods

Sample Preparation

Papayas (*C. papaya* L.) cv Formosa, long, were acquired by the São Paulo General Warehousing and Centers Company, CEAGESP, São José do Rio Preto, São Paulo, Brazil. The papayas were exposed to room temperature when nearly mature until the bark reached a degree of maturity corresponding to the yellow color. Soluble solids content ranged between 8 and 10 g/100 g papaya. They were then stored for short periods in cold storage at 5 °C, to carry out the experiments.

The papayas were washed and cut longitudinally into four pieces and the seeds were removed. Each portion was cut into cylinders (diameter 3.6 cm) with a manual cutter. These cylinders were then cut into slices (thickness 0.9 cm) using an apparatus with a blade fixed in a guide. The slice had 8.08± 0.54 g, and samples were placed in a plastic bag until the slices were randomly removed to be used in the experiments. Approximately 100 slices were used in each experiment.

Edible Coating Application

Low methoxylated amidated pectin Grindsted LA 210 (degree of methoxylation, 0.34; degree of amidation, 0.17) from Danisco (Cotia, Brazil) and ascorbic acid from Vallens (Rio Grande do Sul, Brazil) were used to prepare the coating solutions. The two edible coatings were prepared using deionized

water based on 2 % (*w*/*w*) pectin and a combination of 2 % (*w*/*w*) pectin and 1 % (*w*/*w*) vitamin C.

The pectin solution was prepared according to Garcia et al. (2012). Pectin solution 2 % (*w*/*w*) was heated at 70 °C to achieve complete solute dissolution and then cooled to 40 °C. For preparing the 2 % pectin+1 % vitamin C solution, ascorbic acid was added to the pectin solution at 40 °C. The solution temperature was kept at 40 °C using a thermostatic bath. The samples were placed in a 10-cm-deep mesh basket with partitions to keep each sample separated. All solutions were applied to the sample surface at 40 °C by immersion for 1 min with manual agitation. The gelling was activated in the presence of calcium ions, by placing samples in a 2.8 % (*w*/*w*) aqueous solution of food-grade calcium lactate pentahydrate (PURAC Synthesis, São Paulo, Brazil) for 30 s with manual agitation. After that, samples were placed carefully into a plastic bag to protect them until starting the analysis and experiments.

Convective Drying

The convective drying was carried out in a fixed bed pilot dryer equipped with a centrifugal fan connected to a frequency inverter (WEG, CWF10, Jaguará do Sul, Brazil), to control the air velocity. The air was heated with electrical resistance elements and flowed in parallel with the samples, which were placed on three metal mesh trays. A digital microprocessor unit with a J-type thermocouple was used to control the temperature (Novus, model N440, São Paulo, Brazil). Four PT 100-type probes and one humidity sensor DO9861T-R1 (Delta Ohm, Caselle di Selvazzano, Italy) were connected to a data acquisition system (ImPac, São Paulo, Brazil), so that temperature and relative humidity could be recorded over time.

Slices of papaya, without coating, coated with pectin, or coated with pectin plus vitamin C, were dried at 60 and 70 °C at an air velocity of 1.0 m/s until an approximately 10 % moisture content (w.b.) was achieved. Four experiments were performed at each temperature. Every 30 min, the samples were weighed and the positions of the trays inside the dryers were rotated to ensure a consistent treatment. After drying, the samples were divided into four parts, one for immediate analytical measurements and the others for storage in plastic bags, in a dark and dry environment at ambient temperature for subsequent analyses after 3, 9, and 30 days of storage.

Drying Kinetics

Fick's second law (Eq. 1) was used to model the drying kinetics of papaya slices in the falling drying rate period, because most of the drying of fruits and vegetables occur during this period. Samples were considered to be an infinite flat plate with both surfaces exposed to the drying air; the effective diffusivity and the solids concentration profile were assumed to be constant, and the effect of the temperature gradient on the inside of the sample was assumed to be negligible.

$$\frac{\partial X_w}{\partial t} = D_{\text{eff}} \frac{\partial^2 X_{\text{w}}}{\partial z^2} \tag{1}$$

where D_{eff} is the effective diffusion coefficient; X_{w} is the water content, in dry weight basis (d.b.); t is the drying time; and z is the distance.

The analytical solution of Eq. 1 integrated along the thickness $-l \le z \le l$, assuming a uniform initial moisture content, symmetry of water concentration profile, and equilibrium water content at surface, is given in terms of the mean concentration in the plate at time t (Crank 1975):

$$\frac{\overline{X}_{\text{w},t} - X_{\text{w,sup}}}{X_{\text{w},0} - X_{\text{w,sup}}} = \frac{8}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{(2n-1)^2} \exp\left[-(2n-1)^2 \frac{\pi^2 D_{\text{eff}} t}{4l^2}\right] \tag{2}$$

where $X_{\text{w},0}$ is the initial water content (d.b.); $X_{\text{w,sup}}$ is the water content (d.b.) on the surface; and $\overline{X}_{\text{w},t}$ is the average water content (d.b.) in the plate at time t. The term $\text{MR} = \left[\left(\overline{X}_{\text{w},t} - X_{\text{w,sup}}\right) / \left(X_{\text{w},0} - X_{\text{w,sup}}\right)\right]$ is the average moisture ratio content, non-dimensional.

In the integrated analytical solution for flat plates (Eq. 2), six terms were used in the series, which was sufficient for their convergence. The drying kinetics were also analyzed using the empirical models of Newton (Eq. 3), page (Eq. 4), and Henderson-Pabis (Eq. 5) (Ertekin and Yaldiz 2004)

$$\text{MR} = \exp(-kt) \tag{3}$$

$$\text{MR} = \exp(-kt^n) \tag{4}$$

$$\text{MR} = a \exp(-kt) \tag{5}$$

where k is the drying rate constant, (s^{-1}) or (s^{-n}), and n and a are fitting constants (dimensionless).

Solids Content

The solids content was analyzed in triplicate, gravimetrically, by drying crushed samples in a vacuum oven at 60 °C, 10 kPa, until constant weight.

Color

The color of the fresh and coated fruit slices, dried or not, was evaluated by measuring CIELAB color components in at least eight samples using a Colorflex spectrophotometer (HunterLab, Resto, USA). The coordinate L^*, the lightness component, ranges from 0 (black) to 100 (white), while the coordinates a^* and b^*, the chromatic components, range from

negative a^* values (green) to positive (red) and from negative b^* values (blue) to positive (yellow).

To convert coordinates from the rectangular form to the polar form, the chromaticity components are replaced by correlates of Chroma (Eq. 6) and Hue angle (Eq. 7). Chroma is the radial component, the intensity or saturation level of a particular Hue angle. Hue angle is the angular component of the polar representation, the basic unit of color that, for papaya, is expected to range between 0=red and 90=yellow.

$$\text{Chroma} = \sqrt{\left((a^*)^2 + (b^*)^2\right)} \tag{6}$$

$$\text{Hue angle} = arctg\left(\frac{b^*}{a^*}\right) \tag{7}$$

Vitamin C

The vitamin C content of the samples was determined in triplicate using the standard method (AOAC 1984) modified by Benassi and Antunes (1988). Samples were homogenized in 2 % (*w*/*w*) oxalic acid, diluted in the same solution and titrated with 2.6-dichlorophenolindophenol. The amount of vitamin C was expressed as milligrams of ascorbic acid per 100 g fruit, and the retention values of vitamin C were calculated according to Eq. 8 (Murphy et al. 1975).

$$\text{Ret}\ (\%) = \frac{\text{Vit}_\text{f} M_\text{f}}{\text{Vit}_\text{i}\ M_\text{i}} \times 100 \tag{8}$$

where *Ret* is the retention of vitamin C, Vit_f is the final amount of vitamin C, Vit_i is the initial amount of vitamin C in samples (mg ascorbic acid/100 g product), M_f is the final mass of the sample, and M_i is the initial mass of the sample (g).

Sensory Analysis

The ethical issues regarding sensory analyses were approved by the Research Ethics Committee of the Institute of Biosciences, Language and Physical Sciences of the "Júlio de Mesquita Filho" São Paulo State University (opinion n. 058/11). Experiments were carried out at the Sensory Analysis Laboratory, Department of Food Engineering and Technology, Institute of Biosciences, Languages and Physical Sciences (IBILCE).

Two coating treatments and drying temperatures of 60 and 70 °C were selected for sensory analysis, based on the better retention of vitamin C.

The samples were subjected to sensory analysis by a group of 50 untrained panelists over 18 years old. The panelists evaluated four coded samples, presented separately on a white dish in a randomized manner. Affective tests were carried out regarding overall acceptance, appearance, color, texture, aroma, and flavor of the samples, using a 9-point hedonic scale, where the value 1 equates to the lowest level of acceptance, while 9 represents the highest level of acceptance (Meilgaard et al. 1999).

Statistical Analysis

Results were statistically analyzed using analysis of variance (ANOVA) at a 5 % significance level. Tukey's test was applied to locate significant differences between a balanced number of samples and Tukey–Kramer's test to an unbalanced number of samples, at the 5 % significance level. Effective diffusion coefficients were calculated from the experimental data according to Eq. 2 using Origin 6 (OriginLab Corporation, Northampton, USA). The fitting efficiency was evaluated by the determination coefficient R^2 and the mean relative error (E (%)), which is defined in Eq. 9 (Lomauro et al. 1985; Montgomery 2001).

$$E(\%) = \frac{100}{N}\sum_{n=0}^{N}\frac{\left|\left(X_{\text{cal},\,n} - X_{\text{exp},\,n}\right)\right|}{X_{\text{exp},\,n}} \tag{9}$$

where N is the number of experimental points, $X_{exp,n}$ is the experimental value, and $X_{cal,n}$ is the predicted value.

Results and Discussion

Drying

Figure 1 shows the drying kinetics of papaya through the relationship between moisture ratio and drying time. The mean experimental values and standard deviations based on four replicates for each treatment are also shown in Fig. 1, where the standard deviations are very small for all treatments. Regardless of the treatment used, the drying curves of samples with and without coating exhibit a similar behavior when they are dehydrated at the same temperature. Figure 1 compares experimental and calculated moisture ratio according to Fick's second law model (Eq. 2).

To determine the effective diffusion coefficients, Eq. 2 was fitted to the experimental data. The equilibrium moisture content in Eq. 2 was taken from papaya isotherms (Canizares 2013) based on the average relative humidity measured during drying experiments. Table 1 shows the mean effective diffusivities of four replicates from each treatment, the respective standard deviations, and the coefficients of determination (R^2) obtained by fitting Eq. 2 to the mean experimental moisture, with all values greater than 0.95, an indication of an acceptable model (Vega-Gálvez et al. 2007). These coefficients of determination (R^2) represent good results alongside the very low values of mean relative error (E (%)) obtained. This

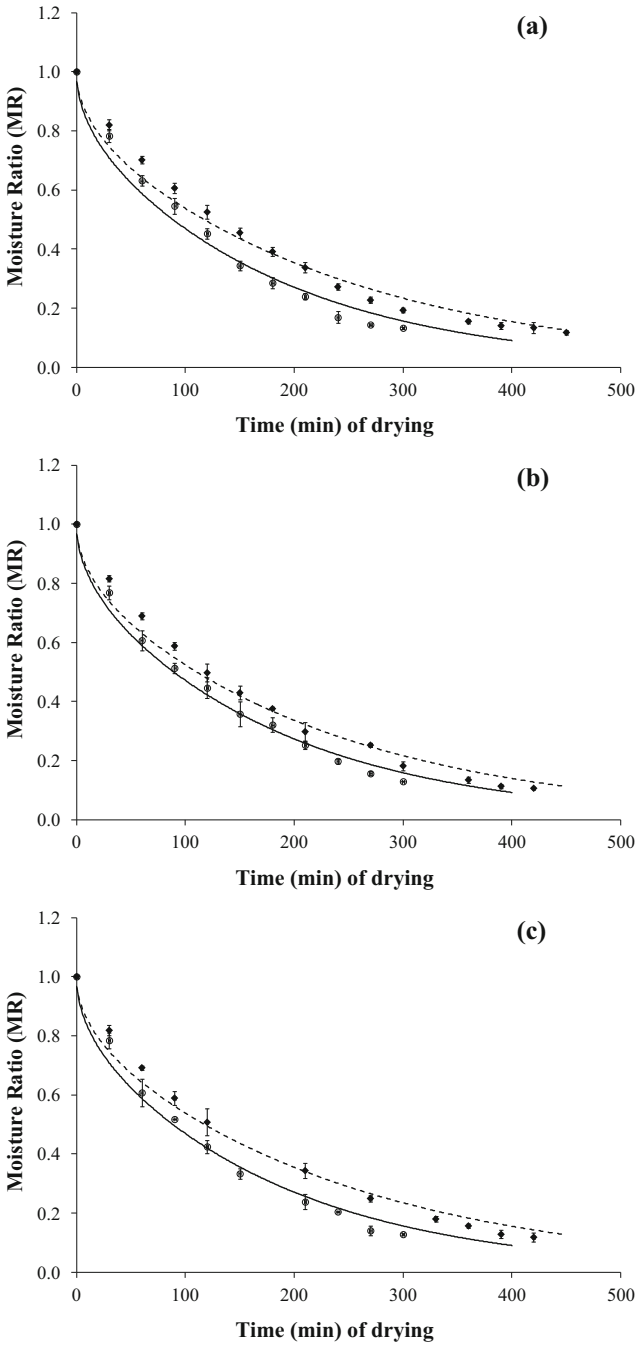

Fig. 1 Experimental and calculated average moisture ratio (*MR*) as a function of drying time at 60 °C (*filled diamond*) and 70 °C (*empty circle*). *Bars* represent standard deviation of four drying replicates. **a** Drying of control samples, **b** drying of samples pretreated with pectin, and **c** drying of samples pretreated with pectin added with vitamin C. *Lines* represent theoretical values of drying at 60 °C (*dashed*) and at 70 °C (*solid*)

demonstrates only small deviations between the observed and calculated values for all treatments and temperatures.

In Table 1, the average effective diffusivities show very similar values between different treatments, with and without coatings, whether conducted at the same temperature of drying. These results demonstrate that the influence of applying an edible coating on the drying kinetics is very small, suggesting that the main resistance to drying is water diffusion through the fruit tissue. This particular result is important because it shows that energy expenditure during the drying process is not affected by the edible coating. Furthermore, there is a considerable dependence of diffusivity on temperature for all treatments (Table 1).

Water diffusivity determined by Kurozawa et al. (2012) during air-drying of papaya cubes with 1 m/s air velocity at 70 °C was 4.4×10^{-10} m/s^2, without shrinkage consideration. This value is lower than that obtained in the present work at the same temperature (Table 1). The difference between the diffusion coefficients found for slices and cubes of papaya could be explained mainly by the shrinkage influence over different sample shapes. In general, a selective shrinkage in thickness over the area of slices is observed (Mauro and Menegalli 2003). As shrinkage is not considered in the models, its effect is included in the diffusion coefficients.

Moreover, Lemus-Mondaca et al. (2009) obtained diffusivities about twice as high as those found in the present study, for the dehydration of Chilean papaya (*Carica pubescens*) slabs, but in this case, it is probably related to the difference between cultivars.

Additionally, the empirical models of Newton, Page, and Henderson-Pabis were fitted to experimental data (Table 2). All the models tested described the drying process well, because $R^2>0.98$ and E (%)<15 % for all models, which indicated a good relationship between theoretical and experimental values during the drying period. Conversely, Page's model, derived from Newton's, presents an exponential parameter, n, which is responsible for the increase of k in relationship with other models.

The parameter k is the velocity of water migration from the product when the external resistances are negligible. This parameter also incorporates some variables, as sample geometry and air dynamic, which causes difference from diffusivity effective values.

To complete the drying analysis, Table 3 presents the sample moisture contents before and after drying, and after 30 days of storage. The drying process was carried on for approximately 8 h for drying at 60 °C and for 6 h at 70 °C. In Table 3, it is possible to observe significant changes in moisture with the application of coatings and no significant change during the storage period.

The addition of coatings significantly increased the sample's initial moisture content; nevertheless, pretreatment caused no effect on dried papaya moisture content, if compared with the control samples dried at the same temperature. Significant differences at the end of drying are found when comparing products dried at different temperatures, despite higher times for drying at lower temperatures. In fact, drying

Table 1 Effective diffusivity for papaya slices with and without coatings, dried at different temperatures

Treatment	60 °C			70 °C		
	Effective diffusivity $\times 10^{10}$ (m^2/s)	R^2	E (%)	Effective diffusivity $\times 10^{10}$ (m^2/s)	R^2	E (%)
Control	$5.68 \pm 0.22^{a\ A}$	0.983	8.85	$7.50 \pm 0.23^{b\ A}$	0.979	11.52
Pectin	$6.02 \pm 0.18^{a\ A}$	0.983	12.37	$7.44 \pm 0.29^{b\ A}$	0.989	7.23
Pectin+vitamin C	$5.66 \pm 0.26^{a\ A}$	0.986	10.96	$7.66 \pm 0.48^{b\ A}$	0.985	8.37

Mean values followed by different lowercase letters in the same row and by different uppercase letters in the same column are significantly different ($P<0.05$) by Tukey–Kramer's test; uppercase letters compare changes between treatments (columns); and lowercase letters compare effective diffusivity changes between temperatures of drying for same treatment (rows)

time was enough to reach relatively stable moisture, very close to equilibrium moisture. Samples exhibited good stability during storage with no significant changes in moisture content.

Color

The color results are presented in Table 4, where the mean values, standard deviations, and significance analysis (Tukey–Kramer) are shown. The color homogeneity of the fresh papaya samples used in all experiments of each treatment can be observed in Table 4, except for the raw materials used in pectin-coated 70 °C treatments, whose mean values were significantly different from the others.

Table 4 shows a tendency for a reduction or maintenance of the sample lightness, L^*, of the fresh papaya with a pectin coating in comparison to the correspondent fresh samples. Drying did cause a slight increasing in the L^* values for papaya samples. During storage, the lightness practically did not significantly change, except for samples pretreated with the pectin+vitamin C coating and dried at 60 °C. Maskan (2001) studied the kinetics of color changes of kiwifruits during drying by hot air at 60 °C. In this case, he observed that L^* could be reduced during drying because of the ascorbic acid browning and the non-enzymatic Maillard reaction. Less sensitive L^* changes would be expected in papaya because this fruit presents an amount of proteins nearly three times lower than that of the kiwifruit (USDA 2012), especially lysine that is the most important protein related with Maillard reaction. Moreover, vitamin C browning is strongly related with the presence of copper, but papaya contains a small quantity of this metal in comparison to kiwifruit (USDA 2012).

The a^* values showed no significant changes in fresh papayas by the addition of coatings. However, drying affected all samples, reducing redness values during drying in relation to samples before drying. Furthermore, the storage of samples significantly reduced a^* values, the redness parameter, for all treatments when comparing 30-day-stored samples with corresponding samples before drying.

For samples pretreated with pectin, the yellowness parameter, b^*, increased significantly when comparing fresh with 30-day-stored dried samples. Other samples showed no significant changes in b^* values.

Table 2 Parameters determined according to the Newton, Page, and Henderson-Pabis models, for papaya slices dried at 60 and 70 °C, with and without coatings and corresponding R^2 and E (%) values

	Treatment	60 °C					70 °C				
		k	n	a	R^2	E (%)	k	n	a	R^2	E (%)
Newton	Control	8.85×10^{-05}			0.996	5.75	11.70×10^{-05}			0.997	4.02
	Pectin	9.41×10^{-05}			0.997	3.82	11.56×10^{-05}			0.991	4.60
	Pectin+vitamin C	8.99×10^{-05}			0.995	5.49	12.03×10^{-05}			0.995	4.58
Page	Control	17.62×10^{-05}	0.93		0.998	3.97	15.97×10^{-05}	0.97		0.997	3.93
	Pectin	18.06×10^{-05}	0.93		0.998	3.82	35.74×10^{-05}	0.88		0.997	4.72
	Pectin+vitamin C	22.48×10^{-05}	0.90		0.999	2.43	27.12×10^{-05}	0.91		0.998	3.50
Henderson-Pabis	Control	8.61×10^{-05}		0.98	0.995	5.01	11.53×10^{-05}		0.99	0.996	4.02
	Pectin	9.15×10^{-05}		0.98	0.997	3.19	11.08×10^{-05}		0.96	0.989	3.60
	Pectin+vitamin C	8.65×10^{-05}		0.97	0.997	3.31	11.70×10^{-05}		0.98	0.996	4.13

k is the constant drying rate, (s^{-1}) or (s^{-n}), and n and a are fitting constants (dimensionless)

Table 3 Moisture content for samples before drying, after drying, and after 30 days of storage

Treatment	Temperature (°C)	Time		
		Before drying	After drying	Thirtieth day of storage
Control	60	$0.875\pm0.013^{a\ B}$	$0.110\pm0.008^{b\ A}$	$0.106\pm0.002^{b\ B}$
Control	70	$0.875\pm0.013^{a\ B}$	$0.087\pm0.010^{b\ B}$	$0.097\pm0.006^{b\ C,D}$
Pectin	60	$0.908\pm0.005^{a\ A}$	$0.104\pm0.005^{b\ A}$	$0.104\pm0.003^{b\ B,C}$
Pectin	70	$0.902\pm0.028^{a\ A}$	$0.084\pm0.005^{b\ B}$	$0.087\pm0.004^{b\ E}$
Pectin+vitamin C	60	$0.898\pm0.004^{a\ A}$	$0.106\pm0.007^{b\ A}$	$0.114\pm0.005^{b\ A}$
Pectin+vitamin C	70	$0.893\pm0.005^{a\ A}$	$0.083\pm0.009^{b\ B}$	$0.095\pm0.007^{b\ D}$

Mean values followed by different lowercase letters in the same row and by different uppercase letters in the same column are significantly different ($P<0.05$) by Tukey–Kramer's test; uppercase letters compare changes between treatments at the same time (columns); and lowercase letters compare moisture changes between periods of analysis for one treatment (rows)

Hue angle is a polar coordinate that relates the rectangular coordinates a^* and b^*. The addition of coating on fresh papaya did not cause significant changes. Conversely, drying significantly increased the Hue value to a more yellow tonality, when comparing dried with fresh samples. For all treatments, samples after 30 days of storage showed significantly higher Hue angle values than the corresponding fresh sample.

The Chroma parameter showed mostly small changes in samples during drying processes at 60 °C. But during storage, it is possible to observe a reduction in Chroma values for control samples and those pretreated by pectin+vitamin C, and the maintenance of this parameter for samples treated with pectin. This maintenance can be explained by the increase in the b^* parameter, particularly in those treatments which balanced the redness reduction and so stabilizing vector Chroma size. Even though pectin coating has been more efficient to retain pigmentation in papayas, the yellowness could be a deceptive result, because it reflects the increase in a color that is not desirable for the red-fleshed papaya cultivars. Lycopene is the major carotene of the red-fleshed papaya (Kimura et al. 1991; Rodriguez-Amaya 2010), and an increasing of the Hue angle together with maintenance of the Chroma could be explained by its isomerization during processing. Shi et al. (1999), studying lycopene retention in tomato products processed by different dehydration methods, reported that the increasing of yellow and the red decreasing could be attributed to the isomerization of the *trans*-lycopene to the less red partly *cis*-isomers. Thus, the better color retention caused by pectin coating would be related to distribution of *trans*- and *cis*-isomers, decreasing the Hue angle without necessarily having lycopene degradation.

Lago-Vanzela et al. (2013) found that the hot-air-dried pumpkins with the better color had the higher retention of *trans*-α-carotene and *trans*-β-carotene. Ahmed et al. (2002) also related visual changes in papaya puree with degradation of carotenes.

According to Vargas et al. (2008), an important characteristic of edible coating is that it causes no changes in product color. In the present study, it can be observed that the addition of pectin or pectin+vitamin C coatings mostly agreed with this opinion. Drying and storage, however, caused significant changes in color samples, principally, increasing the yellowness and Hue angle.

Vitamin C Retention

As presented in Table 5, the content of vitamin C in fresh papaya was similar to values found in other studies (USDA 2012). The coating application procedure slightly changed the vitamin C content of fresh papaya. The addition of pectin coating caused losses of vitamin C that were attributed to sample handling during this process step. On the other hand, application of the pectin+vitamin C coating resulted in 124.89±15.91 mg ascorbic acid per 100 g of fresh papaya which corresponds to 198.78±28.15 % of the initial vitamin C content of the fresh papaya as is shown in Table 5.

Values of vitamin C retention during air-drying and storage in relation to the corresponding fresh products are presented on Table 6. The pretreated samples showed over 80 % retention after drying. After 30 days of storage, the samples pretreated with pectin and dried at 60 °C showed the highest retention of vitamin C, 81 %. This retention represents 41.2 mg vitamin C per 100 g product. With a lower retention percentage, but higher content, the samples pretreated with pectin+vitamin C and dried at 60 °C contained 87.4 mg vitamin C per 100 g product after 30 days of storage.

Comparing samples after drying at 60 °C, between different treatments, it appears that samples coated with pectin and pectin+vitamin C had significantly higher vitamin C retention. The samples coated with pectin and dried at 60 °C showed retentions above 100 %, which probably indicates an analytical or inherent sampling error caused by variability in the raw materials, because the results are averages from four independent repetitions. At 70 °C, all coatings significantly improved the retention compared with the control sample,

Table 4 Results of CIELAB color measurements obtained from different treatments at different times: before drying, after drying at the 3rd, 9th, and 30th day of storage

Parameter	Control		Pectin		Pectin+vitamin C	
	60 °C	70 °C	60 °C	70 °C	60 °C	70 °C
Fresh						
*L**	56.07±3.56$^{b\ A}$	54.36±2.44$^{b\ B}$	54.52±2.17$^{b\ B}$	60.46±5.14$^{a\ A}$	56.07±3.56$^{b\ AB}$	54.36±2.44$^{b\ A}$
*a**	34.44±2.88$^{a\ A}$	36.50±2.2$^{a\ A}$	36.23±1.65$^{a\ A}$	28.70±4.73$^{b\ A}$	34.44±2.88$^{a\ A}$	36.50±2.20$^{a\ A}$
*b**	43.02±3.98$^{ab\ AB}$	45.18±2.58$^{a\ A}$	45.17±1.56$^{a\ C}$	40.24±3.24$^{b\ C}$	43.02±3.98$^{ab\ BCD}$	45.18±2.58$^{a\ AB}$
*C**	55.13±4.62$^{a\ AB}$	58.11±2.97$^{a\ A}$	57.93±1.61$^{a\ A}$	49.56±4.33$^{b\ B}$	55.13±4.62$^{a\ AB}$	58.11±2.97$^{a\ A}$
*H**	51.29±1.72$^{b\ C}$	51.05±1.61$^{b\ C}$	51.26±1.58$^{b\ E}$	54.66±4.47$^{a\ D}$	51.29±1.72$^{b\ D}$	51.05±1.61$^{b\ D}$
Pretreated						
*L**	–	–	51.97±2.09$^{b\ B}$	58.16±4.52$^{ab\ B}$	54.35±2.80$^{b\ AB}$	54.93±3.08$^{a\ A}$
*a**	–	–	35.92±1.22$^{a\ A}$	29.24±4.78$^{b\ A}$	34.53±2.98$^{a\ A}$	33.18±2.93$^{a\ AB}$
*b**	–	–	46.39±2.9$^{a\ BC}$	43.16±2.61$^{b\ B}$	44.71±2.74$^{ab\ AB}$	43.12±1.95$^{b\ B}$
*C**	–	–	58.69±2.77$^{a\ A}$	52.29±3.42$^{c\ AB}$	56.53±3.34$^{ab\ A}$	54.44±2.96$^{bc\ BC}$
*H**	–	–	52.20±1.44$^{b\ E}$	56.03±4.74$^{a\ CD}$	52.33±2.33$^{b\ CD}$	52.47±2.00$^{b\ CD}$
After drying						
*L**	58.35±3.93$^{b\ A}$	58.79±3.61$^{ab\ A}$	57.42±3.53$^{bc\ A}$	62.26±2.5$^{a\ A}$	56.76±3.93$^{bc\ A}$	55.00±3.00$^{c\ A}$
*a**	30.36±3.11$^{ab\ B}$	30.84±3.04$^{ab\ B}$	32.44±2.07$^{a\ B}$	28.13±2.78$^{b\ A}$	31.31±2.86$^{a\ B}$	32.14±1.73$^{a\ BC}$
*b**	40.78±2.64$^{c\ AB}$	41.28±1.81$^{c\ C}$	47.47±3.29$^{a\ ABC}$	46.23±2.07$^{ab\ A}$	44.86±3.82$^{b\ ABC}$	46.49±4.45$^{ab\ A}$
*C**	50.89±3.36$^{c\ B}$	51.57±2.93$^{c\ C}$	57.57±2.58$^{a\ A}$	54.16±2.73$^{b\ A}$	54.79±3.69$^{b\ ABC}$	56.59±3.69$^{ab\ AB}$
*H**	53.38±2.63$^{c\ BC}$	53.32±2.25$^{bc\ BC}$	55.59±2.89$^{b\ CD}$	58.72±2.25$^{a\ BC}$	55.04±3.2$^{bc\ B}$	55.21±3.01$^{bc\ ABC}$
Third day of storage						
*L**	58.34±3.67$^{ab\ A}$	55.46±3.23$^{cd\ B}$	58.55±2.48$^{ab\ A}$	59.67±3.44$^{a\ A}$	56.06±2.43$^{bc\ AB}$	53.8±3.11$^{d\ A}$
*a**	31.06±2.31$^{ab\ B}$	30.95±3.38$^{ab\ B}$	31.30±1.77$^{ab\ BC}$	29.50±2.16$^{b\ A}$	31.48±2.52$^{a\ B}$	31.42±2.71$^{ab\ BC}$
*b**	42.61±3.26$^{c\ A}$	44.18±2.58$^{bc\ AB}$	48.27±2.4$^{a\ AB}$	46.33±2.82$^{ab\ A}$	45.96±3.64$^{ab\ A}$	44.62±2.52$^{b\ AB}$
*C**	52.78±3.29$^{c\ A}$	54.03±2.88$^{bc\ B}$	57.56±2.37$^{a\ A}$	54.98±2.59$^{abc\ A}$	55.76±3.69$^{ab\ A}$	54.64±2.63$^{bc\ BC}$
*H**	53.88±2.45$^{c\ B}$	55.02±3.34$^{abc\ AB}$	57.02±1.8$^{ab\ BC}$	57.47±2.55$^{a\ BCD}$	55.54±2.5$^{bc\ AB}$	54.85±2.73$^{bc\ BC}$
Ninth day of storage						
*L**	59.04±2.98$^{b\ A}$	58.38±4.01$^{b\ A}$	59.67±3.47$^{ab\ A}$	62.9±4$^{a\ A}$	53.76±2.63$^{c\ B}$	54.89±3.15$^{c\ A}$
*a**	29.27±2.52$^{a\ B}$	28.26±3.87$^{ab\ BC}$	30.08±2.14$^{a\ CD}$	26.21±3.63$^{b\ A}$	30.53±2.19$^{a\ B}$	30.20±3$^{a\ CD}$
*b**	41.99±2.54$^{c\ A}$	43.37±2.25$^{bc\ B}$	49.76±3.78$^{a\ A}$	47.42±2.07$^{a\ A}$	42.12±3.12$^{c\ BD}$	44.38±2.86$^{b\ AB}$
*C**	51.23±2.99$^{c\ B}$	51.88±3.01$^{bc\ BC}$	58.24±2.68$^{a\ A}$	54.24±3.24$^{b\ A}$	52.08±2.92$^{bc\ BD}$	53.76±2.92$^{b\ C}$
*H**	55.14±2.22$^{cd\ AB}$	57.01±3.64$^{bc\ A}$	58.74±3.32$^{ab\ AB}$	61.19±2.85$^{a\ AB}$	54.01±2.66$^{d\ BC}$	55.77±3.16$^{cd\ AB}$
Thirtieth day of storage						
*L**	57.84±4.36$^{b\ A}$	59.49±4.92$^{ab\ A}$	59.48±3.02$^{ab\ A}$	62.76±4.16$^{a\ A}$	54.04±3.17$^{c\ B}$	53.5±3.57$^{c\ A}$
*a**	26.30±3.49$^{ab\ C}$	26.44±4.39$^{ab\ C}$	28.67±1.61$^{a\ D}$	24.66±3.87$^{b\ B}$	26.93±2.39$^{ab\ C}$	28.72±2.4$^{a\ D}$
*b**	40.02±2.64$^{e\ B}$	42.56±2$^{cd\ BC}$	49.81±2.85$^{a\ A}$	46.57±2.47$^{b\ A}$	41.65±3.63$^{de\ BD}$	44.78±2.94$^{bc\ AB}$
*C**	48.00±2.89$^{c\ C}$	50.27±2.4$^{c\ C}$	57.51±2.36$^{a\ A}$	52.83±2.64$^{b\ A}$	49.65±3.76$^{c\ D}$	53.28±2.38$^{b\ C}$
*H**	56.74±4.01$^{b\ A}$	58.27±4.93$^{b\ A}$	60.02±2.23$^{ab\ A}$	62.14±4.07$^{a\ A}$	57.07±2.5$^{b\ A}$	57.28±3.17$^{b\ A}$

Means followed by different lowercase letters in the same row and by different uppercase letters in the same column are significantly different ($P<0.05$) using Tukey–Kramer's test; lowercase letters compare changes in the same color parameter between treatments at the same time; and uppercase letters compare changes over time for the same treatment, for each color parameter

and the best result was obtained by the sample coated with pectin+vitamin C.

The drying temperature for the same pretreatment significantly influenced only the samples coated with pectin. A comparison of treatments at different temperatures showed similar vitamin C retention because of the longer drying process times at the lower temperature, resulting in a longer exposure of the sample to oxygen.

During storage, the influence of drying temperature on vitamin C retention was observed mainly in the control samples and in pectin+vitamin C-coated samples. In samples dried at 70 °C, the vitamin C reduced significantly by the third day of

Table 5 Vitamin C values before and after coating application, in mg vitamin C/100 g of final product (wet basis); mass gain; and retention of vitamin C after coating application

	mg of vitamin C/100 g of product		Mass gain (%)	Retention of vitamin C (%)
	Fresh	Pretreated		
Control	74.84±2.54	–	–	–
Pectin	66.42±0.58	50.84±1.38	21	91.9±0.5
Pectin+vitamin C	72.14±2.56	124.89±15.91	16	198.78±28.15

Mass gain was calculated from the mass of edible coating in relation to the fresh sample

storage. All samples showed a significant reduction in vitamin C between post-drying and after 30 days of storage. The stability of samples coated with pectin alone is shown by the high retention values during the storage period. The high retention of vitamin C in dehydrated papaya, even in samples without a coating, appears to be associated with compositional characteristics of this fruit, which naturally exert a protective effect on vitamin C (Garcia et al. 2012). As an example, the retention of vitamin C in papaya, after drying at 45 °C, was 75 %, while guava dehydrated under the same conditions retained only 25 % (Hawlader et al. 2006).

Sensory Analyses

The treatments selected for sensory analysis were samples coated with pectin and pectin+vitamin C and the drying temperatures, 60 and 70 °C. Pretreatment using pectin coating was chosen because of its better ability to retain vitamin C, especially when samples were dried at 60 °C. The samples coated with pectin+vitamin C were chosen because of the high level of vitamin C after drying and during storage. Sensory analyses were performed using 50 panelists between 19 and 56 years old, of which 54 % were female. The results are presented in Table 7.

Table 7 Mean values and standard deviations of the sensory attributes of papaya slices coated with pectin and pectin plus vitamin C and dried at 60 and 70 °C

Attributes	Pectin		Pectin plus vitamin C	
	60 °C	70 °C	60 °C	70 °C
Appearance	5.64 ± 1.78^{a}	5.08 ± 1.73^{a}	5.90 ± 1.68^{a}	5.64 ± 1.80^{a}
Color	6.86 ± 1.41^{a}	5.94 ± 1.64^{b}	6.84 ± 1.25^{a}	6.38 ± 1.29^{ab}
Flavor	5.32 ± 1.47^{a}	5.30 ± 1.41^{a}	5.12 ± 1.17^{a}	5.54 ± 1.14^{a}
Texture	4.58 ± 2.11^{b}	5.08 ± 1.92^{b}	4.72 ± 1.71^{b}	6.10 ± 1.56^{a}
Taste	5.44 ± 1.71^{b}	5.38 ± 1.48^{b}	5.26 ± 1.67^{b}	6.44 ± 1.34^{a}
Overall acceptance	5.30 ± 1.63^{b}	5.52 ± 1.48^{ab}	5.36 ± 1.46^{b}	6.16 ± 1.44^{a}

Means followed by different letters in the same row are significantly different ($P<0.05$) by Tukey's test

Samples coated with pectin+vitamin C and dried at 70 °C, in general, showed the best sensory scores from the panel and in some cases were significantly higher than those of the other treatments. It is possible that lower moisture content in samples, dried at 70 °C, improved the texture. The color of the samples dried at 60 °C was more acceptable than that dried at 70 °C, which agreed with the color changes measured instrumentally. However, the addition of vitamin C to the coating positively affected the texture and flavor in the samples dried at 70 °C and increased their overall acceptability.

Papaya is an abundant raw material and an inexpensive fruit in tropical countries so that it is habitually consumed. The role of this fruit as an ingredient should be studied, because formulations with sugar, honey, and other dried fruits or cereals could improve its sensory acceptance.

Conclusions

Pectin-based coatings added before drying papaya slices do not significantly affect the diffusivity of water and the drying time, showing that the coatings may be applied without

Table 6 Retention values of vitamin C in papaya in relation to the corresponding fresh products, using different pretreatments, after drying and during the storage period

	Control		Pectin		Pectin+vitamin C	
	60 °C	70 °C	60 °C	70 °C	60 °C	70 °C
After drying	$71.17\pm3.74^{d\ A}$	$65.63\pm3.81^{d\ A}$	$102.19\pm1.50^{a\ A}$	$83.31\pm3.8^{c\ A}$	$86.64\pm2.78^{bc\ A}$	$95.04\pm9.69^{ab\ A}$
Third day of storage	$64.90\pm3.38^{c\ A}$	$52.57\pm5.27^{d\ B}$	$96.25\pm5.34^{a\ A}$	$81.79\pm2.33^{b\ A}$	$84.76\pm4.48^{b\ A}$	$61.30\pm6.31^{cd\ B}$
Ninth day of storage	$55.82\pm5.05^{d\ B}$	$55.99\pm2.20^{cd\ B}$	$96.59\pm2.47^{a\ A}$	$77.49\pm2.75^{b\ AB}$	$81.66\pm6.39^{b\ A}$	$64.68\pm3.12^{c\ BC}$
Thirtieth day of storage	$30.28\pm3.21^{d\ C}$	$48.34\pm3.51^{c\ B}$	$81.38\pm4.72^{a\ B}$	$70.33\pm6.28^{a\ B}$	$70.20\pm3.15^{a\ B}$	$51.27\pm5.25^{c\ C}$

Means followed by different lowercase letters in the same row and by different uppercase letters in the same column are significantly different ($P<0.05$) by Tukey–Kramer's test; lowercase letters compare changes between treatments at the same time; and uppercase letters compare changes overtime for the same treatment

reducing the efficiency of the dehydration process. Empirical models show a good fit to the experimental data, making them a useful tool for process design using similar conditions to those in the experimental condition range. Samples with pectin coating showed better results for vitamin C retention during drying and 30 days of storage, whereas samples coated with pectin+vitamin C showed a lower retention percentage but a vitamin C content approximately twice as high as samples coated with pectin alone, after drying and storage. The samples pretreated with pectin+vitamin C and dried at 60 °C contained 87.4 mg vitamin C per 100 g product after 30 days of storage.

Sensory analysis confirmed the feasibility of edible coating as a pretreatment to drying, especially when coated with pectin+vitamin C and dried at 70 °C. These results suggest that the coating can be used as a pretreatment for drying, to protect compounds susceptible to oxidation during drying, and could serve as a carrier for other additives and nutrients. However, more in-depth studies are required which encompass other nutritional compounds, different physical properties, and long-term shelf life tests.

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References

Ahmed, J., Shivhare, U. S., & Sandhu, K. S. (2002). Thermal degradation kinetics of carotenoids and visual color of papaya puree. *Food Engineering and Physical Properties, 67*(7), 2692–2695.

AOAC—Association of Official Analytical Chemists. (1984). *Official methods of analysis of the association of official analytical chemists* (14th ed.). Arlington: AOAC.

Avena-Bustillos, R. J., Krochta, J. M., & Saltveit, M. E. (1997). Water vapor resistance of red delicious apples and celery sticks coated with edible caseinate-acetylated monoglycerides films. *Journal of Food Science, 62*(2), 351–354.

Ayranci, E., & Tunc, S. (2004). The effect of edible coatings on water and vitamin C loss of apricots (*Armeniaca vulgaris* Lam.) and green peppers (*Capsicum annuum* L.). *Food Chemistry, 87*, 339–342.

Benassi, M. T., & Antunes, A. J. (1988). A comparison of metaphosphoric and oxalic acids as extractant solutions for the determination of vitamin C in selected vegetables. *Arquivos de Biologia e Tecnologia, 31*(4), 507–513.

Buettner, G. R., & Schafer, F. Q. (2004). Ascorbate as an antioxidant, in vitamin C. In H. Asard, J. M. May, & N. Smirnoff (Eds.), *Function and biochemistry in animals and plants* (pp. 173–188). Oxford: Bios Scientific.

Canizares, D. (2013). *Efeito da adição de revestimentos comestíveis sobre a qualidade de mamão desidratado após a secagem e durante o armazenamento*. S J Rio Preto: UNESP. 77 p. Thesis (master's degree) - Institute of Biosciences, Language and Sciences (IBILCE), São Paulo State University "Julio de Mesquita Filho", S J Rio Preto, SP, Brazil.

Crank, J. (1975). *The mathematics of diffusion* (2nd ed.). Oxford: Clarendon.

Cuppett, S. L. (1994). Edible coatings as carriers of food additives, fungicides and natural antagonists. In J. M. Krochta (Ed.), *Edible coatings and films to improve food quality* (pp. 121–138). Lancaster: Technomic.

Cuq, B., Gintard, N., & Guilbert, S. (1995). Edible films and coatings as active layers. In M. L. Rooney (Ed.), *Edible active layer*. London: Blackie Academic.

Davey, M. W., Montagu, M. V., Inzé, D., Sanmartin, M., Kanellis, A., Smirnoff, N., Benzie, I. J. J., Strain, J. J., Favell, D., & Fletcher, J. (2000). Plant L-ascorbic acid: chemistry, function, metabolism, bioavailability and effects of processing. *Journal of the Science of Food and Agriculture, 80*(7), 825–860.

Díaz-Mula, H. M., Serrano, M., & Valero, D. (2012). Alginate coatings preserve fruits quality and bioactive compounds during storage of sweet cherry fruit. *Food and Bioprocess Technology, 5*, 2990–2997.

Donhowe, I. G., & Fennema, O. (1994). Edible films and coatings: characteristics, formation, definitions, and testing methods. In J. M. Krochta (Ed.), *Edible coatings and films to improve food quality* (pp. 1–24). Lancaster: Technomic.

Eik, N.M. (2008). *Avaliação de pré-tratamentos e aplicação de coberturas comestíveis sobre a secagem de frutas*. Dissertation (Master in Food Engineering)—Faculty of Food Engineering, University of Campinas – UNICAMP. Campinas, SP, Brazil.

Ertekin, C., & Yaldiz, O. (2004). Drying of eggplant and selection of a suitable thin layer drying model. *Journal of Food Engineering, 63*(3), 349–359.

FAO (2010). FAO Statistical Databases. Site: http://faostat.fao.org/faostat Accessed 25 august, 2012.

Ferrari, C. C., Sarantópoulos, C. I. G. L., Carmello-Guerreiro, S. M., & Hubinger, M. D. (2013). Effect of osmotic dehydration and pectin edible coatings on quality and shelf life of fresh-cut melon. *Food and Bioprocess Technology, 6*, 80–91.

Frias, J., Peñas, E., Ullate, M., & Vidal-Valverde, C. (2010). Influence of drying by convective air dryer or power ultrasound the vitamin C and beta-carotene content of carrots. *Journal Agricultural Food Chemistry, 58*(19), 10539–10544.

Garcia, C. C., Mauro, M. A., & Kimura, M. (2007). Kinetics of osmotic dehydration and air-drying of pumpkins (*Cucurbita* moschata). *Journal of Food Engineering, 88*, 284–291.

Garcia, C. C., Canizares, D., Silva, K. S., Darros-Barbosa, R., & Mauro, M. A. (2012). Utilização de métodos combinados para obtenção de mamão Formosa (*Carica papaya*) seco. *B. SEPPA, 30*(2), 185–196.

Garcia, C. C., Caetano, L. C., Silva, K. S., & Mauro, M. A. (2014). Influence of edible coating on the drying and quality of papaya (*Carica papaya*). *Food Bioprocess Technology, 7*, 2828–2839.

Gonçalves, J. A. (2010). *Secagem de Carambolas (Averrhoa Carambola L.): Desenvolvimento e Aplicação de Coberturas Comestíveis Aditivadas com Agentes Antioxidantes Naturais para a Conservação de suas Propriedades Funcionais*. Dissertation (Master in Food Engineering)—University Campinas, UNICAMP, Campinas.

Hawlader, M. N. A., Perera, C. O., Tian, M., & Yeo, K. L. (2006). Drying of guava and papaya: impact of different drying methods. *Drying Technology, 24*, 77–87.

Kadam, D. M., Rai, D. R., Patil, R. T., Wilson, R. A., Kaur, S., & Kumar, R. (2011). Quality of fresh and stored foam-mat drier Mandarin powder. *International Journal of Food Science & Technology, 46*, 793–799.

Kester, J. J., & Fennema, 0. R. (1986). Edible films and coatings: a review. *Food Technology, 12*, 47–59.

Kimura, M., Rodriguez-Amaya, D. B., & Yokoyama, S. M. (1991). Cultivar differences and geographic effects on the carotenoid composition and vitamin A value of papaya. *Lebensmittel-Wissenschaft und-Technologie, 24*, 415–418.

Kurozawa, L. E., Hubinger, M. D., & Park, K. J. (2012). Glass transition phenomenon on shrinkage of papaya during convective drying. *Journal of Food Engineering, 108*, 43–50.

Lago-Vanzela, E. S., Nascimento, P., Fontes, E. A. F., Mauro, M. A., & Kimura, M. (2013). Edible coating from native and modified starches retain carotenoids in pumpkin during drying. *LWT Food Science and Technology, 50*, 420–425.

Lemus-Mondaca, R., Betoret, N., Vega-Galvéz, A., & Lara-Aravena, E. (2009). Dehydration characteristics of papaya (*Carica pubenscens*): determination of equilibrium moisture content and diffusion coefficient. *Journal of Food Process Engineering, 32*(5), 645–663.

Lomauro, C. J., Bakshi, A. S., & Labuza, T. P. (1985). Evaluation of food moisture sorption isotherm equations. Part I: fruit, vegetables and meat products. *Lebensmittel Wissenschaft und Technologie, 18*(2), 111–117.

Malmo, C., Storia, A. L., & Mauriello, G. (2013). Microencapsulation of *Lactobacillus reuteri* DSM 17938 cells coated in alginate beads with chitosan by spray drying to use as a probiotic cells in a chocolate soufflé. *Food and Bioprocess Technology, 6*, 795–805.

Maskan, M. (2001). Kinetics of colour change of kiwifruits during hot air and microwave drying. *Journal of Food Engineering, 48*, 169–175.

Mauro, M. A., & Menegalli, F. C. (2003). Evaluation of water and sucrose diffusion coefficients in potato tissue during osmotic concentration. *Journal of Food Engineering, 57*, 367–374.

Meilgaard, M., Civille, G. V., & Carr, B. T. (1999). *Sensory evaluation techniques* (3rd ed.). Boca Raton: CRC. Chapter 12.

Montgomery, D. C. (2001). *Design and analysis of experiments* (5th ed.). Hoboken: Wiley. Chapter 3.

Mujumdar, A. S. (1997). Drying fundamentals. In C. G. J. Baker (Ed.), *Industrial drying of foods* (pp. 7–30). London: Blackie.

Murphy, E. W., Criner, P. E., & Gray, B. C. (1975). Comparisons of methods for calculating retentions of nutrients in cooked foods. *Journal Agricultural Food Chemistry, 23*(6).

Pérez-Chabela, M. L., Lara-Labastida, R., Rodriguez-Huezo, E., & Totosaus, A. (2013). Effect of spray drying encapsulation of thermotolerant lactic acid bacteria on meat batters properties. *Food and Bioprocess Technology, 6*, 1505–1515.

Raharitsifa, N., & Ratti, C. (2010). Foam-mat freeze-drying of apple juice part 1: experimental data and ANN simulations. *Journal of Food Process Engineering, 33*, 268–283.

Rodriguez-Amaya, D. B., Kimura, M., Godoy, H. T., & Amaya-Farfan, J. (2008). Updated Brazilian database on food carotenoids: factors affecting carotenoid composition—critical review. *Journal of Food Composition and Analysis, 21*, 445–463.

Rodriguez-Amaya, D. B. (2010). Quantitative analysis, in vitro assessment of bioavailability and antioxidant activity of food carotenoids—a review. *Journal of Food Composition and Analysis, 23*(7), 726–740.

Santos, P. H. S., & Silva, M. A. (2008). Retention of vitamin C in drying processes of fruits and vegetables—a review. *Drying Technology, 26*, 1421–1437.

Shi, J., Le Maguer, M., Kakuda, Y., Liptay, A., & Niekamp, F. (1999). Lycopene degradation and isomerization in tomato dehydration. *Food Research International, 32*, 15–21.

USDA (2012). U.S. Department of Agriculture, Agricultural Research Service.2012. USDA National Nutrient Database for Standard Reference, Release 25. Open software SR25 downloaded from Nutrient Data Laboratory Home Page, http://www.ars.usda.gov/ba/bhnrc/ndl. Accessed 10 Dec 2012.

Vargas, M., Pastor, C., Chiralt, A., McClements, D. J., & González-Martínez, C. (2008). Recent advances in edible coatings for fresh and minimally processed fruits. *Food Science and Nutrition, 48*(6), 496–511.

Vega-Gálvez, A., Lemus-Mondaca, R., Fito, P., & Andrés, A. (2007). Moisture sorption isotherms and isosteric heat of red bell pepper (var. Lamuyo). *Journal of Food Science, 13*, 309–316.

Wawire, M., Oey, I., Mathooko, F., Njoroge, C., Shitanda, D., & Hendrickx, M. (2011). Thermal stability of ascorbic acid and ascorbic acid oxidase in African cowpea leaves (Vigna unguiculata) of different maturities. *Journal of Agriculture and Food Chemistry, 59*, 1774–1783.

Wong, D. W. S., Camirand, W. M., & Pavlath, A. E. (1994). Development of edible coatings for minimally processed fruits and vegetables. In J. M. Krochta (Ed.), *Edible coatings and films to improve food quality* (pp. 65–88). Lancaster: Technomic.

Zhao, Y. P., & Chang, K. C. (1995). Sulfite and starch affect color and carotenoids of dehydrated carrots (*Daucus carota*) during storage. *Journal of Food Science, 60*, 324–347.