LWT - Food Science and Technology 96 (2018) 274–280

Contents lists available at ScienceDirect

LWT - Food Science and Technology

journal homepage: www.elsevier.com/locate/lwt

Development and application of biopolymer coatings to specialty green coffee beans: Influence on water content, color and sensory quality

Laura Fonseca Ferreira[a], Giselle Figueiredo de Abreu[b], Amanda Maria Teixeira Lago[c], Luisa Pereira Figueiredo[c], Flávio Meira Borém[b], Maria Alice Martins[d], Soraia Vilela Borges[c], Marali Vilela Dias[c,*]

[a] Biomaterials Engineering Postgraduated Program, Federal University of Lavras, 37200-000, Lavras, MG, Brazil
[b] Agricultural Engineering Department, Federal University of Lavras, 37200-000, Lavras, MG, Brazil
[c] Food Science Department, Federal University of Lavras, 37200-000, Lavras, MG, Brazil
[d] National Agricultural Nanotechnology Laboratory, Embrapa Instrumentação, São Carlos, 13560-970, SP, Brazil

ARTICLE INFO

Keywords:
Application of edible coatings
Coffee quality
Storage
Conservation of beans

ABSTRACT

Edible biopolymers are used as barrier coatings to preserve food products quality, but they have never been studied for use with green coffee beans. In the present work, biopolymeric coatings were developed and characterized in order to determine the treatment that would best retain the physical and sensorial properties of green coffee beans. The factors investigated were the type of biopolymer (starch and chitosan), pre-drying time (1 and 3 h) of the suspensions in an oven, and the number of immersions (1 and 2) of the green coffee beans in the suspensions. Tests were performed on coated beans (color and water content), films (contact angle with water and moisture), suspensions (rheological behavior after pre-drying), and beverages obtained from coated and roasted coffee beans (sensory quality). Contact angle and moisture analyses revealed that starch resulted in higher resistance to moisture than did chitosan treatments. Pre-drying for 3 h changed only the viscosity resulting from starch-based treatment. The treatment that entailed the use of starch, 3 h of pre-drying, and one immersion was the one that best retained color and water content characteristics of coated green coffee beans compared to control (uncoated green coffee beans). Moreover, neither biopolymer altered the sensory quality.

1. Introduction

Edible coatings have been used efficiently in the food industry to conserve products such as fruits, vegetables, meats, eggs, nuts, and fish (Cerqueira et al., 2009; Chien, Sheu, & Yang, 2007; Aquino, Blank, & Aquino Santana, 2015; Han, Hwang, Min, & Krochta, 2008; Limchoowong, Sricharoen, Techawongstien, & Chanthai, 2016). Coatings are coverages deposited on the surface of food and act primarily as barriers to gas and water vapor, protecting the food from the external atmosphere, reducing deterioration, and preserving the original food characteristics for longer duration (Assis & Britto, 2011). It is therefore believed that the application of polymer coatings on green coffee beans can help reduce their metabolic activity and retain their characteristics throughout the duration of storage. However, this technique needs to be previewed to determine whether it can be employed in large-scale storage facilities because edible coatings on green coffee beans have not been investigated so far.

To efficiently maintain the quality of the coated food, the most appropriate material for coating must be selected. The material will perform well if it does not adversely impact the appearance, flavor, and odor of the food product, can be homogeneously coated on the food surface, and fulfils the specific requirements of food conservation (Souza, Goto, Mainari, Coelho, & Tadini, 2013).

Coffee is an agricultural product marketed according to its qualitative parameters, the beverage's sensorial aspect being one of the most important. Preservation of the chemical compounds present in green coffee beans depends on good storage conditions since almost all coffee produced undergoes a period of storage (Figueiredo et al., 2013).

The initial product condition, light intensity, temperature, relative humidity of the storage environment, and packaging are the main factors that can change the sensorial quality during bean storage (Borém et al., 2013; Ribeiro et al., 2011).

Water content of the beans is the most important initial condition to be regulated to ensure preservation of bean quality during storage. To ensure good bean conservation, the water content should ideally be 10–12% before storage and not exceed 14% during storage. This

* Corresponding author.
E-mail addresses: marali.dias@dca.ufla.br, maralivileladias@gmail.com (M.V. Dias).

https://doi.org/10.1016/j.lwt.2018.05.037
Received 30 October 2017; Received in revised form 8 May 2018; Accepted 13 May 2018
Available online 15 May 2018
0023-6438/

prevents fungi growth that can accelerate bean degradation. The coating on the beans is pre-dried, because it is important to ensure that the coating does not alter the water content of the beans during application. Since the coating is applied in an aqueous suspension, the coating technique must be such that it does not increase the moisture content of the beans. The faster the drying process, the less contact the beans would have with water (Nobre, Borém, Fernandes, & Pereira, 2007).

There are three main coating application techniques: brushing, sprinkling, and immersion. In the brushing technique, the biopolymeric suspension is spread over the food surface with a brush; this is not widely used because each unit of product is coated individually and it is difficult to standardize the process. Moreover, as green coffee beans are small and have a crack in the center, this technique is not appropriate (de Jesús Avena-Bustillos, Krochta, Saltveit, de Jesús Rojas-Villegas, & Sauceda-Pérez, 1994). The sprinkling method entails a spray, which creates a biopolymer suspension mist that is deposited on the food surface. This method requires standardization of the fluid viscosity, and usually calls for low viscosity. However, the coating over the beans must be dried as quickly as possible to avoid water absorption and hence the use of a suspension with low viscosity is not ideal. In the immersion method, the food product is submerged in a container with biopolymer suspension. This method allows for homogenous coating and is hence indicated when the product has a complex surface and is to be coated completely. After the product is soaked and the excess coating is drained, the coated product is dried at room temperature or with the aid of a drier. The immersion technique allows for the use of a suspension with higher viscosity. In addition, a dryer can be used to accelerate the drying of the coating, thereby ensuring that the amount of water absorbed is the least possible. Therefore, the technique of immersion was chosen for this present study (Andrade, Skurtys, & Osorio, 2012).

Besides water content, it is important to ensure that the coating does not alter the beverage's sensorial aspect, which is the most important parameter in the marketing of coffee. Hence, the presence of the coating should not be discernible sensorially. Color and physical aspect are additional parameters that influence how coffee is marketed, hence the coating should be invisible to the naked eye. To ensure that the coating is present homogenously on the surface of every bean, it is necessary to use microscopy techniques (Figueiredo et al., 2013).

Environmental factors exert great influence on beans stored in a conventional storage system, i.e., in permeable packages, which is the most commonly employed mode of storage worldwide. In this system, the beans are packed in jute bags, which are permeable to gas and water vapor. Green coffee beans are hygroscopic and hence more susceptible to loss of quality when stored in a conventional storage system that increases the product's exposure to climatic oscillations (Corrêa, Afonso Júnior, Silva, & Ribeiro, 2003; Vieira, Silva, Silva, & Vilela, 2000).

Research has focused on developing technologies to minimize the effect of the storage environment on green coffee beans and to preserve product quality for longer. Examples include high-barrier packaging such as hermetic polymeric bags (GrainPro®) and impervious *big bags*, with and without CO_2 addition. Furthermore, Brazilian green coffee bean exporters have used vacuum packaging successfully to preserve bean quality. However, there are still no packages that are capable of maintaining the initial quality of the beans throughout the duration of storage (Borém et al., 2008, 2013; Nobre et al., 2007; Ribeiro et al., 2011).

In view of the above, the aim of this study was to develop and characterize biopolymer coatings for application on green coffee beans, and to select the treatment that best retains the original physical characteristics of the bean and the sensorial characteristics of the beverage.

2. Material and methods

2.1. Material

Chitosan with deacetylation degree of 85.9% was supplied by Polymar Ciência e Nutrição S/A (Fontaleza, Brazil). Citric acid was provided by Proquímios (Rio de Janeiro, Brazil), modified cassava starch by Cassava S/A (Rio Grande do Sul, Brazil), and glycerol by Sigma-Aldrich (Missouri, EUA). The coffee beans (*Coffea arabica* L.) used were from a single commercial batch, with a score of 82–85 points, as determined by the Specialty Coffee Association of America (SCAA), 2009.

2.2. Experimental design

Two experiments were designed for the polymeric suspensions: one was to test the film obtained from the suspension, and the other was to test the suspensions applied on the coffee beans.

The rheological behavior of the suspension polymerizations, and the contact angle and moisture of the films were measured to study the respective treatments; three replicates of the measurements were taken using a completely randomized design. The factors examined were: (I) biopolymer type – starch (S) and chitosan (C); and (II) pre-drying time in oven – 1 h and 3 h (Table 1). The films were analyzed 48 h after drying.

To investigate the influence of the coatings on the color and water content of the beans, the following factors were evaluated in a completely randomized design with three replicates: (I) biopolymer type – starch (S) and chitosan (C); (II) pre-drying time in oven – 1 h and 3 h; and (III) number of immersions of the beans in the suspension polymerizations – 1 and 2 (Table 2). The coated beans were analyzed 48 h after drying.

2.3. Coating development

Chitosan suspensions were prepared by adapting the methodologies described by Dias et al. (2014) and Liu et al. (2016). Chitosan (2.0% (p/v)) was dispersed in a 1.6% (p/v) aqueous solution of citric acid, and the mixture was left undisturbed for 2 h for chitosan hydration. The suspensions were then homogenized in an Ultra-Turrax homogenizer

Table 1
Treatments and their acronyms for the characterization of biopolymers.

Treatments	Biopolymer	Pre-drying time in oven (h)
S0	Starch	0
S1	Starch	1
S3	Starch	3
C0	Chitosan	0
C1	Chitosan	1
C3	Chitosan	3

Table 2
Treatments applied on green coffee beans and their acronyms.

Treatments	Biopolymer	Pre-drying time in oven (h)	Immersion (n°)
S11	Starch	1	1
S12	Starch	1	2
S31	Starch	3	1
S32	Starch	3	2
C11	Chitosan	1	1
C12	Chitosan	1	2
C31	Chitosan	3	1
C32	Chitosan	3	2

(T25, IKA-Werke, Staufen, Germany) at 1200 rpm at room temperature (25 °C) for 30 min. The suspensions were then filtered through organza to remove non-solubilized particles.

For the preparation of starch suspensions, modified 3% (p/v) cassava starch and 20% glycerol, based on biopolymer weight, were dispersed in distilled water. The suspensions were homogenized on a magnetic stirrer at 750 rpm under heat until gelatinization temperature (70 °C) was attained and were maintained at this temperature for an additional 5 min (Soares et al., 2007).

The suspensions of chitosan and modified cassava starch were pre-dried in an oven at 100 °C for a period of 1 h or 3 h, depending on the treatment, to lower the moisture absorbed by the beans during immersion and facilitate drying of the coating.

2.3.1. Rheological behavior of suspension polymerizations

The rheological behaviors of the suspension polymerizations were determined to verify the effect of the pre-drying treatment on the viscosity of the suspensions. The study was performed at 25 °C using a rheometer (HAAKE RheoStress 6000, Thermo Fisher Scientific, Germany) equipped with a thermostatic bath (HAAKE A10, Thermo Fisher Scientific) and a universal temperature control system (HAAKE UTM Controller, Thermo Fisher Scientific), coupled with a sensor set of concentric cylinders with a gap of 5.3 mm. For the experiment, the volume of each sample used was 16.1 mL.

In order to decrease the thixotropy effect, i.e., to eliminate the influence of time on the flow behavior of the products, each sample was subjected to a continuous shear rate acceleration in the range 0–300 s^{-1} for 2 min for the rising curve and 2 min for the downward curve. After this procedure, the flow curve was generated by varying the shear rate from 0 s^{-1} to 300 s^{-1} for 3 min at the cooling temperature (López, García, & Zaritzky, 2008). The Newton's law (Eq. (1)), Power Law (Eq. (2)), and Herschel–Bulkley (Eq. (3)) models were adjusted to the experimental data from the flow curves.

$$\sigma = \mu\dot{\gamma} \quad (1)$$

$$\sigma = K\dot{\gamma}^{n} \quad (2)$$

$$\sigma = \sigma_0 + K\dot{\gamma}^{n} \quad (3)$$

where σ is the shear stress (Pa), μ is the Newtonian viscosity (Pa·s), $\dot{\gamma}$ is the shear rate (s^{-1}), K is the consistency index (Pa·s^n), n is the flow behavior index, and σ_o is the yield stress (Pa).

2.4. Film formation

The films were prepared by the casting method in which the polymeric suspensions were poured into circular plates, 13.5 cm in diameter, and maintained at room temperature until the solvent had completely evaporated. The samples were conditioned according to the method D618-00 (ASTM, 2000) at a temperature of 25 ± 2 °C and relative humidity of 50 ± 5%, controlled by BOD (biochemical oxygen demand) for 48 h before analyses.

2.4.1. Contact angle of films with water

The contact angle measurements were taken using a CAN101 Optical Contact Angle Meter (KSV Instruments Ltd., Finland) in air and at room temperature. Three droplets of deionized water (5 μL) were evaluated on each surface. The angles were recorded by the optical system approximately 120 s after the droplets were arranged. All measurements were determined digitally.

2.4.2. Film moisture

The moisture of the films was determined by oven-drying. The films were cut into samples of approximately 0.2 g each, placed in Petri dishes, and heated at 105 °C for 24 h (ASTM, 2007).

2.5. Application of coatings

The coatings were applied on the green coffee beans by the immersion technique. The beans were immersed into the suspension polymerizations in the ratio of 200 ml of suspension per 100 g of beans. Subsequently, the coated beans were dried in a semi-fluidized bed adapted in a coffee dryer for 30 min at 30 °C. In the case of treatments involving two immersions (S12, S32, C12, and C32), the second immersion was performed only after the first application of coating had dried. The same drying conditions were maintained in both the procedures.

2.5.1. Microscopic analyses of the coated green coffee beans

In order to verify the presence of coating on the bean surface, the following microscopic analyses were performed:

2.5.1.1. Microscopy at stereoscope. Images of the coated beans were captured with a stereoscope RZT/100 STAND (Meiji Techno Co., Ltd., Japan), and photographed on the device itself.

2.5.1.2. Scanning electron microscopy (SEM). The beans were cut in a cross-section approximately 5 mm thick to obtain the micrographs from the scanning electron microscope (MEV JSM 6510, JEOL Ltd., Japan) with an acceleration voltage of 10 kV. The samples were placed in *"stubs"* with carbon tape and coated with gold under vacuum for 180 s.

2.5.2. Water content of coated green coffee beans

To evaluate the water content of the coated beans, the oven-drying method was employed at 105 ± 1 °C for 16 ± 0.5 h, following the standard method ISO 6673 (2003).

2.5.3. Color of coated green coffee beans

The color parameters L (luminosity), and a and b (chromaticity coordinates) in a Minolta® CR 310 colorimeter (illuminant C and 10° angle) were measured using the methodology described by Nobre (2005, p. 124) to evaluate possible color changes due to the application of coating.

2.5.4. Sensorial analysis

Prior to the analysis, human participation in the project was approved under opinion No. 1.686.758/2016 by the Research Ethics Committee (CEP) associated with the Pro-Rectory of Research of the Federal University of Lavras (CAAE: 29254114.9.0000.5108). To verify the influence of the different biopolymers on the beverage's sensorial quality, sensorial analysis was performed using beans subjected to three types of treatments: (I) coffee beans coated with starch (S31); (II) coffee beans coated with chitosan (C11); and (III) uncoated beans (control treatment). C11 and S31 treatments were selected based on the results of water content and color of coated green coffee beans.

The sensorial analysis was conducted by three judges certified in the SCAA protocol (2009) and was based on the methodology proposed by Lingle (2011) for the sensorial evaluation of specialty coffees. A sample of 100 g of coffee beans, screen 16 and above, was moderately light-roasted and the temperature was monitored so that roasting time was neither less than 8 min nor greater than 12 min.

In this methodology, grades are attributed to the following parameters: fragrance/aroma, acidity, body, flavor, residual taste, sweetness, uniformity, cleanliness of cup, balance, and overall impression. The sum of the grades assigned to all these attributes yields the final grade of the sensory evaluation.

2.6. Statistical analysis

Evaluation of the results from the suspension polymerization, film, and sensorial analysis was performed using the univariate statistical analysis (ANOVA) and the mean test (Tukey, $P < 0.05$) using the

SISVAR® software (Ferreira, 2011).

The models were fitted to the experimental data of the flow curves using the statistical program Statistical Analysis System (SAS University Edition, USA, 2016), and graphs were plotted using the program Sigma Plot 11.0 (Systat Software Inc., USA, 2008).

To differentiate between coating treatments so that the treatment yielding product characteristics most similar to the control (uncoated green coffee beans) can be identified, the principal component analysis (PCA) was performed for water content and the color parameters L, a and b, using Chemoface software version 1.6 (Nunes, Freitas, Pinheiro, & Bastos, 2012).

3. Results and discussion

3.1. Rheological behavior of suspension polymerizations

In general, the Newton's Law model presented the best fit to the experimental data, with the exception of the S3 treatment (starch suspension with 3 h of pre-drying in the oven), whose data were better adjusted to the Power Law model, as shown in Table 3. The slope of the S3 curve decreases with increase in shear rate, and this treatment showed a n value of 0.8224, which is typical of shear-thinning fluids (Fig. 1). With respect to the fitting of experimental data, it was verified that the models studied were adequate with values of R^2 (coefficient of determination) in the range 0.9886–0.9999 and RMSE (root mean square error) in the range 0.0113–0.0622.

Granular starch does not normally exhibit shear-thinning behavior but does so when heated in the presence of water, and this behavior can vary with change in temperature, concentration, and shear rate due to the gelatinization process (Nurul, Azemi, & Manan, 1999).

The shear rate can be fixed at 100 s^{-1}, since this is generally the rate at which fluids are subjected to in unitary operations such as fluidized bed drying (Ali, Underwood, Lee, & Wilson, 2016). At this rate, the difference among all the treatments in terms of viscosity values is evident: S0 (0.0033 Pa s), S1 (0.0080 Pa s), S3 (0.0318 Pa s), C0 (0.0239 Pa s), C1 (0.0257 Pa s), and C3 (0.0283 Pa s).

Among the starch suspensions, the treatment involving 3 h of oven-drying contributed the most to increase in viscosity ($P < 0.05$). The higher the starch concentration in the suspension, the greater the opposition to viscous flow due to increase in the degree of entanglement at contact points along the chains (Corradini, Teixeira, Agnelli, & Mattoso, 2007).

For the chitosan suspensions, it was verified that oven processing

Table 3
Rheological parameters obtained for the suspension polymerizations.

Treatments	Newton's law		
	μ*	RMSE	R^2
S0	0.0033ᵃ ± 0.0001	0.0113	0.9986
S1	0.0080ᵃ ± 0.0004	0.0223	0.9990
C0	0.0239ᵇ ± 0.0003	0.0278	0.9998
C1	0.0257ᵇ ± 0.0018	0.0622	0.9993
C3	0.0283ᵇ ± 0.0003	0.0227	0.9999

Treatments	Power Law K	n	RMSE	R^2
S3	0.0724 ± 0.0209	0.8224 ± 0.0262	0.0462	0.9986

Values are means ± standard deviation (n = 3). *Means followed by the same lowercase letters in the column do not differ by the Tukey test ($P > 0.05$). μ = Newtonian viscosity (Pa·s); K = consistency index (Pa·s^n); n = flow behavior index (dimensionless); RMSE = root mean square error; R^2 = coefficient of determination. Treatments: S0 - starch without oven; S1 - starch 1 h in the oven; S3 - starch 3 h in the oven; C0 - chitosan without oven; C1 - chitosan 1 h in the oven; and C3 – chitosan 3 h in the oven.

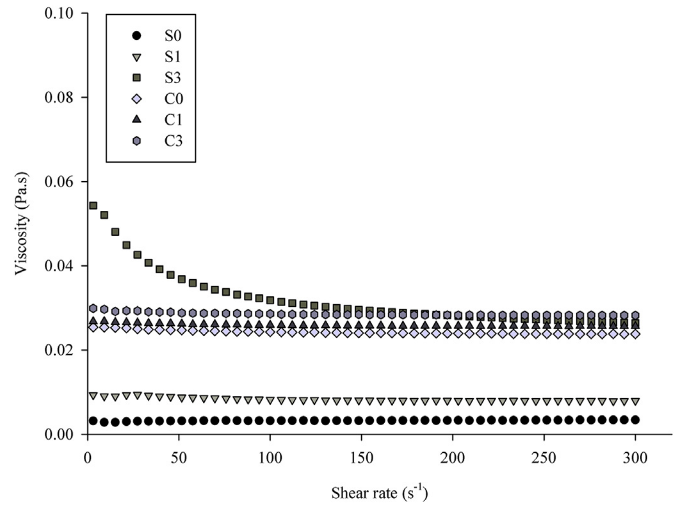

Fig. 1. Rheological behavior of suspension polymerizations. Treatments: S0 - starch without oven; S1 - starch 1 h in the oven; S3 - starch 3 h in the oven; C0 - chitosan without oven; C1 - chitosan 1 h in the oven; and C3 - chitosan 3 h in the oven.

had no significant effect ($P > 0.05$) on viscosity, therefore pre-drying was not necessary to improve this attribute. However, when compared to the S0 and S1 treatments, treatments with chitosan exhibited greater viscosity ($P < 0.05$), which can also be observed in Fig. 1.

The penetration rates during immersion are not only related to the viscosity of the coating suspension but also to the increase in the coating agent concentration during the drying stage (Gällstedt, Brottman, & Hedenqvist, 2005; Khwaldia, Arab-Tehrany, & Desobry, 2010).

3.2. Film analysis

The type of biopolymer significantly influenced ($P < 0.05$) the results obtained for the contact angle and moisture content of the films, but the pre-drying time of the suspensions did not have a statistically significant influence ($P > 0.05$). Table 4 shows the average values calculated from the results obtained for the different treatments using starch (S0, S1, and S3) and chitosan suspensions (C0, C1, and C3). The data show that there was a significant difference ($P < 0.05$) among the biopolymers tested; the starch films had a higher value of contact angle and lower degree of moisture than the chitosan films.

The hydrophobicity degree of the surface can be evaluated by the contact angle made by a water droplet when in contact with the surface. Higher angle indicates greater hydrophobicity.

Contact angles lower than 90° may indicate hydrophobicity, i.e., all films showed hydrophilic character, however, the starch films were less hydrophilic than the chitosan films (Yuan & Lee, 2013).

Table 4
Film contact angle and moisture.

Coating	Contact angle (°)	Moisture (%)
S0	83.9ᵇ ± 0,9	18.3ᵃ ± 1.1
S1	77.6ᵇ ± 1.0	17.0ᵃ ± 0.9
S3	75.8ᵇ ± 2.2	18.7ᵃ ± 1.2
Starch	79.10ᵇ ± 4.25	18.00ᵃ ± 0.89
C0	53.7ᵃ ± 3.0	20.6ᵇ ± 1.2
C1	56.3ᵃ ± 4.1	20.9ᵇ ± 1.4
C3	51.9ᵃ ± 1.9	22.5ᵇ ± 0.4
Chitosan	53.97ᵃ ± 2.21	21.33ᵇ ± 1.02

Values are means ± standard deviation (n = 3). Means followed by the same lowercase letters in the column do not differ by the Tukey test ($P > 0.05$).

Fig. 2. Green coffee beans: (A) without coating; and (B) coated with the C11 treatment (chitosan 1 h in the oven and one immersion). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Colivet and Carvalho (2017) also observed values of contact angle with water close to 80° in the case of cassava starch films modified by cross-linking and with sorbitol in approximately 120 s of contact.

The lower hydrophobicity of the chitosan films can be attributed to the presence of citric acid. Liu et al. (2016) studied the surface modification of chitosan films using citric acid and observed a decrease in hydrophobicity and consequent increase in water absorption by the films. They argued that citric acid participates in hydrogen bonds, which increases the film's interaction with water molecules due to an increase in the number of carboxyl groups.

The hydrophobicity of the materials decreased according to the number of their interactions with water, therefore, these results corroborate those obtained for moisture content, since the starch films had lower average moisture than the chitosan films. Li et al. (2015) observed lower water solubility and water vapor permeability in films with higher values of contact angle with water.

3.3. Analyses of coated green coffee beans

As shown in Fig. 2, the coatings were imperceptible to the naked eye. This is a desirable outcome since the physical aspects displayed by

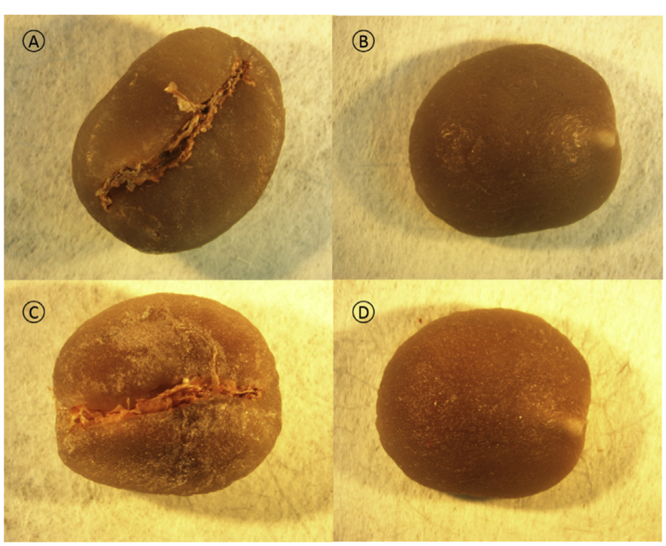

Fig. 3. Images on stereoscope performed in (A) green coffee bean before S32 (starch 3 h in the oven and two immersions) coating application (B) green coffee bean before C31 (chitosan 3 h in the oven and one immersion) coating application (C) green coffee bean after application of S32 treatments (D) green coffee bean after application of C31 treatments. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

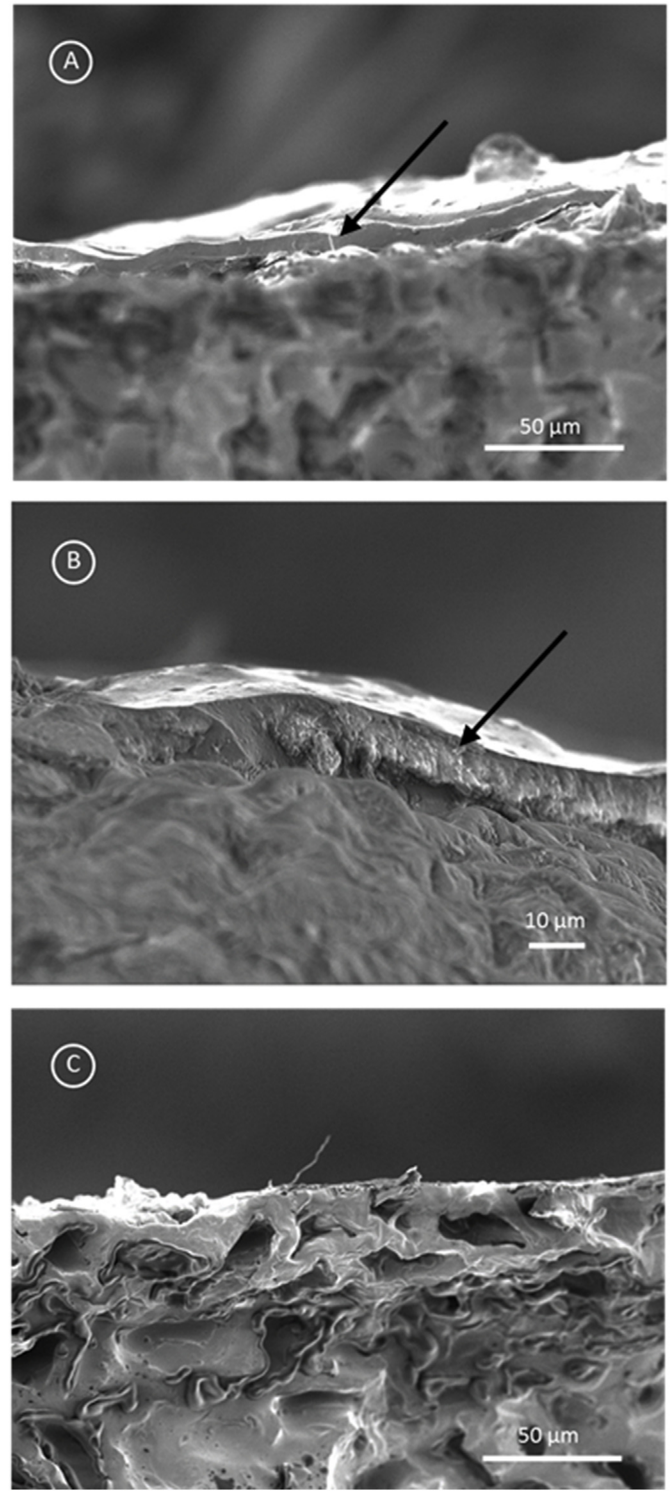

Fig. 4. SEM images of cross sections from coffee beans subjected to the treatments (A) S11 - starch 1 h in the oven and one immersion; (B) C31 - chitosan 3 h in the oven and one immersion and (C) control - uncoated bean.

the green coffee beans, especially color, directly influence their acceptance or rejection and the physical classification of the final product (Ribeiro et al., 2011).

In a stereoscope, it was possible to observe that uncoated green coffee beans (Fig. 3A and B) had opaque surfaces with more uniform color, whereas the same beans when coated (Figs. 3C and 3D, respectively) exhibited surfaces with higher gloss and whitish dots, evidencing the presence of polymer coatings. Therefore, this analysis is a simple and inexpensive alternative to verify the presence of polymer on the bean surface, since it is imperceptible to the naked eye.

Fig. 4, which shows the SEM images, clearly demonstrates the presence of coatings and reveals uniform deposition of polymers on the bean surface.

3.3.1. Color and water content of beans

Fig. 5 shows the graph of the principal component 1 *versus* the principal component 2, which explain 56.14% and 20.01%, respectively, of the variation in data. The PCA allowed the visualization of three distinct groups; each group was formed based on similarities exhibited by the data. Among all treatments, the one entailing starch coating with 3 h of oven pre-drying and one immersion of beans (S31) yielded coated beans that were most similar to the uncoated green beans (control) in terms of color and water content.

That the water content of the treated beans was comparable to that of the control indicates the efficiency of the S31 treatment in not altering the water content of the green coffee beans. Thus, this treatment prevents undesired transfer of moisture to the green coffee beans during coating application. This effect may be related to suspension viscosity, given that a viscous suspension is less likely to penetrate the material (Khwaldia et al., 2010). This is a desirable characteristic, since any increase in water content would favor fungal growth and cause product deterioration during storage (Nobre et al., 2007).

In terms of color, the beans immersed once in the starch suspension (S31) were more similar to the control than were beans immersed twice (S32); this is likely due to the formation of a more homogeneous film with one immersion than with two. Furthermore, the lower water content in the beans yielded by the S31 treatment may also have contributed to their greater proximity with the control in terms of the color parameters, since any increase in moisture may have caused a change in bean tone.

3.3.2. Sensorial analysis

For the sensorial analysis, besides the S31 treatment, which performed better in the color and water content tests (section 3.3.1), the C11 treatment was also selected since this treatment entailed less processing and hence lower production costs for a large-scale application. This analysis aimed to detect whether the coating of the polymers (starch and chitosan) would impart any unpleasant taste to the coffee beans before storage. Table 5 shows that the final grade of the beans coated with chitosan or starch showed no significant difference ($P > 0.05$) in relation to the control (uncoated coffee).

Furthermore, the coating does not affect the process of roasting; the same parameters can be used to roast the control and the coated beans from the two treatments. Thus, it can be inferred that the coatings do not impair the sensorial quality of the coffee beans.

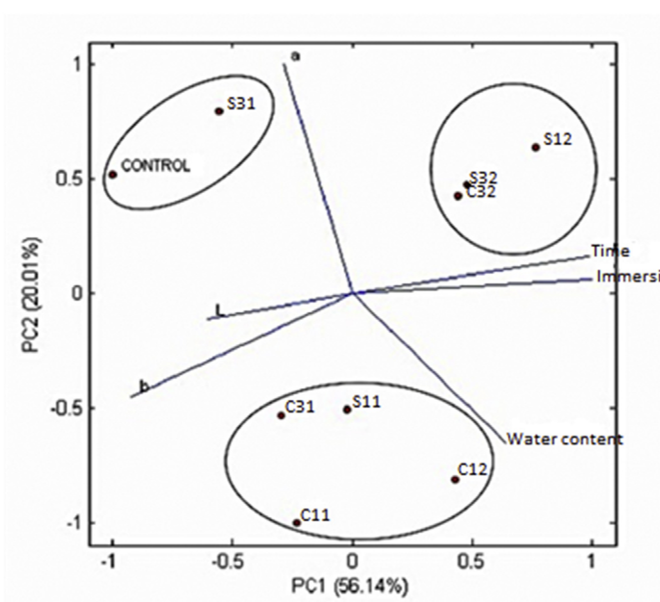

Fig. 5. PCA for staining and bean moisture content analyses. S11 - starch 1 h in the oven and one immersion; S12 - starch 1 h in the oven and two immersions; S31 - starch 3 h in the oven and one immersion; S32 - 3 h starch in the oven and two immersions; C11 - chitosan 1 h in the oven and one immersion; C12 - chitosan 1 h in the oven and one immersion; C31 - chitosan 3 h in the oven and one immersion; C32 - chitosan 3 h in the oven and two immersions; Control - uncoated bean.

Table 5
Final grade for the sensory analysis of coffees with and without coatings.

Coating	Final grade
Control	82.66[a]
C11	83.05[a]
S31	83.55[a]

Values are means ± standard deviation ($n = 3$). Means followed by the same lowercase letters in the column do not differ by the Tukey test ($P > 0.05$).

4. Conclusion

It is possible that both the biopolymer coatings adhere uniformly to the surface of the green coffee beans and are suitable for application considering the beverage's sensorial quality. However, the recommended treatment is the use of starch suspension with 3 h of pre-drying and one immersion to ensure maximum retention of the original physical and sensorial characteristics of the uncoated green coffee beans; this treatment yields coated green coffee beans best suitable for storage.

References

Ali, A., Underwood, A., Lee, Y.-R., & Wilson, D. I. (2016). Self-drainage of viscous liquids in vertical and inclined pipes. *Food and Bioproducts Processing, 99*, 38–50.

Andrade, R. D., Skurtys, O., & Osorio, F. A. (2012). Atomizing spray systems for application of edible coatings. *Comprehensive Reviews in Food Science and Food Safety, 11*(3), 323–337.

Aquino, A. B., Blank, A. F., & Aquino Santana, L. C. L. (2015). Impact of edible chitosan–cassava starch coatings enriched with Lippia gracilis Schauer genotype mixtures on the shelf life of guavas (*Psidium guajava* L.) during storage at room temperature. *Food Chemistry, 171*, 108–116.

Assis, O. B. G., & Britto, D. (2011). Evaluation of the antifungal properties of chitosan coating on cut apples using a non-invasive image analysis technique. *Polymer International, 60*(6), 932–936.

ASTM. American society standard testing and materials (2000). *Standard practice for conditioning plastics for testing.* 4 D618–00. Philadephia, PA.

ASTM. American society standard testing and materials (2007). *Standard test method for moisture content of paper and paperboard by oven drying.* ASTM D644–D699R07.

Borém, F. M., Nobre, G. W., Fernandes, S. M., Gualberto, R., Pereira, F. A., & Oliveira, P. D. (2008). Avaliação sensorial do café cereja descascado, armazenado sob atmosfera artificial e convencional *Ciência e Agrotecnologia*. *Ciência e Agrotecnologia, 32*(6), 1724–1729.

Borém, F. M., Ribeiro, F. C., Figueiredo, L. P., Giomo, G. S., Fortunato, V. A., & Isquierdo, E. P. (2013). Evaluation of the sensory and color quality of coffee beans stored in hermetic packaging. *Journal of Stored Products Research, 52*, 1–6.

Cerqueira, M. A., Lima, A. M., Souza, B. W. S., Teixeira, J. A., Moreira, R. A., & Vicente, A. A. (2009). Functional polysaccharides as edible coatings for cheese. *Journal of Agricultural and Food Chemistry, 57*(4), 1456–1462.

Chien, P.-J., Sheu, F., & Yang, F.-H. (2007). Effects of edible chitosan coating on quality and shelf life of sliced mango fruit. *Journal of Food Engineering, 78*(1), 225–229.

Colivet, J., & Carvalho, R. A. (2017). Hydrophilicity and physicochemical properties of chemically modified cassava starch films. *Industrial Cropsand Products, 95*, 599–607.

Corradini, E., Teixeira, E. D. M., Agnelli, J. A. M., & Mattoso, L. H. C. (2007). *Amido termoplástico* (1st ed.). São Carlos: Embrapa Instrumentação Agropecuária (Chapter 2).

Corrêa, P. C., Afonso Júnior, P. C., Silva, F. S., & Ribeiro, D. M. (2003). Qualidade dos grãos de café (*Coffea arabica* L.) durante o armazenamento em condições diversas.

Revista Brasileira de Armazenamento, 7, 137–147.
Dias, M. V., Azevedo, V. M., Borges, S. V., Soares, N.de. F. F., de Barros Fernandes, R. V., Marques, J. J., et al. (2014). Development of chitosan/montmorillonite nano-composites with encapsulated α-tocopherol. *Food Chemistry, 165*, 323–329.
Ferreira, D. F. (2011). Sisvar: A computerstatisticalanalysis system. *Ciencia E Agrotecnologia, 35*(6), 1039–1042.
Figueiredo, L. P., Borém, F. M., Cirillo, M.Â., Ribeiro, F. C., Giomo, G. S., & Salva, T. J. G. (2013). The potential for high quality bourbon coffees from different environments. *Journal of Agricultural Science, 5*(10), 87–98.
Gällstedt, M., Brottman, A., & Hedenqvist, M. S. (2005). Packaging-related properties of protein- and chitosan-coated paper. *Packaging Technology and Science, 18*, 161–170.
Han, J. H., Hwang, H. M., Min, S., & Krochta, J. M. (2008). Coating of peanuts with edible whey protein film containing α-tocopherol and ascorbyl palmitate. *Journal of Food Science, 73*(8).
ISO International Standard (2003). *Green coffee: Determination of loss in mass at 105ºC ISO 6673* (2nd ed.). Switzerland: ISO 2003.
de Jesús Avena-Bustillos, R., Krochta, J. M., Saltveit, M. E., de Jesús Rojas-Villegas, R., & Sauceda-Pérez, J. (1994). Optimization of edible coating formulations on zucchini to reduce water loss. *Journal of Food Engineering, 21*(2), 197–214.
Khwaldia, K., Arab-Tehrany, E., & Desobry, S. (2010). Biopolymer coatings on paper packaging materials. *Comprehensive Reviews in Food Science and Food Safety, 9*(1), 82–91.
Limchoowong, N., Sricharoen, P., Techawongstien, S., & Chanthai, S. (2016). An iodine supplementation of tomato fruits coated with an edible film of the iodide-doped chitosan. *Food Chemistry, 200*, 223–229.
Lingle, T. R. (2011). *The coffee cupper's handbook: A systematic guide to the sensory evaluation of coffee's flavor* (4th ed.). Long Beach: Specialty Coffee Association of America.
Liu, K., Liu, J., Li, H., Yuan, C., Zhong, J., & Chen, Y. (2016). Influence of postharvest citric acid and chitosan coating treatment on ripening attributes and expression of cell wall related genes in cherimoya (*Annona cherimola* Mill.) fruit. *Scientia Horticulturae, 198*, 1–11.
Li, X., Wang, C., Lu, F., Zhang, L., Yang, Q., Mu, J., et al. (2015). Physicochemical properties of corn starch isolated by acid liquid and l-cysteine. *Food Hydrocolloids, 44*, 353–359.
López, O. V., García, M. A., & Zaritzky, N. E. (2008). Film forming capacity of chemically modified corn starches. *Carbohydrate Polymers, 73*(4), 573–581.
Nobre, G. W. (2005). *Alterações qualitativas do café cereja descascado durante o armazenamento.* Lavras: UFLA (Dissertação Mestrado).
Nobre, G. W., Borém, F. M., Fernandes, S. M., & Pereira, R. G. F. A. (2007). Alterações químicas do café-cereja descascado durante o armazenamento. *Coffee Science, 2*(1), 1–9.
Nunes, C. A., Freitas, M. P., Pinheiro, A. C. M., & Bastos, S. C. (2012). Chemoface: A novel free user-friendly interface for chemometrics. *Journal of the Brazilian Chemical Society, 23*(11), 2003–2010.
Nurul, M., Mohd Azemi, B. M., & Manan, D. M. (1999). Rheological behaviour of sago (Metroxylonsagu) starch paste. *Food Chemistry, 64*(4), 501–505.
Ribeiro, F. C., Borém, F. M., Giomo, G. S., De Lima, R. R., Malta, M. R., & Figueiredo, L. P. (2011). Storage of green coffee in hermetic packaging injected with CO2. *Journal of Stored Products Research, 47*(4), 341–348.
Soares, N. F. F., Lopes, F. A., Medeiros, E. A. A., Silva, W. A., Gomes, S. G. S., Chaves, D. V., et al. (2007). Avaliação de revestimento contendo extrato de mostarda e da sanitização na conservação de batata-baroa. *Revista Ceres, 54*(314), 383–388.
Souza, A. C., Goto, G. E. O., Mainardi, J. A., Coelho, A. C. V., & Tadini, C. C. (2013). Cassava starch composite films incorporated with cinnamon essential oil: Antimicrobial activity, microstructure, mechanical and barrier properties. *LWT-Food Science and Technology Journal of Food Science, 54*(2), 346–352.
Specialty Coffee Association of America (2009). *Metodologia SCAA de avaliação de cafés especiais: Guia rápido – green coffee.* http://coffeetraveler.net/wp-content/files/903-SCAACuppingMethod_RESUMO_3a.pdf/, Accessed date: 20 June 2017.
Vieira, G., Silva, J. N. D., Silva, J., & Vilela, E. R. (2000). Avaliação da qualidade de café beneficiado armazenado em silo metálico modular. Setembro *Resumo Expandido do Simpósio de Pesquisa dos Cafés do Brasil* (Poços de Caldas, MG).
Yuan, Y., & Lee, T. R. (2013). Contact angle and wetting properties. In G. Bracco, & B. Holst (Eds.). *Surface science techniques* (pp. 3–34). Berlin: Springer.