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Research Article
Physicochemical and Mechanical Characteristics of Potato Starch-Based Biodegradable Films

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Abstract
Background and Objective: Plastics come from non-renewable sources and generate a high amount of non-biodegradable waste. The global demand for the reduction of plastic waste encourages the development of biodegradable films based on polymers and organic compounds. In this study, physicochemical (color, thickness) and mechanical characteristics (tension fracture and elongation percentage) of potato starch-based biodegradable films were determined. **Materials and Methods:** The films were elaborated with starch extracted from Canchán, Yungay and Peruana potato varieties. Results were statistically analyzed using one way variance of analysis followed by Tukey's test. **Results:** All the films had a transparent appearance and the color parameters were similar between the films made of Canchán and Yungay variety starch, differing slightly from those made with Peruana variety starch. All elaborated films showed thickness >1 mm. **Conclusion:** The best mechanical characteristics were observed in films from the Canchán variety starch, with a tension fracture of 1.43±0.12 MPa and elongation percentage of 36.67±2.80%. These results, in addition to contributing academically, show the potential for the industrial production of biodegradable films from potato starch.

Key words: Potato (*Solanum tuberosum*), peruvian, variety, polymer, starch, films, biodegradable, plastic

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The continuous use of plastic in production, conservation, transportation and food protection processes contributes significantly to increase in pollution. Approximately 100 million tons of polystyrene is used to produce food packaging, of which more than 90% is not recyclable and 75% is disposed of after use[1]. Plastics come from non-renewable sources and are non-biodegradable products, i.e. they take hundreds of years to get completely degraded, releasing toxic gases into the atmosphere during this process[2]. In light of this problem of global pollution, the food packaging sector, which represents the greatest demand for petroleum-based plastics, is the most interested in finding low cost alternatives such as biodegradable coatings[3,4].

A practical solution to the global demand for plastic waste reduction is the development of biodegradable films or coatings based on polymers and organic compounds[5]. A biodegradable film is defined as, a thin continuous matrix, able to be degraded naturally in short periods of time. These have mainly been used as coatings on fresh and minimally processed fruits, favoring their preservation and quality[6-9]. Films can be made from various materials of natural origin. For production of these films at industrial scale, an abundant and economical renewable raw material source is preferred. Materials such as polysaccharides, resins and some lipids have been considered as the main compounds that can be exploited to produce a degradable film[10]. Starch, being a polysaccharide, has relevant properties to be considered in the development of degradable films; it is one of the most abundant natural materials, easy to obtain with low cost, renewable and biodegradable[11]. Starch can be made into a transparent film that has moderate mechanical properties; however, its applications are limited. Owing to the high hygroscopic properties of this polysaccharide the films are water soluble and permeable to water vapor[12]. Starch can be obtained from various natural sources. According to Tapia *et al.*[13], potato is possibly the most climatically and ecologically versatile crop, being several regions of Peru suitable for the cultivation of thousands of varieties. The use of potato starch in the production of alternative materials to replace plastic, in the face of the global problem of environmental pollution, represents a great contribution to the development of agro-food technology. Thus, the objective of this study was to evaluate the mechanical and physicochemical properties of biodegradable films obtained from the starch of three potato varieties grown and commercialized in Peru.

MATERIALS AND METHODS

This study, including raw material collection, experimental analysis and data processing, was carried out from August, 2016-January, 2017.

Raw materials: Potatoes *(Solanum tuberosum)* from the highlands of Peru in the province of Otuzco, were used in this study. The varieties used were Canchán (C), Peruana (P) and Yungay (Y).

Obtaining potato starch: The starch of the three potato varieties was obtained based on the methodology used by Bello-Perez *et al.*[14] with few modifications. For this, the potato was peeled and cut into pieces, then washed and immersed in 5% sodium bisulfite solution (Dropaksa, Trujillo, Peru) for an average of 5 min. The potato pieces were liquefied in a domestic blender model 4655 (Osterizer, Wisconsin, U.S) for 2 min. The liquid phase was separated from the solid and foam phase using a mesh strainer. The solid particles were allowed to settle for 6 h at 4°C until a consistent layer formed. After the remaining liquid phase was removed, the sediment was washed with distilled water and then allowed to settle for a further 6 h. This was repeated 3 times. The liquid phase was removed and the final starch paste was placed in plastic trays and dried at 28°C for 24 h. After drying, the size was reduced and the samples were sieved by an automatic sifter (Tyler model RX-30-16, Ohio, U.S), using a N° 140 mesh with a 106 µm opening. The final starch obtained was stored in glass flasks for preservation until the films were made.

Elaboration of biodegradable starch films: To prepare the films, was employed the method described by Zamudio-Flores *et al.*[15]. For each starch variety, 800 mL solution was prepared. The starch and distilled water (4% w/v) were mixed at 300 rpm at room temperature (23$\pm$1) and then glycerol (SuMan, Trujillo, Peru) (2% w/v) was added. The solution was heated on a magnetic stirrer (AREX Velp Scientifica, Usmate Velate, Italy), from 25-65°C, over 15 min at a uniform stirring speed of 300 rpm. The final temperature was maintained for 10 min with a continuous stirring. The films were prepared by casting (Fig. 1), i.e., by depositing 40 g of the gelatinized suspensions on sterile polystyrene petri dishes and drying in an oven at 40°C for 15 h. The films formed were detached from the petri dishes. The films were then stored in an incubator (FOC 225i Velp Scientifica, Usmate Velate, Italy) at 25°C during characterization. The starch films obtained were named based on the potato variety from which

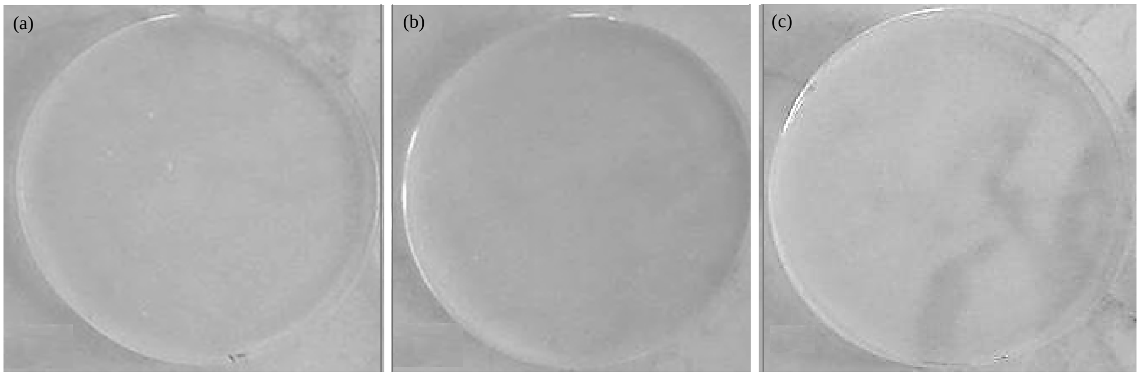

Fig. 1(a-c): Films prepared with gelatinized suspensions using starch from the (a) Canchán, (b) Peruana and (c) Yungay variety, deposited in sterile petri dishes

they were obtained as follows: starch films of the Canchán variety, "C", starch films of the Yungay variety, "Y'' and films of the Peruana variety, "P".

Characteristics

Physicochemical characteristics

Color: The color of films was determined using a colorimeter (JZ-300, Shenzhen Kingwell Instrument Co. Ltd, Guangdong Sheng, China). The CIELab technique was used that includes the following parameters and values: L* (luminosity) ranging from L = 0 (black) to L = 100 (white), a* ranging from red to green and b* ranging from yellow to blue. The values L*, a* and b* were determined and then used to express the total color change (ΔE). The values reported are the means of 3 measurements per sample. A white calibration plate (L_0^* = 83.10, a_0^* = 1.40 and b_0^* = -4.00) was used as the standard. The total color change (ΔE) of the films compared to the standard was calculated[16] using Eq. (1). Where $\Delta L^* = L^* - L_0^*$, $\Delta a^* = a^* - a_0^*$ and $\Delta b^* = b^* - b_0^*$; L_0^*, a_0^* and b_0^* are the standard color values and L*, a* and b* are the color values of the films:

$$\Delta E = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2} \quad (1)$$

Thickness of films: The thickness of the films was determined by using a Vernier caliper (Mitutoyo, Tokyo, Japan) with a sensitivity of 0.01 mm. The cited values are the mean of four measurements per sample.

Mechanical characteristics: The mechanical tests consisted of the determination of the fracture tension (TF) and elongation percentage (%E). Measurements were performed using a texturometer (TA.HD Plus Stable Micro Systems, UK), with a load cell of 100 kg. The tests were performed using the Standard Test Method for Tensile Properties of Thin Plastic Sheeting ASTM D-882-95[17] as reference. The films were cut into rectangles of 7.5×2.5 cm and then were conditioned in a refrigerated incubator for 48 h at 23±2°C and relative humidity of 53±2% before the test. The initial fixation spacing and the speed of the mechanical crosshead were set at 1 cm and 1 mm sec^{-1}, respectively. The TF was calculated by dividing the maximum force applied to the film during the fracture and the cross-section area of the film. The %E was determined as the percentage change in the original length (Lo) between the initial separation of the jaws during the rupture and the final length (L) achieved (being a Cauchy deformation) using Eq. (2). Both tests were performed as reported by Zamudio-Flores *et al.*[15]:

$$E\ (\%) = \frac{L - L_0}{L_0} \times 100 \quad (2)$$

Statistical analysis: The experiments were performed using a completely randomized design. Data were analyzed using Statistica 12 software (Statsoft, USA). One-way analysis of variance (ANOVA) with a 95% confidence interval (α = 0.05) was performed[18], followed by a Tukey's test to identify differences between the characteristics of the films of different potato starch varieties.

RESULTS

Starch extraction: The yield percentage of the starch extraction process for each potato variety is shown in Fig. 2, where it was observed that the highest percentage was obtained from the Yungay variety with 11.70%.

Table 1: Color parameters of films made with the three potato varieties

Potato variety	L*	a*	b*	ΔE
C	80.03±1.74^a	0.74±0.17^b	-4.09±0.50^b	3.81±1.10^b
Y	80.48±0.61^a	0.81±0.19^b	-4.27±0.16^b	2.89±0.70^b
P	77.22±1.66^b	1.61±0.41^a	-2.94±0.48^a	6.12±1.80^a

C: Canchán starch-based films, Y: Yungay starch-based films, P: Peruana starch-based films. Mean values±Standard deviation is presented. Differences between superscript letters indicate significant difference (p<0.05)

Table 2: Mechanical properties of films: Fracture results voltage (TF) and percent elongation (%E)

Potato variety	TF (MPa)	E (%)
P	1.04±0.05^a	17.58±1.05^b
C	1.43±0.12^a	36.67±2.80^a
Y	1.14±0.15^a	18.79±5.23^b

C: Canchán starch-based films, Y: Yungay starch-based films, P: Peruana starch-based films. Mean values±Standard Deviation is presented, Differences between superscript letters indicate significant difference (p<0.05)

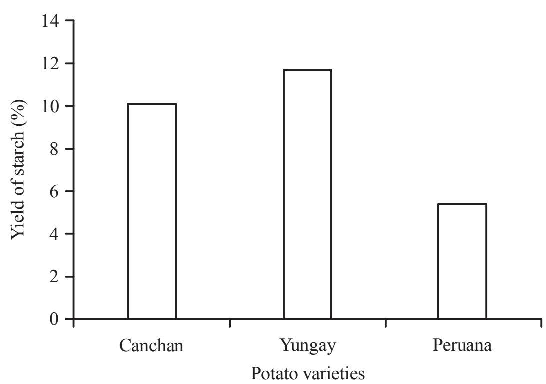

Fig. 2: Yield percentage of the starch extraction process for each potato variety

Physicochemical characteristics

Color: Starch films of the Yungay, Canchán and Peruana varieties presented a transparent visual appearance. Was observed a decrease in the L* values and the smallest increase in the a* and b* values for the film of Peruana variety, when compared with the values of the other two potato variety films (Table 1). These variations in color parameters, in turn, are related to an increase in ΔE. The transparency of the films can be explained based on the fact that their L*, a* and b* values are close to the values of the standard or control (standard value L_0^* = 83.10, a_0^* = 1.40 y b_0^* = -4.00).

Thickness: The mean thickness values of the Peruana, Canchán and Yungay potato starch films were 0.31±0.01, 0.40±0.05 and 0.42±0.02 mm, respectively. The film that showed the smallest thickness was the one made with Peruana variety starch.

Mechanical characteristics

Fracture tension and elongation percentage: The values of TF and %E are shown in Table 2. There was no significant difference in the TF values of the different potato varieties, whereas, the %E values between the potato starch films did have significant differences (p<0.05); the Canchán variety film was different from the other two films. Therefore, when comparing the three varieties of potato starch, it was observed that the film made with starch obtained from the Canchán variety presented a higher TF, with 1.43±0.12 MPa, while the film made with starch obtained from the Peruana variety had a low value (1.04±0.05 MPa). On the other hand, the film that presented the greatest percentage of elongation (36.67±2.80%) was the one made with the starch obtained from the Canchán variety.

DISCUSSION

It was observed that the highest yield percentage of starch during the extraction process was obtained from the Yungay variety with 11.70%,while the lowest was for Peruana variety.

Regarding color parameters, the observed variations in L*, a* and b* parameters for the starch films of the Yungay, Canchán and Peruana varieties are related to an increase in ΔE, explained by a very slight opacity. The transparency of the films is correlated with the crystallinity of starch. According to Bemiller and Whistler[19] and Bertolini[20], the starch films differ in their amylose and amylopectin contents. It was reported that higher the amylopectin content, greater is the crystallinity of the starch films. Another characteristic of the films is their thickness. According to the ASTM[17], films in the form of a thin layer are those with a thickness of less than 1 mm, therefore, the thickness of all elaborated potato starch films should be in this range.

The mechanical characteristics of TF and %E are the typical mechanical measurements used to characterize plastic films[17,21]. The TF value indicates the capacity of biofilms to resist rupture and %E represents the total deformation (stretching) that a film may resist before being completely ruptured[22]. Therefore, both mechanical variables reflect the ability of a film to protect the integrity of a given product.

The properties of a biodegradable film made from the combination of glycerol with starch depend strongly on the new chemical structure that is formed. The interaction between the different components greatly influences values of TF and %E. By comparing the three varieties of potato starch, it was observed that the film made with starch obtained from the Canchán variety presented a higher TF, while the starch obtained from the Peruana variety had a lower value. Likewise, the film that presented a greater percentage of elongation was the Canchán starch film. The increase in fracture tension is due to the presence of a greater amount of amylose[23]. Additionally, the relationship of amylose and amylopectin is important in the formulation of films, because the mechanical properties are influenced by the proportions in which these two components are found[24].

The results of the present study contribute to academic knowledge in development of biodegradable films and reveal the potential for industrial production of biodegradable films from potato starch. On the other hand, this study raises future research questions. It is recommended that to complement this work, future studies should explore other analyses such as determination of permeability, absorption and/or water retention, as well trial with different types and formulations of plasticizers.

CONCLUSION

It is concluded that the suspensions made with starches obtained from the three potato varieties (Canchán, Yungay and Peruana) were able to form homogeneous films. The films made of starch obtained from the Canchán variety presented promising results in terms of their mechanical characteristics (TF and %E). All elaborated biodegradable films showed a transparent appearance, with similar color and thickness values. Based on the obtained results, the Canchán variety is the variety from which the obtained starch gave films with the best properties. The degradable films of potato starch thus represent a viable, economic and ecological solution against plastic.

SIGNIFICANCE STATEMENT

This study determined, through physicochemical and mechanical analysis, the properties of Peruvian potato starch-based films. Results suggested that the potato starch has suitable characteristics to be used in the production of biodegradable films, which could be beneficial from academic and industrial points of view. This study will act as a basis for future studies in this field and it also raises a possibility to add industrial value to one of the highly cultivated but little explored resources in Peru.

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