International Journal of Biological Macromolecules 120 (2018) 1639–1645

Contents lists available at ScienceDirect

International Journal of Biological Macromolecules

journal homepage: http://www.elsevier.com/locate/ijbiomac

Development and characterization of edible films based on eggplant flour and corn starch

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ARTICLE INFO

Article history:
Received 5 June 2018
Received in revised form 3 September 2018
Accepted 20 September 2018
Available online 21 September 2018

Keywords:
Edible films
Eggplant flour (EF)
Corn starch (CS)
Physical properties

ABSTRACT

In this study, biodegradable and edible films based on eggplant flour (EF) and corn starch (CS) were prepared using casting method at proportion of 0–100, 25–75, 50–50, 75–25 and 100–0%, w/w. The mechanical, barrier, physical, and biodegradability properties were evaluated. Tensile strength, elongation at break, Young's modulus, thickness, density and L^* parameter of pure starch films were higher than those of other films. Solubility, water vapor permeability (WVP), moisture content and swelling index of films were augmented with the substitution of CS by EF. Color measurement of the edible films indicated that increasing the proportion of EF increased a^*, b^* and opacity values. The highest amount of water sorption was obtained for pure EF films. Moreover, the incorporation of EF accelerated films biodegradability compared to ones with only starch. In general, EF is a promising material for the formulation of edible and biodegradable films with adequate physical properties for food applications by direct contact.

1. Introduction

The largest part of materials used in packaging is produced from fossil fuels and non-renewable sources. The increase in synthetic polymers has been pushing researchers toward the development of new biodegradable and natural polymers, suitable for food packaging [1,2]. To extend the shelf-life of foods and the preservation them from oxidation, and microbial spoilage, while reducing packaging waste, the tendency is to use natural materials such as edible films and coatings [3]. These materials as thin layer barriers can control the transfer of moisture, gas and flavor components [4]. Biodegradable films can be developed using proteins, carbohydrates, lipids or mixture of them [5,6]. Among the natural and renewable resources, starch is one of the most important ingredients of films due to its low cost, availability, biodegradability, and forming odorless, colorless, nontoxic biodegradable films [5,7]. Good film-forming of wheat [8], cassava [9], potato [10], corn [11], rice [1] and quinoa [12] starch have been reported. Recently, there is an increasing interest in developing edible films using agriculture crop flours because of their low cost, easy obtaining and availability compared to pure components such as starch and proteins [13]. Thus, in the recent years, many studies have focused on the evaluation of biodegradable films from variety of flours such as pinhao [5], banana [2], chia [14], quinoa [15], achira [16] and rice [1]. According to the obtained results, most of the films made from the flours had a heterogeneous structure with poor mechanical properties and water vapor permeability compared to those from starches. Thus, it has been revealed that combination of flour with starch improves the mentioned characterization of the films [6].

Eggplant (*Solanum melongena* L.) is an economical vegetable crop with different shapes, sizes, and colors depending on its cultivars [17]. It is one of the functional ingredients due to its high dietary fiber content, minerals, antioxidant capacity and oxygen radical scavenging capacity [17,18]. The purple pigment of eggplant peel is caused by anthocyanins, belonging to the family of flavonoids [19]. EF contains significant amount of protein (12.9–15.9%), fat (0.8–5.1%), carbohydrates (38–62.7%) and crude fiber (13.1–19%) [17]. Since the proteins, carbohydrates and lipids are the main film-forming materials, it seems that EF can be used in producing edible and biodegradable films. On the other hand, due to the presents of high amounts of antioxidants in eggplant [17], EF can be promising material with the added value of oxidation protection for food they contain.

According to our current survey, there are no studies on the development of edible films using eggplant. Therefore, the aim of this study was to develop biodegradable films based on EF and CS and to evaluate the influences of their different ratio on film properties.

2. Materials and methods

2.1. Materials

The eggplants (*Solanum melongena* L.) used in this study were grown in Urmia, West Azerbaijan province, Iran. Corn starch was purchased

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https://doi.org/10.1016/j.ijbiomac.2018.09.126
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from Merck Company (Germany). All reagents used in this research were purchased from Merck Company (Germany).

2.2. Preparation of eggplant flour

EF was prepared according to the method of Uthumporn et al. [17]. The eggplants were washed in tap water and cut into disk-shaped slices without peeling off the skin. They were dried in hot air oven at 50 °C for 24 h. The dried eggplants were grinded into powder form with a kitchen blender (Arno, model wwB3 400 W, Brazil) and screened through a 60 mesh (250 μm) sieve. All grounded samples were packed into glass dishes and wrapped with aluminum foil to protect the sample from light. Then, they were stored at 4 °C.

2.3. Chemical analyses of eggplant flour

The moisture, ash, crude protein, fat, and crude fiber contents of the EF were determined according to AOAC methods [20], and the carbohydrate content was calculated by subtracting the sum of the moisture, ash, protein, and fat content from 100 [17]. The crude protein content was calculated using a conversion factor of 5.7. Antioxidant activity of EF was determined by DPPH radical scavenging capacity assay [17].

2.4. Film preparation

Films were prepared according to the method of Dick et al. [14] with a slight modification. The film forming solutions were prepared by dissolving EF and CS in 6% w/v in distilled water with different ratios EF to CS (0:1, 1:3, 1:1, 3:1 and 1:0 w/w). Solutions were mechanically stirred for 1 h at room temperature (25 °C), and their pH was adjusted to 7.5 with NaOH (0.1 *N*). The dispersions were then gelatinized by heating at 85 °C for 30 min in a water bath for the dissociation of starch granules and the formation of homogenous solution. After heating, glycerol (w/w) was added at 36% (w/w, based on the content of dry materials) as plasticizer, and the solution was stirred for 30 min. Then, the formulations were degassed for 5 min with an ultrasonic homogenizer (1200 W, 20 kHz). The aliquots of 30 ml of the resulting solutions were added in petri dishes (diameter of 10 cm). The films were then dried at room temperature (25 °C) for 48 h. After this time, the dried films solutions were peeled off the casting surface and conditioned under controlled relative humidity of 55% (maintained by saturated $Ca(NO_3)_2$ solution) at 25 °C for 48 h before experiments. All the tests were carried out in triplicate.

2.5. Characterization of films

2.5.1. Film thickness

Film thickness was measured by a digital micrometer (Mitutoyo-Co, Japan) with an accuracy of 0.001 mm. The mean thickness of each film was determined from an average of 10 random positions on the film samples [21].

2.5.2. Swelling index

The swelling index of samples was determined according to the method of Basiak et al. [8]. The film samples (2 × 2 cm) were first weighed (W_1). They were then submersed in a flask with distilled water (25 °C) for 2 min. Then, the samples were removed from the flask and excess water was removed by wiping them with filter paper. The films were weighed (W_2) and the amount of adsorbed water was calculated in percentage.

$$\textit{Swelling index}\ (\%) = [(W_2 - W_1)/W_1] \times 100$$

2.5.3. Solubility

The film solubility was determined according to Gontard et al. [22] and expressed as the percentage of dry matter of the film solubilized after 24 h immersion in water. Film samples were cut into 2 × 2 cm pieces and weighed. Then, the film pieces were immersed in 30 ml of distilled water, and the system was shaken for 3 h at room temperature. After removing excess water by filter paper, samples were dried in an oven at 105 °C for 24 h. The water solubility of the films was calculated according to the following equation:

$$\textit{Solubility}\ (\%) = \left[(W_i - W_f)/W_i\right] \times 100$$

where, W_i and W_f are the initial and final weights of the dried samples, respectively.

2.5.4. Density and moisture content

The films' density was determined from the weight and the volume of the samples according to the method of Pelissari et al. [2]. The film samples were cut into 2 × 2 cm pieces and weighed. The volumes of the samples were calculated from area and thickness.

The moisture content of the films was measured according to Maniglia et al. [23]. The film samples were cut into 2 × 2 cm and weighed. Samples were dried in an oven at 105 °C until constant weight. Moisture content was calculated according to the following equation:

$$\textit{Moiture content}\ (\%) = [(M_w - M_d)/M_w] \times 100$$

where, M_w is the initial weight of the films and M_d is the dry weight of the films.

2.5.5. Water uptake

The water uptake was determined according to the method of Angles & Dufrense [24]. The dried film samples (2 × 2 cm) were conditioned at $CaSO_4$ (RH = 0%) for 24 h, and samples were weighed. After that, they were conditioned in a desiccator containing $Ca(NO_3)_2$ saturated solution (RH = 55%) at 25 °C. The samples were weighed after 72 h until the equilibrium state was reached. The moisture absorption of the films was calculated as follows:

$$\textit{Water uptake}\ (\%) = [(W_t - W_0)/W_0] \times 100$$

where, W_t and W_0 are the weights of the samples after 72 h and the initial weight of the samples, respectively.

2.5.6. Water vapor permeability (WVP)

WVP tests were conducted according to Jahed et al. [25]. The film samples were sealed over a circular opening of a permeation cell, containing $CaSO_4$ (0% RH). Then, the cells were weighed and placed in a desiccator containing K_2SO_4 saturated solution (97% RH). Changes in the weights of the cells were recorded for 72 h. Water vapor transmission rate (WVTR) ($g \cdot m^{-2} \cdot h^{-1}$) was determined from the slope obtained from the regression analysis of moisture weight gain (Δw), transferred from a film area (A) during a definite time (Δt). WVP ($g. mm.m^{-2} \cdot h^{-1} \cdot Pa^{-1}$) was calculated using the following equation:

$$WVTR = \Delta w / A\Delta t$$

$$WVP = (WVTR \times Thickness)/\Delta P$$

where, A is the area (m^2), and Δp is the partial water vapor pressure gradient between the inner (p_1) and outer (p_2) surfaces of the film in the chamber (Δp = 3169 Pa at 25 °C).

2.5.7. Water vapor sorption kinetics

Water vapor sorption kinetics of the films was determined according to the method of Basiak et al. [8]. The film samples (2 × 2 cm) were placed in a desiccator containing the saturated solution of NaCl (75% RH). Then, the samples were weighed periodically every 24 h until reaching constant weight. The results were averaged and fitted by an exponential equation [26] as follows:

$$u = a + b(1 - \exp(-c\tau))$$

where, u is the water content (g water g d·m^{-1}), a, b and c are the constant parameter of the equation, and τ is time (h).

2.5.8. Light transmission and opacity

The light transmission values of the films were taken from ultraviolet-region (UV) to visible-light wavelengths, between 200 and 800 nm, with an UV–visible spectrophotometer (Model T60 UV, USA) according to the method described by Shiku et al. [27]. The films were cut into rectangles (1 × 4 cm) and placed on quartz spectrophotometer cell. An empty test cell was used as the reference. Opacity values of the films were expressed as the ratio between the absorbance at 600 nm (A600) and the film thickness (mm) [28].

2.5.9. Color measurement

The colors of the film samples were determined by the colorimeter (Minolta model CR-410, Tokyo, Japan). Results were expressed as lightness-darkness (L*), greenness-redness (a*) and blueness-yellowness (b*). The total differences in color (ΔE) were calculated by the following equation [29]:

$$\Delta E = \sqrt{\left(L_{sample} - L^*_{standard}\right)^2 + \left(a_{sample} - a^*_{standard}\right)^2 + \left(b_{sample} - b^*_{standard}\right)^2}$$

where, ΔL, Δa and Δb are the differences between the corresponding sample color parameters and standard parameters of white calibration plate ($L^* = 97.39$, $a^* = -5.11$ and $b^* = 7.16$).

2.5.10. Mechanical properties

Tensile strength, elongation at break and Young's modulus of the films were measured using a TA.XTPlus texture analyzer to determine the maximum tensile strength (TS, MPa), the maximum percentage of elongation at break (EAB, %) and Young's modulus (YM, MPa) according to the ASTM D882–95 method [30]. The samples were conditioned for 48 h at 55% RH and 25 °C before measurements. The initial grip distance and crosshead speed were 30 mm and 0.83 mm/s, respectively. The film specimens were cut into 5 × 1 cm^2 strips.

$$TS = F_{max}/A$$

$$EAB = (L_{max}/L_0) \times 100$$

$$YM = FL_0/A\Delta L$$

where, A is cross section area (m^2), F$_{max}$ is maximum load (N), L$_0$ is initial length of the film samples (m), L$_{max}$ is extension at the moment of rupture (m), F is force in Newton (N) and ΔL is change in length (m).

2.5.11. Biodegradation tests

Composting test was conducted according to Pineros-Hernandez et al. [9]. Film samples (2 × 2 cm) were placed on to an aluminum mesh and buried at 2 cm depth in plastic trays containing natural organic soil at room temperature. Water was sprayed to the soil twice a day. After 7 days, the film samples were taken out and photographed.

2.6. Statistical analysis

The analysis of variance (ANOVA) was applied to the data and the means were compared by Duncan's test. All data are presented as mean ± standard deviation. SPSS 16.0.0 statistical software (SPSS Inc., Chicago, IL, USA) was used for data analysis. Non-linear regression procedure was performed employing STATISTICA 10.0 software (Statsoft OK, USA).

3. Results and discussion

3.1. Chemical analyses of eggplant flour

The EF contains 10.68 ± 0.53 g/100 g moisture, 5.64 ± 0.74 g/100 g ash, 24.47 ± 2.43 g/100 g protein, 2.64 ± 0.21 g/100 g fat, 7.49 ± 1.91 g/100 g crude fiber and 56.57 ± 2.87 g/100 g carbohydrate. The antioxidant activity of EF was 22.22 ± 0.01 g/100 g. The moisture and protein contents of EF are higher than amaranth [31], chia [14], rice [1] and achira [16] flours. The fiber content of EF is lower than chia [14] and babassu mesocarp [23] flours and it is higher than pinhao flour [5]. In addition, the carbohydrate amount of EF is lower than pinhao flour [5] and it is higher than chia flour [14]. The EF has the highest fat and ash contents among rice [1], achira [16] and babassu mesocarp [23] flours. According to these results, EF has the highest contents of protein and fat among the other flours in this literature, so maybe it has good film forming ability.

3.2. Thickness

The thickness values for EF- and CS-based films ranged from 0.217 to 0.244 mm (Table 1). The films prepared with only starch (0:1 ratio) showed the highest thickness among the film formulations ($p < 0.05$). The film thickness decreased with the substitution of EF. Similar results were found by Sun et al. [32], which reported that the thickness of films decreased with the addition of peanut protein isolate to pea starch films. Furthermore, Dias et al. [1] observed that the thickness of rice flour was lower than rice starch films.

3.3. Swelling index

Swelling index showed the conservation of quality during storage of food products [33]. The results of film swelling are presented in Table 1, according to which the films prepared with only starch (0:1 ratio) had the lowest swelling index. It was also observed that the addition of EF to starch caused a great increase in the swelling index. The pure CS films had a swelling index of 103%, while the pure EF films had a swelling index of 406%, more than triple as high as for pure CS films. This may be related to the high amount of free hydroxyl groups of phenolic acid in EF, causing the enhancement of film moisture uptake. In a similar manner, Basiak et al. [8] observed that the addition of whey protein isolate in wheat starch films caused a great increase of the swelling index.

3.4. Solubility

The solubility values of different ratios of EF and CS films are shown in Table 1. Results confirmed that the solubility of CS films was the lowest (32.16%), while with the addition of EF, the solubility values significantly ($p < 0.05$) increased. The solubility of the EF films ranged from 59.27 to 82.60%. Therefore, these films were more soluble than amaranth (41.9%) [31], chia (25.34%) [14], quinoa (18.7%) [15], banana (27.9%) [2] and achira (38.3%) [16] flour films. Pelissari et al. [2] reported that the presence of hydrophilic groups from proteins and soluble fibers in the flour probably led to interactions between the flour components and water molecules. Consuming edible films together

Table 1
Thickness, swelling index and solubility of the EF-CS based films.

EF (%)	Thickness (mm)	Swelling index (%)	Solubility (%)
0	0.244 ± 0.008^a	103.39 ± 18.41^d	32.16 ± 0.61^e
25	0.240 ± 0.001^a	221.74 ± 8.41^c	59.27 ± 1.09^d
50	0.220 ± 0.003^b	222.50 ± 7.30^c	65.01 ± 1.76^c
75	0.219 ± 0.002^b	279.44 ± 23.26^b	76.85 ± 0.81^b
100	0.217 ± 0.002^b	406.11 ± 9.04^a	82.60 ± 0.75^a

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

with packed products required films with high degrees of solubility [34]. Similar results were found by Basiak et al. [8], in which the addition of whey protein isolate in wheat starch films was suggested to increase the water solubility of the films. Furthermore, Pelissari et al. [2] found that the solubility of banana flour films was higher than that of banana starch films.

3.5. Density and moisture content

Density and moisture content of films are presented in Table 2. An increase in the ratio of EF decreased the density, while increasing the moisture content of the films. This behavior could be related to the more open and more porous structure of EF films, compared to the CS films [2]. The irregularities and pores on the structure of the EF films may be related to the presence of other components beside starch in the polymer matrix, as protein, lipids and fiber [5].

Moisture content of pure EF films was significantly ($p < 0.05$) higher than CS films. The high moisture content of EF films maybe due to the presence of hydrophilic components (protein, carbohydrate and fiber) in the flour led to the interaction with water molecules and increase the water retention in the film [2,14]. Dick et al. [14] reported that the moisture content of starch films was lower than chia flour films. It was also reported that the densities of banana starch films were higher than those of banana flour films and the moisture contents of banana flour films were higher than those of banana starch ones. The moisture content for the EF films were higher than those reported in films elaborated from amaranth (13.78%) [31], banana (15.1%) [2] and babassu mesocarp (11.82%) [23] flour films.

3.6. Water uptake

Water uptake is an important property for starch films because water acts as a plasticizer. Plasticized films at higher water and plasticizer content had greater flexibility [7]. The water uptake results of the films showed that with the addition of EF to films, the water uptake significantly ($p < 0.05$) increased (Table 2). The pure EF films displayed higher water uptake capacity, probably due to its content of proteins, fibers, and total phenolic compounds [23]. Similar results were found by Maniglia et al. [23] who showed that water uptake of babassu mesocarp flour film was higher than that of babassu starch film.

3.7. Water vapor permeability

Water vapor permeability is an important property of films for their application because of water role in deteriorative reactions. Furthermore, moisture content has a great effect on the foods quality, so selecting a packaging material with appropriate moisture permeability is necessary to protect food quality during storage [13]. The results of WVP are presented in Table 3. As can be seen, the values of WVP for pure CS films are the lowest level (0.0019 ± 0.0001 $g\cdot mm/m^2\cdot h\cdot Pa$). The WVP values increased significantly ($p < 0.05$) with the addition of EF to films. The highest level of WVP was found for the pure EF films (0.0027 ± 0.0000 $g\cdot mm/m^2\cdot h\cdot Pa$), attributable to their low densities, more open, more porous structures and irregular surface than the structure of films containing starch. The irregularities on the surface of EF films are due to the existence of different molecules in the film matrix like protein, starch and lipid [13]. In addition, the presence of proteins and soluble fibers in flour due to their hydrophilic groups, probably resulting in a greater number of interactions between the flour components and water molecules, made the flour more permeable to water vapor than the starch films [23]. On the other hand, the moisture barrier properties of film improved by decreasing biopolymer size [14]. CS had a smaller size than EF led to reduction of WVP of films containing CS. In similar researches, Dick et al. [14] and Daudt et al. [5] reported that the addition of chia flour and pinhao flour to starch films increased the WVP of the films. The moisture barrier properties of the EF films were lower than those of many other films, including wheat gluten (0.0045 $g\cdot mm/m^2\cdot h\cdot Pa$) [35], apple peel (0.0042–0.0075 $g\cdot mm/m^2\cdot h\cdot Pa$) [36], whey protein isolate (0.0052 $g\cdot mm/m^2\cdot h\cdot Pa$) [37], chia flour (0.0057 $g\cdot mm/m^2\cdot h\cdot Pa$) [14] and mustard-meal (0.0034–0.0050 $g\cdot mm/m^2\cdot h\cdot Pa$) [38]. However, the moisture barrier properties of the EF films were higher than those obtained from an amaranth (0.0000 $g\cdot mm/m^2\cdot h\cdot Pa$) [31], banana (0.0008 $g\cdot mm/m^2\cdot h\cdot Pa$) [2], achira (0.0019 $g\cdot mm/m^2\cdot h\cdot Pa$) [16], rice (0.0004 $g\cdot mm/m^2\cdot h\cdot Pa$) [1] and quinoa (0.0005 $g\cdot mm/m^2\cdot h\cdot Pa$) [15] flours.

Table 2
Density, moisture content and moisture absorption values of the EF-CS based films.

EF (%)	Density (g/cm^3)	Moisture content (%)	Water uptake (%)
0	1.444 ± 0.033^a	13.28 ± 0.88^c	4.60 ± 0.41^c
25	1.391 ± 0.016^a	13.89 ± 0.93^c	5.03 ± 0.71^c
50	1.322 ± 0.005^b	19.20 ± 0.35^b	6.57 ± 0.76^b
75	1.268 ± 0.060^{bc}	19.49 ± 0.16^b	6.61 ± 0.49^b
100	1.221 ± 0.024^c	26.03 ± 1.56^a	8.20 ± 0.87^a

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

Table 3
WVP values of the EF-CS films.

EF (%)	WVP ($g\cdot mm/m^2\cdot h\cdot Pa$)
0	0.0019 ± 0.0001^b
25	0.0024 ± 0.0002^{ab}
50	0.0022 ± 0.0004^{ab}
75	0.0025 ± 0.0003^a
100	0.0027 ± 0.0000^a

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

3.8. Water vapor sorption kinetics

Water vapor sorption kinetic curves of EF and CS films at room temperature and 75% RH are shown in Fig. 1. In all films, the equilibrium condition was achieved after 10 h of the kinetic process. The results demonstrated that water sorption was rapid at the first step of the storage and lower amounts of water were adsorbed during the time. Mali et al. [39] and Medina Jaramillo et al. [40] reported rapid water sorption at the first step of storage for cassava starch films and *yerba mate* extract/cassava starch films, respectively. In addition, Galus and Lenart [41] found that an equilibrium state achieved after 10 h of the test for films based on pectin and alginate. The highest water sorption was observed for pure EF films and the lowest for pure CS films. Final water content for pure CS films and pure EF films were 0.129 and 0.231 g water g $d\cdot m^{-1}$, respectively. The addition of EF to CS films

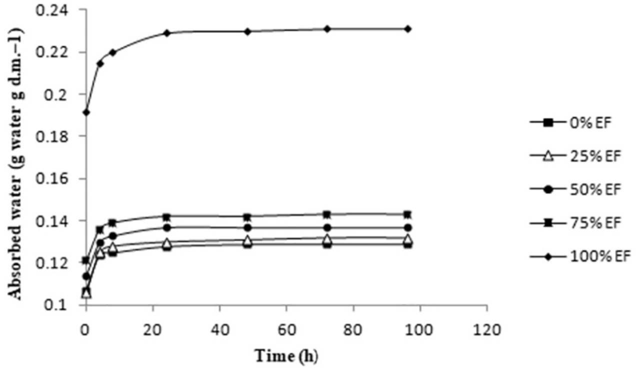

Fig. 1. Water content as a function of sorption time for eggplant flour and corn starch films.

increased the water sorption of the films. This behavior could be related to the hydrophilic groups (protein, carbohydrate and fibers) in EF [8]. Similar observation was obtained by Basiak et al. [8] who reported that the addition of isolated whey protein increased the water sorption of wheat starch films. Measured water sorption data were fitted to an exponential equation. The constants parameter a, b and c, derived from the fit, are shown in Table 4. The efficiency of fit was evaluated with $P < 10\%$, least RMSE, and the maximum R^2. Values of both root mean square error (RMSE) and mean relative modulus (%P) were low and the coefficients of determination are found to be high in all films ($R^2 > 0.95$).

3.9. Light transmission and opacity

Fig. 2 depicts the visual aspect of the EF- and CS-based edible films. The light transmission and opacity results are shown in Table 5. As can be seen, in the range of 200 to 400 nm (UV light region), the light transmittance of EF films was negligible and with an increase in the wavelength (visible light region), the light transmittance of the films increased. According to the results, the maximum light transmittance was related to pure starch film and by addition of EF, the light transmittance decreased, possibly because of natural pigments and the content of EF which were available to act as an excellent UV barrier. This property recommends their potential preventive effect on oxidation of product induced by UV light [14]. Similar results were reported by Dick et al. [14] and Pineros-Hernandez et al. [9], reporting that the replacement of starch with chia flour and rosemary extract with cassava starch, diminished the light transmittance of edible films.

The evaluation of the opacity values revealed that the pure starch films showed lower opacity compared to the films incorporated with EF. As can be seen in Table 4, the opacity of the films increased from 1.04 ± 0.23 for pure CS films to 7.44 ± 0.07 for pure EF films. This behavior was attributed to the composition of raw material and the presence of phenolic compounds, protein, lipid, and fiber in flour [2]. These components may have agglomerated in the film matrix to produce the dark surface [23]. The results indicated potential preventive effect of EF based films on product oxidation due to UV light. Similar observation was obtained by Daudt et al. [5], who reported that the pinhao flour films (10.30%) was more opaque than pinhao starch films (8.5%). In addition, Maniglia et al. [23] observed this behavior when they compared babassu mesocarp flour films (opacity of 6.23%) with starch films (opacity of 4.09%).

3.10. Color

One of the most important parameters for consumers to choose food products is color. The color values L^*, a^*, and b^* of the films are presented in Table 6. Results showed significant differences ($p < 0.05$) between the color parameter, indicating that color was affected by the different ratios of CS to EF in the films and the EF films is darker and more yellowish and reddish than CS films. These values indicated the characteristic color of raw material [2]. The high lightness values (L^*) proved the high transparency of starch films. The substitution of starch with EF decreased L^*, while increasing a^* and b^*, significantly. The L^* parameter for pure starch and pure EF films were 90.60 ± 0.05 and 28.51 ± 0.01, respectively. The amount of L^* parameter for EF films was lower than chia ($L^* = 52.15 \pm 1.03$) [14] and babassu mesocarp ($L^* = 73.24 \pm 0.55$) [23] flour films. The lower value for ΔE and the higher value for L^* of pure CS films were explained by the higher amounts of starch in these films compared to other ones. In a similar study, Pellisari et al. [2] reported that banana flour films were darker than banana starch films. Parameter a^* had minus value for pure starch films, meaning that the color of films changed to green and the parameter (a^*) for EF films changed the color to red. The amount of b^* index for pure CS films, 50% CS and 50% EF, and pure EF films were 4.063 ± 0.005, 12.633 ± 0.005 and 37.980 ± 0.010, respectively.

These results were consistent with those of Maniglia et al. [23], who reported that a^* and b^* parameters for babassu flour films were higher than those for babassu starch films. Also, Daudt et al. [5] found that the pinhao flour films were darker than pinhao starch films and the a^* parameter of pinhao flour films was higher than pinhao starch films. The greater values of differences in color (ΔE) indicated the films with higher color intensity. The highest ΔE value obtained for pure EF films, which could be interpreted considering the EF dark color. It can be concluded that with the addition of EF to CS films, the L^*decreased while a^*, b^*, and ΔE values increased.

3.11. Mechanical properties

Mechanical properties indicate the strength of films and their ability to increase the mechanical integrity of foods [3]. The results obtained for the mechanical properties are shown in Table 7. The substitution of EF in films caused significant differences in TS, EAB and YM. In fact, CS films were demonstrated to be stronger than EF films, with significantly higher YM and TS values. The substitution of EF decreased films' TS, EAB and YM. The EAB of films with addition of EF decreased significantly ($p < 0.05$) from 65.091 to 20.426%. Moreover, by the replacement of EF

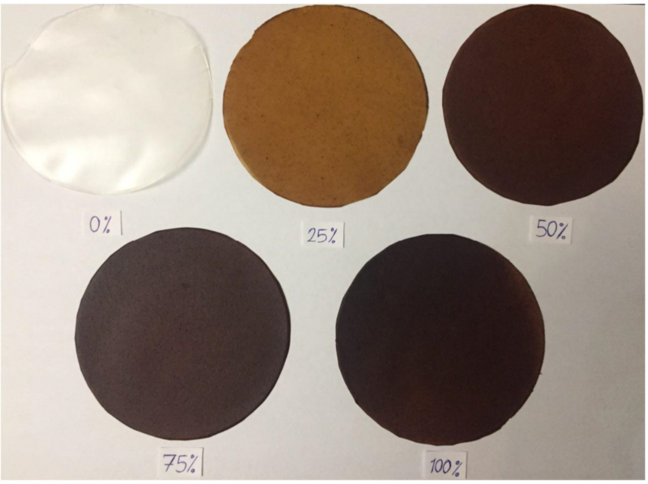

Fig. 2. Visual aspect of the edible films based on replacement percentage of corn starch with eggplant flour.

Table 4
Exponential equation parameters fitted water vapor sorption kinetics data by of EF and CS films.

	The equation constant and statistical parameters					
EF (%)	a	b	c	%P	RMSE	R^2
0	0.107	0.021	0.337	−0.015	0.761	0.98
25	0.106	0.025	0.307	−0.232	0.713	0.97
50	0.114	0.022	0.270	−0.009	0.444	0.99
75	0.121	0.020	0.240	0.195	0.570	0.97
100	0.192	0.037	0.194	−0.009	0.595	0.99

EF: eggplant flour, CS: corn starch.

Table 5
Light transmittance and opacity values of the EF-CS based films.

Light transmittance (%) at different wavelengths (nm)									
EF (%)	200	280	350	400	500	600	700	800	Opacity
0	0.3	19.86	38.01	42.26	45.91	48.08	49.54	50.81	1.04 ± 0.23^c
25	0.1	0.77	0.97	1.24	6.09	14.99	21.52	25.35	4.41 ± 0.12^b
50	0.1	0.73	0.87	0.92	1.74	3.86	9.59	14.32	6.97 ± 0.36^a
75	0.1	0.47	0.58	0.60	0.64	3.49	6.16	9.37	7.00 ± 0.69^a
100	0.1	0.22	0.30	0.35	0.40	2.79	5.04	6.65	7.44 ± 0.07^a

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

Table 6
Color measurement of the EF-CS based films.

Color indices value				
EF (%)	L^*	a^*	b^*	ΔE
0	90.60 ± 0.05^{a}	-4.30 ± 0.02^{e}	4.063 ± 0.005^{e}	7.508 ± 0.456^{e}
25	47.70 ± 0.01^{b}	6.66 ± 0.01^{d}	7.006 ± 0.011^{d}	51.066 ± 0.006^{d}
50	31.75 ± 0.05^{c}	10.46 ± 0.01^{c}	12.633 ± 0.005^{c}	67.679 ± 0.003^{c}
75	29.73 ± 0.05^{d}	11.18 ± 0.01^{b}	16.233 ± 0.005^{b}	70.179 ± 0.006^{b}
100	28.51 ± 0.01^{e}	11.26 ± 0.01^{a}	37.980 ± 0.010^{a}	77.212 ± 0.018^{a}

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

with starch, the TS decreased from 5.33 ± 0.08 MPa to 1.94 ± 0.01 MPa in pure starch and pure EF films, respectively, confirming that the EF films were more flexible than starch films, whereas starch films were more resistant and rigid compared to EF films. These properties were possibly due to the presence of proteins and lipids in the EF. Pelissari et al. [2] reported that lipid-protein interactions improved film flexibility. These results are in a good agreement with the findings of Daudt et al. [5], who investigated the development of biodegradable films prepared from pinhao starch with incorporating pinhao flour. The films prepared with only starch exhibited a significantly higher TS, YM and EAB compared to the ones prepared with pinhao flour. In addition, in another study, the TS and YM values of developed films from banana flour were also lower as compared to ones prepared from blends of banana starch and banana flour [5]. Similarly, the addition of starch to chia flour films also caused significant improvement in their mechanical characteristics [14]. Cohesion of ingredients could have direct impact on the mechanical properties of biopolymers. High amylose and low lipid content of starch compared to flour led to the improvement of mechanical strength. Lipids probably did not have any participation in the formation of cohesive and continuous structure of film matrix. Moreover, the improvement of mechanical characteristics at high amounts of amylose could be related to the development of matrix with high polymer per area [6].

3.12. Biodegradation tests

Biodegradation test evaluates the tendency of material components to break down via microorganisms. The evaluation of the biodegradation behavior of films based on starch and EF is substantial to find their environmental compatibility. The images of the films prior to their burial in soil and after 7 days of experiment are depicted in Fig. 3. It can be seen after 7 days of test, the films containing EF showed high loss of their original shape and integrity. The decomposition of EF and pure CS films occurred in 7th and 14th day of the test, respectively. This behavior could be related to presence of low molecular weight compounds in the EF and, therefore, they degraded before starch [42]. Pineros-Hernandez et al. [9] reported that the addition of rosemary extract increased the biodegradation time of the cassava starch films. Medina Jaramillo et al. [23] reported that the addition of yerba extract to cassava starch film decreased the biodegradation time. The important result of the biodegradation test in this work was that the incorporation of the EF improved the biodegradability of the starch films due to new polymeric materials, making them suitable for being returned to the environment without causing damage.

Table 7
Mechanical properties of the EF-CS based films.

EF (%)	TS (MPa)	EAB (%)	YM (MPa)
0	5.33 ± 0.08^{a}	65.091 ± 0.010^{a}	92.24 ± 0.04^{a}
25	4.29 ± 0.02^{b}	37.277 ± 0.005^{b}	65.46 ± 0.27^{b}
50	3.80 ± 0.07^{c}	21.221 ± 0.005^{c}	65.17 ± 0.07^{b}
75	2.36 ± 0.02^{d}	19.730 ± 0.003^{e}	42.59 ± 0.38^{c}
100	1.94 ± 0.01^{e}	20.426 ± 0.003^{d}	27.23 ± 0.13^{d}

Mean with different letters within a column indicate significant differences ($p < 0.05$).
EF: eggplant flour, CS: corn starch.

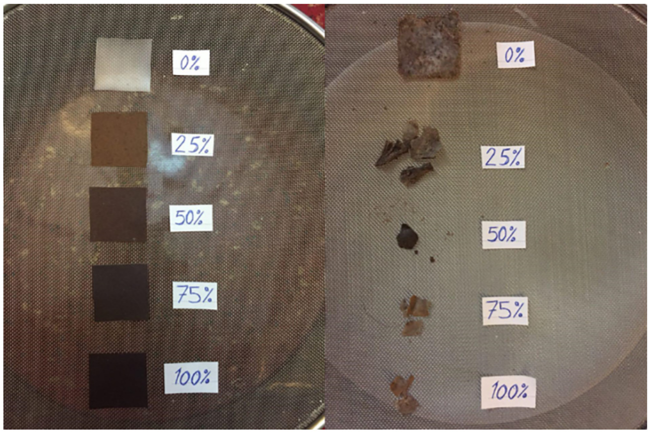

Fig. 3. Visual appearance of edible films after 7 days of composting.

4. Conclusions

As a novel biopolymer basis for the edible films, the film formability of EF was investigated in this research. The work showed the main characteristics of EF edible films alone and incorporated with corn starch through studying mechanical properties, WVP, water uptake, water solubility, water vapor sorption kinetics, opacity, color analysis, and biodegradability. Although EF had the ability to form edible films without the addition of starch, WVP and mechanical properties of the pure EF films were impaired. This may be related to the other components beside starch, as lipids, fibers and proteins in EF. The interactions between these components and starch and between each other could affect WVP, opacity and the mechanical properties of the EF films. The films showed complete biodegradation after 14 days of composting. According to the results, the combination of starch with EF (ratio of 50:50) was necessary in the films to obtain EF edible films with suitable physical properties. The results obtained in this work suggest that EF is a promising material with strong potential in the development of edible and biodegradable films and coatings as packaging of food products.

Acknowledgment

The authors thankfully appreciate Urmia University to provide the financial support (No. RD/4223; March/07/2018).

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