Application of different carbohydrates to produce squash puree based edible sheet

Asghar Torabi¹ · Mohebbat Mohebbi¹ · Farideh Tabatabaei-Yazdi¹ · Fakhri Shahidi¹ · Mohammad Khalilian-Movahhed¹ · Younes Zahedi²

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Abstract The production possibility of squash puree-containing edible sheet and its improvement by different hydrocolloids were studied. In this study, two hydrocolloids [carboxymethyl cellulose (CMC) and tragacanth gum] and also one plasticizer (glycerol) were used to produce squash puree-based edible sheets and optimization was performed to produce an edible sheet sample with the optimum properties. The results revealed that the CMC increased the tensile strength, elongation, and water vapor transition (WVT) of the edible sheets, whilst decreased their moisture content. The tragacanth increased the edible sheets elongation, oxygen transition (OT) and opacity. The glycerol also increased the elongation, density, OT, WVT, opacity and water solubility of the edible sheets; whereas the water activity, tensile strength, elastic modulus, and swelling capacity were decreased. The optimum quality of edible sheets was obtained from a combination of 0.14 g of CMC, 0.25 g of tragacanth and 1.88 g of glycerol.

Keywords Squash puree · Tragacanth · Carboxymethyl cellulose · Edible sheet

Introduction

Due to their omnipresence, low cost and desirable functional properties, crude oil-based plastics have been widely used (approximately 12 million tons per year) as packaging materials. However, environmental problems as well as the migration of the ingredients of the plastic package such as plasticizers, monomers and solvent residual into foodstuffs, leading to safety reduction and off-flavor of foods (Tharanathan 2003), have inspired the researchers to study the production of naturally based films in recent years. Utilization of such films has drawn attention during the last decade due to their potential in replacing common polymers in food packaging and their resistance to the transition of gasses, moisture, and solutes (Zahedi et al. 2011). Edible films are thin layers of natural substances encompassing the surface of the food material and act as a protector hence preventing undesirable changes in flavor, texture and exterior properties of foods (Robertson 2016) and exert barrier properties against moisture, gases, lipids, and odors. Therefore they are resistant enough to preserve foodstuffs and extend their shelf-lives (McHugh and Senesi 2000).

Proteins, lipids, and polysaccharides are the major ingredients of edible films which could be employed alone or in combination with each other (Gennadios et al. 1994). Starch, non-starch carbohydrates, gums, and fibers are of the most common polysaccharides used for edible film preparation (Rodríguez et al. 2006).

Preparation of edible sheets from the puree of fruits and vegetables could be considered as an innovative idea. Edible films from fruit puree were first invented by McHugh et al. (1996) who examined water vapor and oxygen transition of the films. Rojas-Graü et al. (2007) developed a new method to extend the shelf-life and improve the quality of fresh apple slices. Their sheets were

✉ Mohebbat Mohebbi
m-mohebbi@um.ac.ir; mohebbatm@gmail.com

¹ Department of Food Science and Technology, Faculty of Agriculture, Ferdowsi University of Mashhad, P.O. Box 91775-1163, Mashhad, Iran

² Faculty of Agriculture, University of Mohaghegh Ardabili, Ardabil, Iran

made out of apple puree and contained various amounts of fatty acids, waxes, vegetable oils, and pectin.

Various fruits and vegetable purees have been applied for the preparation of edible sheets carrot (Wang et al. 2011), peach (McHugh et al. 1996), apple (Rojas-Graü et al. 2007), banana (Perez-gago and Krochta 2001) and tomato (Du et al. 2009) are some of these examples. Edible sheets prepared from the puree of fruits and vegetables are cheap and their utilization -especially in seasons when the respective fruit or vegetable is highly harvested- could be a method to prevent agricultural waste by processing surplus raw material into products with extended shelf-life.

Squash (*Cucurbita pepo*) is a perennial plant from *Cucurbitaceae* family. 100 g of a fresh squash contains nearly 96.8 g moisture, 1.4 g protein, 0.2 g fat, 3.9 g carbohydrate, 17 mg calcium, 38 mg phosphorus, 0.5 mg iron, 38 mg magnesium, 340 mg potassium, 140 IU vitamin A, 0.07 mg thiamin, 0.04 mg riboflavin, 0.6 mg niacin and 18 mg vitamin C. Its average energy content is 22 cal/100 g fresh matter (Paksoy and Aydin 2004; Vural et al. 2000).

Gums are high molecular weight hydrophilic polymers which enhance viscosity and consistency through water absorption; thus increasing the stability of some food systems (Varela and Fiszman 2011). Tragacanth is obtained from vetch milk which is the common name of the genus *Astragalus*. The most desirable tragacanth is produced in Iran. This gum is comprised of two polysaccharides named bassorin and tragacanthin. Bassorin accounts for 60–70% of tragacanth and is a complex of polymethoxylated acids which swells in water, but does not dissolve (López-Franco et al. 2009). Tragacanthin is probably a methoxyl free bassorin, constitutes almost 30–40% of the gum and is a water-soluble compound (Anderson and Wang 1994).

CMC has been used alone or in combination with lipids or proteins to make edible films or coatings. In a research, Ghanbarzadeh et al. (2010) examined the physical properties of edible films based on modified starch and CMC. Also, Ghanbarzadeh et al. (2010) improved the barrier and mechanical properties of corn starch-based edible films by adding citric acid and CMC. Su et al. (2010) investigated the structural and physical properties of edible soybean protein isolate/CMC films. Arnon et al. (2014) studied the application of Chitosan/CMC-based edible coatings in the postharvest quality of citrus fruit.

Application of vegetable-based edible sheets especially for children consumption is a novel approach to incorporate such nutritious ingredients with attractive appearance into their food resources. Such sheets could also increase the diversity of food products and improve their marketability as well. So, the objective of this research was to optimize the formulation of squash-based edible sheets and evaluate the effects of CMC, tragacanth and glycerol on

some of their barrier and physical properties including oxygen transition, water vapor transition, mechanical properties, opacity, color, density, swelling capacity, water solubility, water activity, and moisture content through response surface methodology (RSM).

Materials and methods

Materials

Squash (*Mashhadi* var) was provided from the local market. Tragacanth gum (Sigma-Aldrich, USA), CMC (Merck, Germany), glycerol (Merck, Germany), ethanol (Merck, Germany), and Calcium nitrate 6H₂O (Ghatran Chemistry Company, Iran) were also purchased.

Puree preparation

In order to produce the squash puree, firstly the squashes were washed, peeled and sliced. The slices were then steam-cooked for nearly 12 min to soften their texture. Finally, the slices were mixed using a mixer (TM-767 OmniBlend) with a constant agitation speed for about 3 min to homogenize the mixture.

Preparation of the edible sheets

CMC (g)—0.1, 0.5 and 0.9 were weighed and dispersed in 60 ml of distilled water. The resulting solution was mixed by a magnetic stirrer at 75 °C for 10 min. Tragacanth gum (g)—0, 0.2 and 0.4 were weighed and dispersed in 3 ml of ethanol so that a homogenous suspension was obtained. After adding 60 ml of distilled water, the suspension was heated at 90 °C for 30 min until the gel was formed. The gel and glycerol (g)—1.5, 4 and 6.5 were added to 4.5 g of squash puree. The samples were then homogenized using a digital homogenizer (Ultra-Turrax-IKA T25, Germany) at 900 rpm for 3 min. Finally, the edible sheet paste was transferred into a mold and was kept at 23 ± 2 °C with the relative humidity of 36 ± 2%. After 24 h, samples were dried and the edible sheets were placed in a desiccator with the relative humidity of 50 ± 2% at 25 °C for 48 h to reach to equilibrium.

Water vapor transition (WVT)

A water vapor permeability tester (Brugger DIN 53122-WDDG, Germany) according to the method described by Khoshakhlagh et al. (2014), was utilized to determine the water vapor transition of the sheets. The samples (78.4 cm²) were located in the water vapor permeability testers so that the device chamber divided into

two partitions. Distilled water was shed in the lower partition providing the required water vapor. After fixing the sample and closing the chamber, nitrogen gas (1 bar) was circulated throughout the upper partition to be in contact with the sheet sample at room temperature.

Oxygen transition (OT)

Oxygen transition of the sheets was measured by the Gas Transition Tester (Brugger, Germany). This apparatus measures the oxygen diffused through the sheet during the time. The sample with the surface area of 78.4 cm² was placed in the device which divided the device chamber into two parts. After fixing the sample and closing the chamber, the lower part was evacuated and the sample was pressurized with oxygen (1.5 bars) in the upper part (the oxygen volume was 370 mm³) inducing the transition of oxygen through the sheet to the coulometric sensor. This test was carried out at room temperature (Colla et al. 2006).

Mechanical properties

The tensile strength (TS), elongation percent (%E) and elastic modulus of the sheets (14 × 2 cm²) were determined using a QTS texture analyzer (CNS Farnell, Essex, UK) according to ASTM D882-02 (2002) method. Initial grip separation and crosshead speed were 100 mm and 50 mm/min, respectively. TS was calculated by dividing the maximum load for breaking the sheet by the original minimum cross-sectional area, and %E was calculated by dividing the sheet elongation at rupture by the initial gauge length.

Opacity measurement

Opacity measurements were performed according to the method described by Gontard et al. (1992) with some further modifications. The edible sheets were cut to rectangles and placed in the spectrophotometer cell. A spectrum of each sheet was recorded by a UV–vis spectrophotometer (Shimadzu UV-160A). The area under the absorbance curve from 400 to 800 nm was determined by an area meter (Li-3100C) and defined as the sheet opacity. Opacity was expressed as the product of the absorbance value and wavelength (AV—nm).

Color analysis

A colorimeter (4510 HunterLab, Colorflex, USA) was employed to determine the color parameters including a^* , b^* and L^* . Color saturation (c), yellowness (YI) and whiteness (WI) of the sheets also were calculated using the following equations (Marvdashti et al. 2017):

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

$$YI = \frac{142.86b}{L} \quad (2)$$

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad (3)$$

Density

The film density was calculated as the ratio of film mass to its volume (Salgado et al. 2010). After conditioning of the sheets pieces of 4 × 4 cm dimensions, the thickness was measured at 9 points for each replicate. Film thickness was measured with a digital micrometer (QLR digit-IP54, China) at 4 different locations of each film sample.

Water solubility (WS)

The water solubility of films was determined according to the method of Gontard et al. (1994). The initial dry matter (%) was determined gravimetrically by drying 2 × 2 cm² film samples (about 0.16 g) at 103 ± 2 °C for 24 h. The same films (2 × 2 cm²) were then immersed in 50 ml of distilled water containing sodium azide (0.02% w/v) to prevent microbial growth. After 24 h, the samples were dried (103 ± 2 °C, 24 h) to determine the weight of dry matter which not dispersed in the water. By subtracting this from the weight of the initial dry matter, the weight of dissolved dry matter was obtained and expressed as a percentage of the initial dry matter content.

Water activity

The cup of water activity meter (ROTRONIC, HYGRO-LAB) was filled with a certain amount of the sample in 20 ± 1 °C (Rico-Peña and Torres 1991).

Swelling capacity

The swelling capacity of the sheets was calculated according to the approach proposed by Fajardo et al. (2010). The edible sheets (2 × 2 cm²) were immersed in 25 ml of distilled water (4 °C) for 180 s. The surface water was removed with blotting paper. The swelling capacity was calculated as follows:

$$ESR = \frac{W_s - W_d}{W_d} \times 100 \quad (4)$$

where W_s and W_d are the swelled and dried sample weights (g), respectively.

Moisture content (MC)

The moisture content of the sheets was determined by drying in an oven at 103 ± 2 °C for 24 h (Mettler UNB400, Germany) (Seyedi et al. 2014).

Statistical analysis

The principal objective of this study was to investigate the main and interactive effects of CMC, glycerol and tragacanth contents on some of the physical and mechanical properties of the edible sheets (tensile strength, elongation, elastic modulus, opacity, color, OT, WVT, whiteness, yellowness, density, moisture content, swelling capacity, water solubility and water activity). A 3-factor face-centered central composite design (CCD) was created and analyzed by Response surface methodology (RSM) using Design Expert (6.0.2, Minneapolis, MN). In RSM, each dependent variable is described through a model comprised of the main, quadratic and interactive effects of the independent variables. The coefficient of determination (R^2) and the probability of lack of fit are routinely applied to assess the adequacy of the models. Analysis of variance (ANOVA) was applied to evaluate the significance of the variable effects by computing the F-value. The higher the F-value and the lower the p value, the more significant the corresponding variable will be. The effects of the process variables on the responses were analyzed at a confidence level above 95% ($p < 0.05$).

Results and discussion

Squash puree and barrier properties

Some of the physicochemical properties of squash puree are as follows: soluble solids (Brix) 0.11 ± 5.4 , pH 0.02 ± 5.8 , Color parameters: L^* 72.8 ± 0.52 , a^* -5.7 ± 0.22 , and b^* 39.7 ± 0.33 .

The results showed a quadratic model of OT was significant ($p < 0.05$) and the lack of fit probability was insignificant ($p > 0.05$). The linear effects of tragacanth, the quadratic effects of CMC and tragacanth, and the interactive effect of CMC and glycerol significantly influenced the OT of the edible sheets; but the glycerol had the highest effect on OT ($p < 0.01$) (Table 1). OT is highly dependent on the polymers-oxygen interaction (Zhong and Xia 2008). The rise in the intermolecular interactions will result in structural compression of the sheets, thus, reducing their OTs (Zhong and Xia 2008).

In general, hydrophilic biofilms are highly transient to oxygen (Sothornvit and Krochta 2000). As portrayed in Fig. 1a, in a constant amount of CMC, OT was enhanced

significantly ($p < 0.05$) with increasing the tragacanth which could be attributed to the hydrophilic nature of tragacanth. Moreover, increasing the glycerol provokes rising in bio-polymeric chains mobility and formation of empty pores in the matrix of edible sheets which was the reason for OT increase in the sheets (Sothornvit and Pitak 2007).

The ANOVA of WVT showed that the linear effects of glycerol and CMC, the quadratic effect of glycerol, and the interaction between all three independent variables were significant in which the glycerol amount had the highest effect on the WVT of the edible sheets ($p < 0.01$) (Table 1).

WVT depends on the diffusion rate and solubility of water molecules in the matrix of the edible sheet (Gontard et al. 1994). In a constant amount of tragacanth, there was a significant increase in the WVT of the sheets by increasing the CMC ($p < 0.01$) (Fig. 1b). This phenomenon could be associated with hydrophilicity of CMC. The results are in agreement with those obtained by Jia et al. (2009) and Wang et al. (2011) for konjac glucomannan–chitosan–soy protein isolate and carrot puree edible films, respectively. Furthermore, in a constant amount of tragacanth, the increase of glycerol will give rise to significant WVT enhancement of the sheets ($p < 0.01$) (Fig. 1b). This could be due to the hydrophilic nature of glycerol, in addition to the mobility of large polymeric chains and enlargement of the spaces between them by glycerol increase (Pérez-Mateos et al. 2009; Wang et al. 2011).

Mechanical properties

The result showed that the fitted models were significant for tensile strength and elastic modulus ($p < 0.05$) and also for elongation ($p < 0.01$). The lack of fit probability of the three variables was insignificant ($p < 0.05$). The ANOVA revealed that the glycerol and CMC amounts had significant effects on the tensile strength of the sheets. Also, the linear effects of all three factors, the quadratic effect of tragacanth, and interactive effects were significant in the case of elongation. The linear effects of CMC and glycerol, as well as the quadratic effects of tragacanth and CMC, significantly affected the elastic moduli of the sheets (Table 1).

In general, hydrocolloids, due to the creation of a polymeric network, increase the tensile strength and elongation of edible sheets (Chen and Lai 2008). The interactive effect of CMC and glycerol is depicted in Fig. 2a, c. In a constant amount of tragacanth, the increase of CMC elevated the tensile strength and elongation of the sheets which could be attributed to the formation of a polymeric network in the sheets. As the CMC amount increased to 0.5 g, the elastic moduli of the sheets increased, and then decreased (Fig. 2b). The increase in the tragacanth amount

Table 1 Actual second-order regression coefficients for tensile, elongation, elastic modulus (EM), oxygen transition (OT), water vapor transition (WVT), saturation, whiteness, and yellowness

Regression coefficient	Tensile	Elongation	EM	OT	WVT	Saturation	Whiteness	Yellowness
b_0	2.78754	− 13.448	0.568	− 18.63	11.40	37.209	53.577	73.21
b_1	2.12433	7.657	0.543	4.35	− 0.164	16.957	− 14.437	32.635
b_2	− 0.59333	72.247	− 0.901	20.33	4.566	− 164.718	140.846	− 331.99
b_3	− 0.63753	9.944	− 0.106	7.038	0.418	− 1.464	1.544	− 3.543
b_1^2	− 2.00417	10.697	− 0.529	32.14	0.270	− 15.095	11.622	− 26.882
b_2^2	2.95833	− 129.708	2.233	97.20	− 8.041	338.419	− 285.633	677.21
b_3^2	0.011733	− 0.086	− 0.0007	0.099	− 0.105	0.2007	− 0.234	0.51
b_{12}	− 0.66667	137.479	− 0.747	− 23.16	− 11.41	− 0.853	− 2.197	0.998
b_{13}	0.24867	− 8.531	0.066	− 9.032	0.906	− 0.585	0.826	− 1.591
b_{23}	0.28133	− 18.013	0.132	− 4.455	1.133	3.272	− 2.570	6.264
R^2	0.94	0.97	0.96	0.97	0.98	0.85	0.85	0.85
R^2 (adj)	0.86	0.94	0.90	0.94	0.97	0.72	0.73	0.72
Lack-of-fit F value	5.41	4.77	5.30	3.86	0.49	1.74	2.17	2.08
Lack-of-fit p value	0.0562	0.0694	0.0581	0.0970	0.5171	0.2790	0.2081	0.22

b_0 constant term, b_1 linear coefficient of CMC, b_2 linear coefficient of tragacanth, b_3 linear coefficient of glycerol, b_1^2 quadratic coefficient of CMC, b_2^2 quadratic coefficient of tragacanth, b_3^2 quadratic coefficient of glycerol, b_{12} interaction effect of CMC and tragacanth, b_{13} interaction effect of CMC and glycerol, b_{23} interaction effect of tragacanth and glycerol

Fig. 1 The interaction effects of **a** tragacanth and glycerol on OT and **b** CMC and glycerol on WVT

had no significant effect on tensile strength and elastic modulus. However, in a constant amount of CMC, it increased elongation till reaching to 0.2 g which could be induced by the creation of the polymeric network. Nevertheless, exceeding this amount made the sheets fragile because of the sheets dehydration; as a result, the sheets elongation was reduced (Fig. 2c). Wang et al. (2011) acquired similar results in their studies on the mechanical properties of carrot puree-based edible films.

Generally, the addition of softening agents to edible films will reduce their mechanical strength and increase their flexibility (Lai et al. 1997). Also adding a low amount

of softening agents to the formulation of edible films will increase their mechanical strength. It should be noted that the mechanical properties of a sheet should be in such a way that its flexibility is high as well as its mechanical strength (Ghanbarzadeh and Almasi 2011). Figure 2a, b illustrate that by increasing the glycerol amount the tensile strength and elastic modulus of the sheets reduced while their elongation increased which could be due to the reduction of intermolecular forces and the mobility of polymeric chains, in addition to the reduction of polymer–polymer interactions by glycerol (Wang et al. 2011).

Fig. 2 The interaction effects of CMC and glycerol on **a** tensile strength **b** elastic modulus and **c** elongation and the interaction effects of tragacanth and glycerol on **d** color saturation **e** whiteness and **f**: yellowness of the edible sheets of the edible sheets

Color

The color is one of the highly important parameters because of its direct effect on the marketability of the products (Seyedi et al. 2014). The parameters of L^* , a^* , and b^* were measured. Because of the color variation of the sheets affected by the independent factors, the color

functions such as saturation, yellowness, and whiteness were calculated. The results showed the linear and quadratic effects of tragacanth were significant in the color functions (saturation, whiteness, and yellowness) ($p < 0.05$). The CMC and glycerol had no significant effect on color saturation, whiteness, and yellowness of the sheets. Whereas, tragacanth influenced all three parameters

significantly ($p < 0.05$) (Table 1). By increasing the tragacanth amount to 0.2 g, the color saturation and yellowness of the sheets decreased and then increased subsequently (Fig. 2d, f). At the same time, by increasing the tragacanth amount to 0.2 g, the whiteness of the sheets increased and then decreased (Fig. 2e). Glycerol also increased the color saturation, whiteness, and yellowness of the sheets, however insignificantly.

Opacity

The cubic model fitted to the experimental data of opacity was significant ($p < 0.05$) and the lack of fit was insignificant ($p < 0.05$). Also, the linear effects of glycerol and tragacanth were significant ($p < 0.05$) (Table 2). As indicated in Fig. 3b, by increasing the CMC, the opacity of the sheets increased but the increment due to CMC was less than that of tragacanth. The effect of CMC was not significant, while the effect of tragacanth was significant ($p < 0.05$). This phenomenon could be ascribed to the transparency of CMC. In general, the increase in the total dissolved solids of the edible sheets will lead to an increase in their opacity (Gounga et al. 2007).

Density

The quadratic model fitted to the data of the edible sheet densities ($p < 0.05$) and its lack of fit were insignificant at the same confidence level (Table 2). The edible sheet densities varied in the range of 0.107–0.132 g/cm³. Tragacanth and CMC had no significant effect on density; yet,

as illustrated in Fig. 3c, the density of the edible sheets increased significantly by the increase of the glycerol content ($p < 0.05$).

Solubility in water and swelling capacity

The quadratic models were fitted for solubility in water and swelling capacity of the sheets; both lacks of fits were insignificant ($p > 0.05$). The linear effect of glycerol and all interactive effects were significant in the case of the sheets solubility. Also, the linear effect of glycerol was significant on the swelling capacity of the sheets, as well as interactive effects of CMC-tragacanth and CMC-glycerol ($p < 0.05$) (Table 2). At the constant amount of tragacanth, the increase in the glycerol amount caused an increase in the solubility of the sheets ($p < 0.01$) (Fig. 3d), which could be attributed to the glycerol-water solubility (Araujo-Farro et al. 2010).

As described in Fig. 3e, tragacanth, and CMC did not have significant effects on the swelling capacity of the sheets. In a constant amount of tragacanth, with the glycerol amount increased, the swelling capacity of the sheets decreased significantly ($p < 0.01$) confirming the results obtained by (Mu et al. 2012).

Water activity

The water activity of the sheets should be considered to show free and bound water. The water activity of the sheets differed from 0.206 to 0.350. This property represents the presence of free water in a sheet; high water activity will

Table 2 Actual second-order regression coefficients for water activity, density, moisture content (MC), swelling capacity (SC), and water solubility (WS)

Regression coefficient	Aw	Density	Opacity	MC	SC	WS
b_0	0.2804	0.107	22.019	11.345	200.158	43.916
b_1	0.023	0.035	12.656	− 1.167	7.750	16.166
b_2	− 0.0045	0.036	7.867	− 4.340	− 68.25	38.833
b_3	− 0.0096	0.0019	− 1.7381	2.515	− 52.587	10.670
b_1^2	0.105	− 0.0364	− 1.979	− 2.301	− 66.66	−
b_2^2	0.5583	− 0.1333	− 50.416	− 1.704	233.33	−
b_3^2	0.0049	− 0.0002	0.477	− 0.21	2.333	−
b_{12}	0.6427	− 0.0021	36.145	− 0.156	− 329.166	75.00
b_{13}	− 0.0535	0.0018	− 3.411	0.537	26.875	− 8.041
b_{23}	− 0.1106	0.0047	− 1.273	0.975	32.25	− 16.083
R^2	0.88	0.89	0.78	0.97	0.97	0.88
R^2 (adj)	0.75	0.75	0.50	0.94	0.94	0.80
Lack-of-fit F value	5.69	5.49	3.71	2.33	4.51	3.92
Lack-of-fit p value	0.051	0.0548	0.1029	0.1879	0.0760	0.0799

b_0 constant term, b_1 linear coefficient of CMC, b_2 linear coefficient of tragacanth, b_3 linear coefficient of glycerol, b_1^2 quadratic coefficient of CMC, b_2^2 quadratic coefficient of tragacanth, b_3^2 quadratic coefficient of glycerol, b_{12} interaction effect of CMC and tragacanth, b_{13} interaction effect of CMC and glycerol, b_{23} interaction effect of tragacanth and glycerol

Fig. 3 The interaction effects of tragacanth and glycerol on **a** water activity, **b** opacity and **c** density and the interaction effects of CMC and glycerol on **d** solubility in water, **e** swelling capacity and **f**: moisture content of the sheets

lead to the more possibility of microbial growth. The results also revealed that the linear effect of the glycerol amount had a significant effect on the water activity of the sheets ($p < 0.05$) (Table 2). As depicted in Fig. 3a, the water activity of the sheets was reduced with the increase of the glycerol content as glycerol acts as a water-binding agent (Arvanitoyannis and Biliaderis 1999).

Moisture content

The results showed that the linear effects of CMC and glycerol, the quadratic effect of glycerol and the interactive effect of CMC and glycerol influenced the moisture content of the sheets significantly (Table 2). Since glycerol acts as a holder for water (Arvanitoyannis and Biliaderis 1999), therefore at constant tragacanth content, increasing the

glycerol caused an increase in the moisture content of the edible sheets (Fig. 3f) (Mu et al. 2012). The different researchers also emphasized when the glycerol amount was increased in the formulation of carbohydrate-based edible films the moisture content increased as well (Jouki et al. 2013; Zhang and Han 2006).

Optimization

Numerical optimization was performed by Design expert software and RSM to determine the optimum levels of the independent variables. The desired characteristics of the product were considered as follows: lower OT, WVT, water activity, moisture content, opacity, and water solubility, higher tensile strength and elongation, and other parameters in the range and all in a similar weight.

A combination of the factors levels was obtained rendering the most desirable formulation. In fact, numerical optimization detects a point associated with the highest desirability. The results indicated that the desirability was higher at larger amounts of tragacanth and smaller amounts of CMC and the best formulation was found the one containing 0.14 g of CMC, 0.25 g of tragacanth and 1.88 g of glycerol with the desirability of 0.634. The RSM values for each characteristic under the optimum conditions were predicted as 2.09 for tensile strength (MPa), 10.32 for elongation (%), 0.39 for elastic modulus (MPa), 1.88 for oxygen transition, 12.8 for water vapor transition, 70.17 for whiteness, 34.23 for yellowness, 18.54 for color saturation, 68.79 for water solubility, 117.24 for swelling capacity, 21.7 for opacity, 14.53 for moisture content, 0.118 for density, and 0.27 for water activity.

Conclusion

This study revealed that edible sheets could be manufactured from the squash puree. As the CMC amount increased, the tensile strength, elongation, and WVT of the sheets increased, but in 0.5 g of CMC, the elastic modulus increased. However, it was much lower at 0.9 g elastic modulus as compared with 0.5 g. By increasing the tragacanth amount, the OT and opacity of the sheets increased, whereas the rise in the tragacanth amount to 0.2 g initially improved elongation, but reduced this characteristic subsequently. The increase of glycerol content reduced the tensile strength, elastic modulus, water activity, opacity, and swelling capacity of the sheets and improved their elongation, OT, WVT, density, moisture content and solubility in water. The low values of the tragacanth resulted in a decrease of color saturation and yellowness; while the whiteness increased. However, at higher levels of tragacanth, the results were reversed. The

optimum quality of edible sheets obtained from a formulation containing 0.14 g of CMC, 0.25 g of tragacanth and 1.88 g of glycerol.

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