Meat Science 156 (2019) 231–239

Contents lists available at ScienceDirect

Meat Science

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

Modeling of osmotic treatment of ostrich meat coated by tragacanth and salep

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ARTICLE INFO

Keywords:
Osmotic treatment
Coating
Hydration
Dehydration
Peleg's model
Diffusion coefficient

ABSTRACT

This study involved coating of ostrich meat pieces (30 × 30 × 20 mm) with tragacanth gum (0.25%, 0.5%, and 1%) and salep gum (1%, 2%, and 3%) before osmotic treatment with salt solution (5, 15, and 27%) with the immersing duration of 1, 2, 4, 12, and 24 h to accelerate the transfer of moisture and minimize solid gain. This study also involved the investigation of the efficiency of the Peleg's model, Azuara's model, and diffusion equation in modeling water gain/loss and solid gain in meat pieces. Water gain/loss and solid gain were significantly affected by osmotic and coating concentrations during osmotic treatment. The Peleg's model had the best efficiency in the prediction of water loss at 5% and 27% concentrations and solid gain at 27% concentration. Diffusion model showed a favorable performance in the prediction of water loss and solid gain at 27% and 15% concentrations, respectively. It can be concluded that coating pre-treatment could control solid gain and facilitate water loss/gain.

1. Introduction

Osmotic treatment of raw meat with sodium chloride solution is widely used in the industry in order to increase the shelf-life and water-holding capacity of meat and obtain products with specific sensory characteristics (Schmidt, Carciofi, & Laurindo, 2009). Given the natural capacity of meat for moisture gain, this process leads to the transfer of salt and water in the same or opposite direction, depending on the osmotic concentration. This procedure leads to the dehydration or hydration of meat. The direction of fluid flow in the intercellular spaces of raw meat cannot be predicted only by the osmotic pressure of the solution since the water-holding capacity of meat, induced by the capillary forces in intercellular spaces, plays a significant role in fluid direction. In this regard, the dynamic reactions of actin-myosin-sodium chloride determine the relative importance of the mechanism of mass transfer (i.e., swelling or contraction). Several studies are investigating this domain, such as those conducted by Gallart-Jornet et al., 2007; Schmidt, Carciofi, & Laurindo, 2008; Barat, Aliño, Fuentes, Grau, & Romero, 2009; Alino, Grau, Fernández-Sánchez, Arnold, & Barat, 2010; Ozuna, Puig, García-Pérez, Mulet, & Carcel, 2013.

Osmotic dehydration has been accepted as a suitable method for obtaining medium-moisture food. Accordingly, it is a processing technique implemented before the execution of a wide range of processes, such as air drying, pasteurization, and freezing (Schmidt et al., 2008). Some of the benefits of osmotic dehydration include better color and taste preservation, better protection of cell wall selection, and less energy requirement. However, this method is limitedly used in industrial development due to the difficulty of controlling the broad absorption of solutes, which has an adverse effect on nutritional profiles and food sensory features, recycling and microbial stability of osmotic solutions, and release of substances, such as vitamins, organic acids, sugars, and mineral salts into osmotic solutions. Some studies have been conducted targeting the reduction of the broad absorption of solutes using edible coatings before osmotic dehydration (Jalaee, Fazeli, Fatemian, & Tavakolipour, 2011; Khin, Zhou, & Yeo, 2007).

The osmo-coating or osmotic membrane is performed to improve the quality of food during the osmotic process, in which coating of food leads to dehydration with an artificial barrier at the surface that might prevent the penetration of solutes into foodstuffs. Meanwhile, this process has no effect on the pace of dehydration. Therefore, coating food with polymeric materials having water permeability prior to osmotic treatment can result in a higher osmotic dehydration efficiency (Sabetghadam & Tavakolipour, 2015). Several studies (e.g., Camirand, Forrey, Popper, Boyle, & Stanley, 1968; García, Díaz, Martínez, & Casariego, 2010; Jalaee et al., 2011; Khin et al., 2007; Khin, Zhou, & Perera, 2006; Lazarides, Mitrakas, & Matsos, 2007; Lević et al., 2008; Matuska, Lenart, & Lazarides, 2006; Sabetghadam & Tavakolipour, 2015) are available on the use of edible coatings prior to the osmotic

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https://doi.org/10.1016/j.meatsci.2019.05.031
Received 27 January 2019; Received in revised form 15 April 2019; Accepted 29 May 2019
Available online 10 June 2019

process of fruits and vegetables. However, there is limited research on the osmotic membrane process of raw meat, including the study conducted by Camirand et al., 1968 (which includes limited information) and Yuan, Ya, & Qilong, 2016. The study performed by Yuan et al. (2016) showed that the pretreatment coating of scallop adductor resulted in the improvement of dehydration efficiency during osmotic treatment in some samples, as well as the efficiency index of osmotic treatment.

There are limited studies on the use of tragacanth (Izadi, Ojagh, Rahmanifarah, Shabanpour, & Sakhale, 2015; Mohebbi, Amiryousefi, Ansarifar, & Hasanpour, 2012; Mohebbi, Ansarifar, Hasanpour, & Amiryousefi, 2012) and salep (Ekrami & Emam-Djomeh, 2013; Papandreopoulou, Tzoumaki, Adamidis, & Zinoviadou, 2015) gums as coatings of foodstuffs. Given the indigenous growth of these gums in Iran and limited studies on this field, the present study involved the use of two tragacanth and salep gums to coat meat pieces separately.

Knowledge of the kinetics of water and solid transfer during osmotic process has a special technological significance. This knowledge facilitates the estimation of the immersion time of meat pieces in the osmotic solution to obtain products with specific moisture and salt content (Schmidt et al., 2008). Classical models are used to describe the kinetics of mass transfer during osmotic treatment and based on diffusion equation (Chiralt et al., 2001; Telis, Romanelli, Gabas, & Romero, 2003). Diffusion equation provides an analytic solution for only classical geometries. Numerous studies are investigating the application of this equation in the modeling of mass transfer in the osmotic process and the diffusion coefficients of water and soluble solid contents. However, the resolution of non-classical geometries requires the adopting of numerical techniques (Schmidt et al., 2009). Empirical models have the advantage of applying non-classical geometries. The Peleg's and Azuara's models are among two-parameter empirical models, used to model gain curves and predict the rate of dehydration and the equilibrium concentrations of water and soluble solids in many foods (Assis, Morais, & Morais, 2016).

The aim of the present study was to evaluate the effect of tragacanth and salep coatings on water loss/gain and solid gain in the pieces of ostrich meat during an osmotic treatment process by investigating osmotic solution concentration and immersion time. This study also involved the modeling of mass transfer (i.e., water and solid contents) and determining water and solid diffusion coefficients in a range of osmotic solvent concentrations.

2. Materials and methods

2.1. Sample preparation

For the sampling purpose, fresh meat samples were prepared from the thigh muscles of 10 to 12-month-old male Blue Neck ostrich (*Struthio camelus australis*) from the Industrial Slaughterhouse of Mashhad, Mashhad, Iran. In the laboratory, the visible fat of the samples was separated, followed by cutting the meat into 30 × 30 × 20 mm pieces using a sharp knife parallel to the fibers. Afterward, the samples were kept in plastic films at freezing temperature (−18 ± 0.5 °C). Samples were defrosted, dried, and weighted at 4 ± 1 °C 24 h before the test.

2.2. Coating

After purchasing the strips of tragacanth from the local market of Mashhad, they were ground with a laboratory blender and then passed through a 0.425-mm sieve. Palmate-tubers of salep were purchased from a producer in Kurdistan, Iran. The tubers of salep were processed into dry yellow powder following the method used by Farhoosh and Riazi (2007).

Subsequently, tragacanth gum solutions and salep gum solutions were prepared at concentrations of 0.25%, 0.5% and 1% *w/v* (Izadi et al., 2015; Zolfaghari, Mohebbi, & Haddad Khodaparast, 2013) and 1%, 2%, and 3% w/v (Ekrami & Emam-Djomeh, 2013) respectively.

In order to coat the meat samples, they were separately immersed in gum solutions at the given concentrations for 2 min. In the next stage, the samples were dehydrated on metal mesh filters (Bazargani-Gilani, Aliakbarlu, & Tajik, 2015). Then, the samples were immersed in 0.25%, 0.5%, 1%, 2% and 3% calcium chloride solutions (depending on the concentration of the gum) for 30 min to consolidate the coating. Afterward, to further consolidate the coating, the samples were maintained on a metal filter at ambient temperature for 5 min before being weighed (Yuan et al., 2016).

2.3. Osmotic treatment

Osmotic solutions were prepared from sodium chloride and distilled water in three concentrations of 5%, 15%, and 27% w/v 24 h. In order to minimize the dilution of osmotic solution during osmotic treatment, the solution to sample ratio was determined as 12.5:1 (Dimakopoulou-Papazoglou & Katsanidis, 2017). Osmotic treatment of the samples was carried out in two-liter plastic beakers with a magnetic stirrer for 1, 2, 4, 12, and 24 h at 15 °C.

2.4. Measurement of water loss and solid gain

Water loss and solid gain are two important kinetic parameters in an osmotic treatment. These parameters are determined after weighing the samples removed from the osmotic solution and placing them in the oven using Eqs. (1) and (2) (Sabetghadam & Tavakolipour, 2015). where, x_{w0} and x_{wt} are moisture levels at $t = 0$ and t time of osmotic treatment, respectively. Furthermore, x_{s0} and x_{st} are solid levels at $t = 0$ and t time of osmotic treatment, respectively. Moreover, m_0 and m_t are respectively the weights of the sample at $t = 0$ and t time of osmotic treatment. In order to measure moisture level (X_w), the samples were dried in an oven at 102 °C until obtaining a stable weight (i.e., for approximately 24 h) based on the AOAC, 1997 standard. Moisture level was estimated using the following *Eq.(3)*, where, w and w_{ov} are the weights of the meat sample before and after being placed in the oven, respectively.

$$WL = \frac{(m_0 \times x_{w0}) - (m_t \times x_{wt})}{m_0} \tag{1}$$

$$SG = \frac{(m_t \times x_{st}) - (m_0 \times x_{s0})}{m_0} \tag{2}$$

$$Xw = (w - w_{ov})/w \tag{3}$$

2.5. Mathematical modeling

2.5.1. Peleg's model

In 1988, Peleg presented a two-parameter empirical model for describing the water and solid content levels for the kinetic prediction of mass transfer under an equilibrium condition. This model has been used in several reports to predict the mass transfer kinetics of muscle tissue during osmotic process (Corzo & Bracho, 2006; Dimakopoulou-Papazoglou & Katsanidis, 2017; Filipovic´ et al., 2014; Yuan et al., 2016). This model was adopted in the present study for the investigation of the kinetics of water gain curve in the osmotic process in meat pieces under equilibrium conditions using Eq. (4) (Assis et al., 2016; Pezo et al., 2013; Schmidt et al., 2009):

$$X = \pm \frac{t}{k_1 + k_2 .\, t} \tag{4}$$

where, X shows water loss or solid gain (g/g) and t is the time of osmotic treatment (s). In this regard, the constants of $k_1{}^w$, $k_1{}^s$, $k_2{}^w$, and $k_2{}^s$ are obtained by the linear regression of laboratory results using MATLAB R, 2014. In this equation, the symbol of ' ± ' becomes '+'

during water or solid gain and '–'during dehydration. In this research, k_1[1] (k_1^w and k_1^s) depends on the initial rate ($t = 0$) of mass transfer. In addition, k_2[2] (k_2^w and k_2^s) depends on equilibrium values of water loss or solid gain (X^{∞} *is* WL^{∞} or SG^{∞}).

$$\frac{dX}{dt} = \pm\frac{1}{k_1} \tag{5}$$

$$X^{\infty} = \pm\frac{1}{k_2} \tag{6}$$

2.5.2. Azuara's model

In 1992, Azuara et al. developed a model based on mass balance to predict water loss and solid gain during osmotic treatment. This two-parameter model estimates the mass transfer coefficients and final equilibrium point. This model was used in the studies performed by Schmidt et al., 2009, Pezo et al., 2013 and Dimakopoulou-Papazoglou & Katsanidis, 2017 to assess the mass transfer kinetics of muscle tissue during an osmotic process. This model is shown in Eq. (7):

$$X = \frac{k.\ t(X^{\infty})}{1 + k.\ t} \tag{7}$$

where, X and X^{∞} represent water loss and solid gain, respectively, at times t and $t = \infty$, and t signifies the duration of osmotic treatment. In this model, k (k_w and k_s) is a parameter that depends on the immersion time and mass transfer rate (moisture or solid). Linearization of Eq. (7) leads to the following equation:

$$\frac{t}{X} = \frac{1}{k.\ X^{\infty}} + \frac{t}{X^{\infty}} \tag{8}$$

where, X^{∞} is determined by the slope of the linear regression t/x diagram against t with MATLAB R, 2014. In the present study, the values of WL^{∞} and SG^{∞} were obtained by the Peleg's and Azuara's models. However, considering the value of R^2 and RMSE, the water and solid diffusion coefficients were determined using the WL^{∞} and SG^{∞} estimated by the Peleg's equation.

2.5.3. Diffusion model

The diffusion coefficients of a rectangular mass (2a × 2b × 2c) for water loss and solid gain were obtained using Eqs. (9) and (10) (Crank equation), respectively, according to the Fick's 2nd law (Crank, 1975; Rastogi & Niranjan, 1998).

$$\frac{WL}{WL^{\infty}} = 1 - \sum_{n=1}^{\infty} C_n^3.\ \exp\left(-D_w.\ t.\ q_n^2\left[\left({}^1/_{a^2}\right) + \left({}^1/_{b^2}\right) + \left({}^1/_{c^2}\right)\right]\right) \tag{9}$$

$$\frac{SG}{SG^{\infty}} = 1 - \sum_{n=1}^{\infty} C_n^3.\ \exp\left(-D_s.\ t.\ q_n^2\left[\left({}^1/_{a^2}\right) + \left({}^1/_{b^2}\right) + \left({}^1/_{c^2}\right)\right]\right) \tag{10}$$

where, WL^{∞} and SG^{∞} are equilibrium water loss and solid gain, respectively. In addition, D_w and D_s signify water and solid diffusion coefficients, respectively, and C_n is equal to $2\alpha(1 + \alpha)/(1 + \alpha + \alpha^2.q_n^2)$. The values of q_n are non-zero positive roots of tan $(q_n) = -\alpha\ (q_n)$. Factor α is the ratio of the solution volume to each piece (in the present study, α was equal to 100). In addition, $1/A^2 = [(1/a^2) + (1/b^2) + (1/c^2)]$ was established. Given the fact that the Fourier number (Dt/A^2) was above 0.1, the first mathematical phrase of Eqs. (9) and (10) is considerable, while the rest of the phrases could be neglected (McCabe, Smith, & Harriot, 1993). Therefore, Eqs. (9) and (10) are summarized as follows:

$$-\ln\left(\frac{1 - (WL/WL^{\infty})}{c_1^3}\right) = \frac{D_w.\ t.\ q_1^2}{A^2} \tag{11}$$

$$-\ln\left(\frac{1 - (SG/SG^{\infty})}{c_1^3}\right) = \frac{D_s.\ t.\ q_1^2}{A^2} \tag{12}$$

In Crank equation, WL^{∞} and SG^{∞} can be estimated from the Peleg's and Azuara's models; however, in the present study, these values were obtained by means of the Peleg's equation. Moreover, water and solid diffusion coefficients were determined using linear regression in MATLAB R 2014a.

2.6. Osmotic treatment efficiency index

Osmotic treatment efficiency index is defined as water to solid diffusion coefficient ratio (D_w/D_s). This index is used as a criterion for the optimization of osmotic process, especially the dehydration efficiency index (Khin et al., 2006).

2.7. Statistical analysis

The present study adopted a completely randomized design with nested factorial arrangement in three replications. Data analysis was performed in MiniTab (version 17.3.1). P-value < .05 was considered statistically significant. Modeling was carried out using MATLAB R, 2014. The parameters of Peleg's, Azuara's, and diffusion models were obtained via linear regression. Moreover, the models and parameters were evaluated using R^2 and root-mean-square error (RMSE) tests according to Eq. (13). Based on residual analysis, RMSE was the difference between the predicted ($X_{predicted}$) and laboratory ($X_{experimental}$) values of water loss/gain and solid gain (Schmidt et al., 2009).

$$RMSE = \frac{1}{n}\left[\sum_n (XGpredicted - XGexp)^2\right]^{0.5} \tag{13}$$

3. Results and discussion

3.1. Water loss

In this study, the mean initial moisture level of the ostrich meat pieces was 74 ± 0.02%. The analysis of water loss variance in the osmified meat samples showed that coating and osmotic solution concentrations had a significant effect on water loss ($P < .05$). Both coated and non-coated meat samples had water gain and water loss during the osmotic process at the salt solution concentrations of 5% and 27%, respectively, which is in line with the results obtained by Mujaffar and Sankat (2006), Schmidt et al. (2008), Alino et al. (2010), Ozuna et al. (2013) and Yuan et al. (2016).

In a 5% osmotic treatment, low salt concentration and formation of actin-myosin-salt network resulted in the partial denaturation of protein and swelling of myofibril in the meat samples, followed by the development of a protein network for water trapping and water gain. However, with an increase of up to 27% in salt concentration, chlorine ions produce high repulsion, and protein denaturation occurs in an extensive scope, which ultimately leads to the contraction of the protein network and water loss. On the other hand, at 15% sodium chloride concentration, there is a small degree of water loss and gain since the existing salt content is not sufficient to create a strong protein network to maintain moisture or create sufficient repulsion for protein depolymerization. In this regard, the forces available for the control of water loss and gain act instantly (Fig. 1).

Fig. 2 illustrates the comparison of the meat samples osmified with tragacanth and salep coatings with control samples in terms of water loss. At 5% and 27% concentrations, the levels of water gain and loss were higher in the samples pre-treated with tragacanth and salep, compared to those in the control group ($P < .05$). This might be due to the polysaccharide structure and hydrophilic nature of tragacanth and salep that show a slight resistance to moisture because of their polar structure. During osmotic treatment at 5% and 27% concentrations, the

[1] Rate constant of Peleg, s $(g/g)^{-1}$

[2] Capacity constant of Peleg, $(g/g)^{-1}$

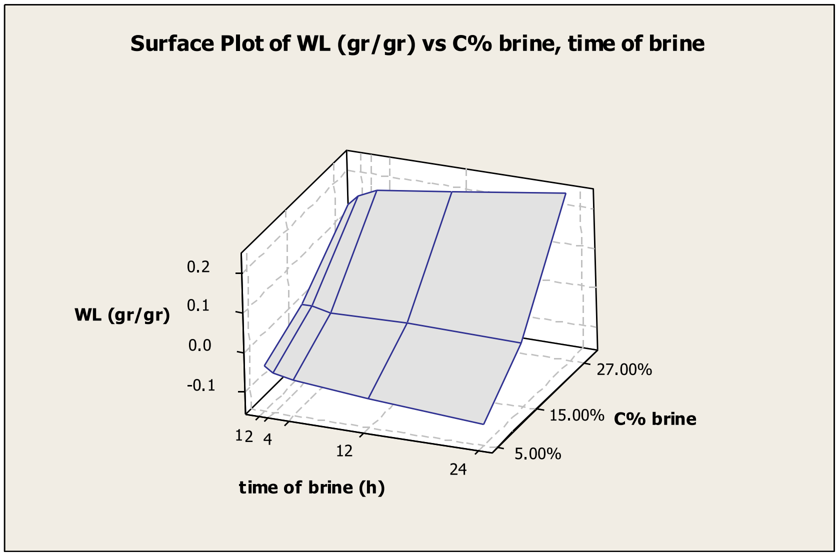

Fig. 1. Effect of the brine concentration and time of osmotic treatment in the water loss/gain of ostrich meat pieces.

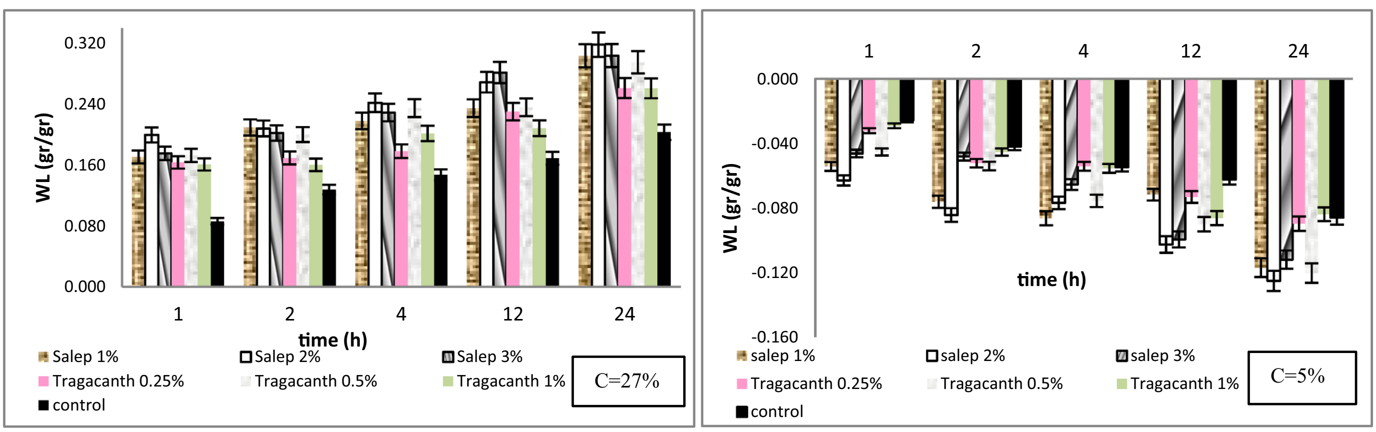

Fig. 2. Comparison of the meat samples osmified with tragacanth and salep coatings with control samples in terms of water loss/gain.

levels of water gain and loss were respectively higher in the meat samples coated with salep, compared to those in the samples treated with tragacanth. This was indicative of the lower inhibitory effect of salep gum on moisture under the test conditions, compared to that of tragacanth gum. Given the limited variability of water loss and gain at 15% concertation, the results obtained at this concentration were not presented.

In a similar research, Yuan et al. (2016) reported the coated scallop muscle samples had a higher water loss level, compared to the control samples in the osmotic process, which was attributed to the chemical nature of the coating polysaccharides.

The pre-treatment of meat samples in osmotic treatment of 5% increased water absorption and, as a result, swelling of fibers. Considering that marinating meat is done to improve the texture and flavor of the meat (Goli, Ricci, Bohuon, Marchesseau, & Collignan, 2014) and Increasing water absorption and curing agents or fiber swelling during marinating meat before cooking has the most impact on improving meat tenderness (Sharedeh, Gatellier, Astruc, & Daudin, 2015). As it can be seen, the amount of water gain with pre-treatment of 2% salep in two hours of osmotic process or pre-treatment of 1% salep during three hours of osmotic process can result from the osmotic process for the control sample the in 24-h osmosis. Therefore, the more and faster tenderness of meat pieces can be expected by saving the time and cost of the osmotic treatment process with the pre-treatment coating.

Also the pre-treatment of meat samples during osmotic dehydration of 27% increased water loss and fiber contraction. With pre-treatment, the amount of time required to achieve a certain dehydration decreased, indicating a higher rate of fall in water content. It can be seen that pre-treatment of meat samples with 1% salep or 2% salep or 3% salep and or 0.5% tragacanth during two hours of osmotic process, results in a water loss equal to the control sample for 24 h of osmosis.

3.2. Solid gain

The results of ANOVA for solid gain in osmified meat samples showed that all significant treatment parameters, including the type of coating, coating concentration, osmotic solution concentration, and osmosis duration, had a significant effect on solid gain ($P < .05$). In this regard, the solid gain of both coated and non-coated meat samples increased by the enhancement of salt concentration in osmotic treatment considering the osmotic gradient of the environment. These findings are in congruence with the results obtained by Mujaffar and Sankat (2006), Schmidt et al. (2008), Alino et al. (2010), Ozuna et al. (2013) and Yuan et al. (2016).

The effect of osmotic solution on the solid gain of osmified meat samples was completely significant. As observed in Fig. 3, there was a stepwise increase in solid gain by the enhancement of salt concentration. However, the level of solid gain had no increasing trend at 5% concentration, which might be due to the instant absorption of moisture

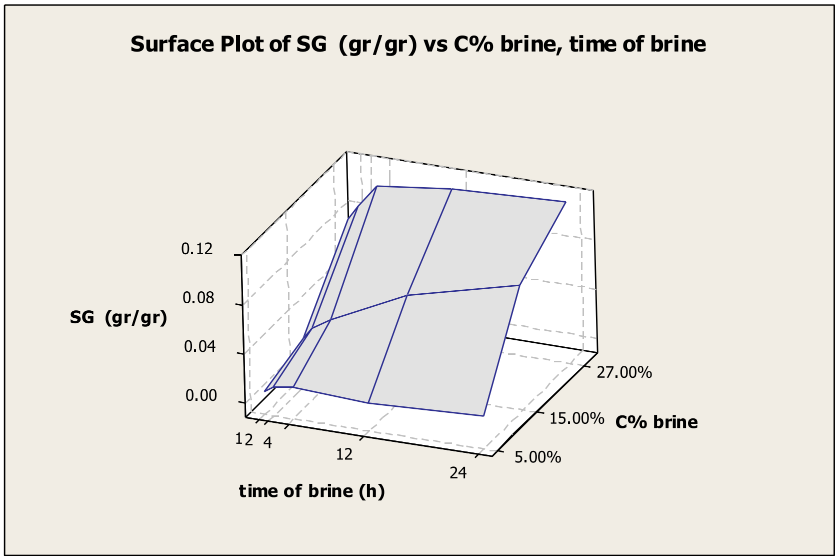

Fig. 3. Effect of the brine concentration and time of osmotic treatment in the solid gain of ostrich meat pieces.

at this osmotic concentration, followed by environmental dilution and relative reduction of solid gain, where solid gain undergoes a drop relative to the initial weight. In the first 4 h of osmosis, there is a fast increase in solid contents, which then turns into a relatively slow solid gain during the process. This trend is considered logical due to the high difference between the chemical potential of osmotic solution and meat pieces at the onset of osmification. As observed, solid gain reached its maximum level at 27% concentration in 12 h and approached its maximum value in 5% osmotic treatment.

Fig. 4 displays the comparison of the solid gain of meat pieces osmified with tragacanth and salep coatings with the control samples. At 5%, 15%, and 27% concentrations, the samples coated with 2% salep had a lower level of solid gain, compared to the control samples ($P < .05$). This is indicative of the proper performance of 2% salep; accordingly, coating with 2% salep could prevent the excessive entrance of solutes. Moreover, the coating with 0.5% tragacanth at 15% and 27% osmotic treatments had this positive feature as well. There are multiple similar reports regarding the prevention of the entrance of solutes by coatings during the osmotic treatment of fruits and vegetables (García et al., 2010; Khin et al., 2007; Lazarides et al., 2007; Matuska et al., 2006). In addition, similar results were reported by Yuan et al. (2016) regarding muscle tissue.

The solid gain, at all osmotic treatment concentrations examined, in the pre-treated and control samples were more affected by the osmotic solution. However, the results of 5% osmotic treatment were not presented due to the high variability of solid gain at this concentration.

In a study performed by Yuan et al. (2016), the coated scallop muscle samples acted similarly to the uncoated samples in terms of solid gain during osmotic treatment, where solid gain increased by the enhancement of salt concentration. However, this enhancement was lower in the coated samples, which was ascribed to the inhibitory properties of coating that limited the salt diffusion.

3.3. Result of mathematical modeling

3.3.1. Peleg's model

Table 1 presents the results of the Peleg's model fitted by linear regression (least absolute residuals) for water loss and solid gain of the coated and non-coated pieces of meat during an osmotic treatment. Based on the Peleg's model, water loss and solid gain had an R^2 of 0.961–0.999 and 0.638–0.999 and RMSE of 0.002–0.226 and 0.001–0.005, respectively, at 5% and 27% concentrations. At 15% concentration of osmotic treatment, the Peleg's model lacked the necessary ability to show the laboratory results due to the variation of moisture flow direction during the immersion time. Consistent transfer of water loss and gain was observed at this concentration. Therefore, the concentration of solutes varied due to the changes in the moisture level of the samples and environmental dilution, which is consistent

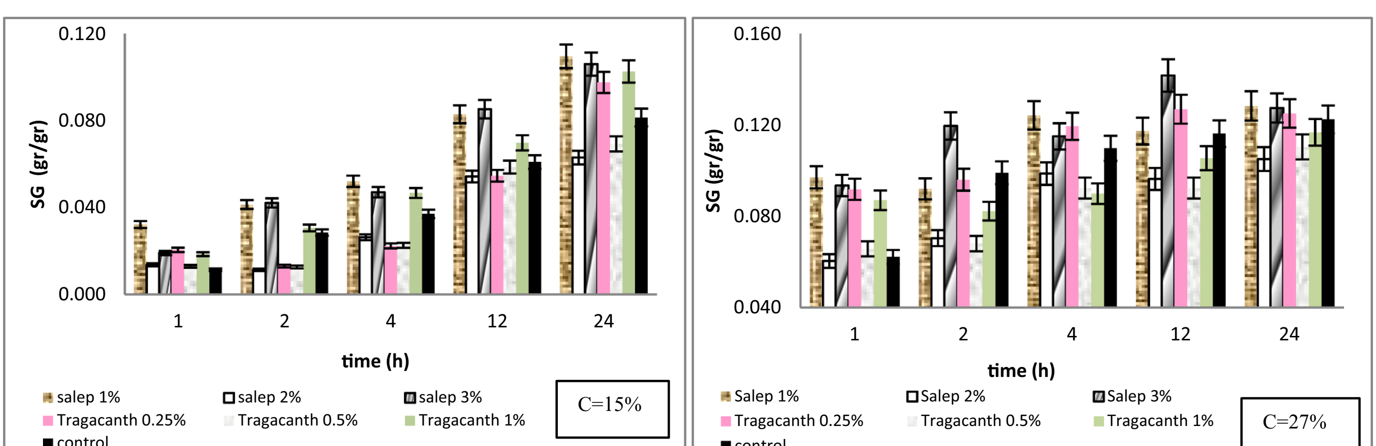

Fig. 4. Comparison of the meat samples osmified with tragacanth and salep coatings with control samples in terms of solid gain.

Table 1
Peleg's constants for water loss and solid gain during osmotic treatment.

Estimated parameters of the peleg's model for water loss and solid gain											
Samples	Concentration of salt %	k_1^w	k_2^w	R^2	RMSE	WL^∞	k_1^s	k_2^s	R^2	RMSE	SG^∞
		(s (g/g)$^{-1}$)	(g/g)$^{-1}$			(g/g)	(s (g/g)$^{-1}$)	(g/g)$^{-1}$			(g/g)
Control	5	102,700	10.44	0.989	0.003	−0.096	152,100	72.62	0.974	0.002	0.014
	15	105,900	108.4	0.345	0.009	0.009	253,500	9.345	0.982	0.002	0.107
	27	25,180	4.635	0.997	0.138	0.216	16,280	7.979	0.999	0.004	0.125
Tragacanth 0.25%	5	75,090	10.28	0.986	0.003	−0.097	174,900	81.08	0.970	0.003	0.012
	15	24,070,000	3279	0.714	0.008	0.000	518,600	4.249	0.535	0.003	0.235
	27	16,290	3.643	0.994	0.184	0.274	10,880	7.874	0.999	0.002	0.127
Tragacanth 0.5%	5	80,480	7.379	0.975	0.004	−0.136	314,200	56.36	0.684	0.002	0.018
	15	103,800	50.82	0.224	0.013	0.020	506,800	8.557	0.825	0.002	0.117
	27	12,650	3.246	0.994	0.210	0.308	30,530	8.71	0.990	0.004	0.115
Tragacanth 1%	5	84,260	10.95	0.994	0.002	−0.091	415,800	77.01	0.917	0.003	0.013
	15	7,513,000	1087	0.828	0.010	0.001	179,500	7.673	0.987	0.003	0.130
	27	18,890	3.618	0.984	0.181	0.276	28,270	8.236	0.997	0.005	0.121
Salep 1%	5	37,140	8.125	0.961	0.008	−0.123	53,550	67.56	0.897	0.002	0.015
	15	961,300	161.1	0.974	0.016	0.006	117,800	7.764	0.975	0.004	0.129
	27	11,630	3.162	0.973	0.214	0.316	9455	7.683	0.997	0.004	0.130
Salep 2%	5	30,360	7.642	0.979	0.006	−0.131	251,800	80.42	0.638	0.002	0.012
	15	126,500	100.4	0.652	0.010	0.010	381,900	11.45	0.909	0.002	0.087
	27	13,060	2.993	0.992	0.226	0.334	26,490	9.217	0.998	0.002	0.108
Salep 3%	5	93,060	7.86	0.993	0.003	−0.127	1,401,000	19.64	0.639	0.001	0.051
	15	23,200,000	3269	0.736	0.012	0.000	161,100	7.569	0.988	0.002	0.132
	27	13,010	3.144	0.999	0.218	0.318	10,720	7.722	0.998	0.004	0.130

with the results reported by Schmidt et al. (2009).

Table 1 shows the Peleg's rate constants (k_1^w and k_1^s) in the samples with coating pre-treatment at various osmotic concentrations for water loss and solid gain. According to Eq. (5), the initial rates of water loss/gain and solid gain were $1/k_1^w$ and $1/k_1^s$, respectively. In this regard, a lower k_1 level was indicative of higher initial rates of water loss/gain and solid gain. In addition, 27% osmotic treatments had the highest initial rate of water loss (11630–25,180 s g/g^{-1}) and solid gain (9455–30,530 s g/g^{-1}), which is reasonable considering the cell response to osmotic pressure elevation. In terms of 5% osmotic treatments, the initial rates of water gain and solid gain were obtained as 30,360–102,700 and 53,550–1,401,000 s g/g^{-1}, respectively. The lowest initial rate of mass transfer was observed in 15% sodium chloride treatments since the samples neither tolerated constant osmotic pressure at 27% concentration nor had the continuous condition of the swelling of myofibrils and water gain pressure at 5% concentration. This process occurs by a slight change in the value of chlorine ion concentration and instant alternation of the pressure of osmotic loss or water gain.

In all samples subjected to coating pre-treatment, the Peleg's rate constant ($1/k_1^w$) was higher at 5% and 27% concentrations of osmotic treatments, compared to that of the control samples. This finding demonstrated the positive effect of tragacanth and salep gums on moisture transfer. The leading cause of this issue could be related to the polar structure of these two gums and faster transfer of moisture relative to the cell membrane wall. The highest water loss rate was attributed to 1% salep treatment at 27% salt concentration. In 5% osmotic treatment, all coated samples had a lower initial solid gain rate ($1/k_1^s$) than the control samples, except 1% salep treatment. In this regard, the positive performance of coating pre-treatment was in line with the goal of the current research, which was the prevention of the entrance of solid mass that is mainly sodium chloride. In 27% osmotic treatment, a weak performance was observed for 1% and 3% salep and 0.25% tragacanth, which had a higher initial solid gain rate ($1/k_1^s$) than the control samples.

Table 1 demonstrates the Peleg's capacity constants (k_2^w and k_2^s) in the samples pre-treated with the coating at various concentrations of osmotic treatment for water loss/gain and solid gain. According to Eq. (6), equilibrium water loss/gain and equilibrium solid gain were estimated as $1/k_2^w$ and $1/k_2^s$, respectively. The equilibrium water loss/gain and equilibrium solid gain were higher at 27% concentration, compared to those at 5% and 15% concentrations, which is reasonable considering the effect of osmotic pressure during the immersion time in salt water.

Accordingly, Corzo and Bracho (2006), Schmidt et al. (2009) and Yuan et al. (2016) reported similar results regarding the equilibrium solid gain, where increased concentration of sodium chloride led to the elevation of equilibrium solid gain. In terms of equilibrium water loss or gain, Yuan et al. (2016) report was consistent with the results of this study. In the study carried out by Schmidt et al. (2009), the meat samples had a lower equilibrium water loss at 20% concentration of sodium chloride than at 5% concentration. Table 1 presents the supportive effect of some concentrations of pre-treatment coating with salep and tragacanth on the reduction of equilibrium solid gain and enhancement of equilibrium water loss. However, equilibrium water loss/gain was higher than the equilibrium solid gain, which might be due to faster distribution of moisture in equilibrium conditions than that of solid. In addition, unlike equilibrium water loss/gain, the level of equilibrium solid gain was not significantly different between the coated and non-coated samples. In other words, the concentration of sodium chloride had a significant impact on equilibrium solid gain, which is in accordance with the results obtained by Yuan et al. (2016).

3.3.2. Azuara's model

Based on the Azuara's model, water loss had an R^2 of 0.912–0.995 and 0.981–0.999 and RMSE of 0.002–0.008 and 0.005–0.015, respectively, at 5% and 27% concentrations. At 15% concentration of osmotic treatment, the Azuara's model Similar to the Peleg's model lacked the necessary ability to show the laboratory results due to the variation of moisture flow direction during the immersion time. Also based on the Azuara's model, solid gain had an R^2 of 0.629–0.988 and 0.992–0.999 and RMSE of 0.001–0.004 and 0.002–0.006, respectively, at 15% and 27% concentrations. At 5% concentration of osmotic treatment, the Azuara's model was very weak in solid gain.

Based on the results of the RMSE factor to predict of water loss, the Azuara's model showed a higher efficiency compared to the Peleg's model, and the results were satisfactory in predicting solid gain level of both Peleg's and Azuara's models. However, according to the R^2, the

Table 2
Parameters of diffusion model for water loss and solid gain during osmotic treatment.

Estimated parameters of the diffusion's model for water loss and solids gain							
Samples	Concentration of salt %	D_w ($\times 10^{-9}$ m^2/s)	R^2	RMSE	D_s ($\times 10^{-9}$ m^2/s)	R^2	RMSE
Control	5	0.456	0.953	0.010	0.764	0.912	0.003
	15	1.016	0.725	0.004	0.319	0.985	0.011
	27	0.537	0.966	0.027	0.667	0.884	0.021
Tragacanth 0.25%	5	0.512	0.983	0.011	1.538	0.189	0.005
	15	1.531	0.832	0.005	0.121	0.986	0.034
	27	0.551	0.996	0.036	0.889	0.372	0.024
Tragacanth 0.5%	5	0.434	0.974	0.013	0.460	0.519	0.002
	15	0.646	0.624	0.003	0.216	0.933	0.014
	27	0.535	0.909	0.041	0.568	0.912	0.016
Tragacanth 1%	5	0.584	0.703	0.012	0.534	0.791	0.004
	15	1.378	0.959	0.006	0.341	0.990	0.014
	27	0.487	0.930	0.035	0.540	0.988	0.018
Salep 1%	5	0.521	0.783	0.014	0.623	0.427	0.003
	15	0.895	0.839	0.008	0.409	0.999	0.013
	27	0.564	0.911	0.040	0.652	0.705	0.024
Salep 2%	5	0.597	0.960	0.016	0.529	0.424	0.002
	15	1.012	0.950	0.004	0.305	0.936	0.010
	27	0.525	0.973	0.045	0.577	0.773	0.018
Salep 3%	5	0.444	0.971	0.014	0.171	0.953	0.006
	15	1.643	0.801	0.009	0.362	0.981	0.014
	27	0.578	0.986	0.045	0.559	0.771	0.027

Peleg's model showed a favorable efficiency for water loss and solid gain compared to the Azuara's model. Pezo et al. (2013) and Dimakopoulou-Papazoglou and Katsanidis (2017) also similarly showed a favorable efficiency of the Peleg's model compared to the Azuara's model.

In this study, according to the results of statistical analyzes of R^2 and RMSE, the results of the Azuara's model have not been reported. In order to obtain the water and solid diffusion coefficients, the values of WL^∞ and SG^∞ for the diffusion model were used from the Peleg's model.

3.3.3. *Diffusion model*

Table 2 tabulates the results of the diffusion model fitted by linear regression for water loss and solid gain of coated and non-coated meat pieces during the osmotic treatment. Based on Eqs. (11) and (12), in order to fit the model, equilibrium water loss and solid gain values were required; therefore, the results of the Peleg's model were utilized. Regarding the efficiency of the diffusion model for water gain at 5%, 15%, and 27% concentrations of osmotic treatment, R^2 values were estimated as 0.703–0.983, 0.624–0.959, and 0.909–0.996, and RMSE were obtained as 0.002–0.006, 0.01–0.034, and 0.016–0.027, respectively. Nonetheless, the diffusion model had a significantly weak efficiency in the prediction of solid gain, especially at 5% concentration of osmotic treatment. Meanwhile, the results of this model were presented for comparing the models in terms of their efficiency.

Table 2 displays the water and solid diffusion coefficients of the coated and non-coated pieces of meat during an osmotic treatment. Among the evaluated concentrations, 15% concentration had the highest water diffusion coefficient. It seems that in the conditions of the current research, 15% concentration was the border of water loss and gain for meat samples. Although the initial rate of water loss ($1/k_1^w$) at this concentration was lower than that at 27% concentration due to lower osmotic pressure, the continuation of the osmosis process might lead to the maximization of water diffusion coefficient up to 1.643×10^{-9} m^2/s due to higher environmental dilution and instant transfer of water loss/gain. In addition, the water diffusion coefficient increased in all coated samples by the enhancement of sodium chloride concentration from 5% to 27%, except for 1% tragacanth and 2% salep treatments. This indicates the stronger effect of osmotic pressure at 27% concentration, compared to the pressure caused by salt-induced swelling of muscle fiber at 5% concentration.

Tragacanth and salep gums coating pre-treatments at the discussed concentrations (with the exception of 0.5% tragacanth and 3% salep in 5% osmotic treatment and 1% tragacanth and 2% salep in 27% osmotic treatment), increased D_w. This is suggestive of the positive effect of coating pre-treatment on the enhancement of moisture transfer. According to the results (by matching the results of Fig. 4 and Table 2), the amount of water diffusion coefficient increases with increasing solids gain. Probably absorption of solids, especially sodium chloride, increases the D_w during osmotic treatment, which is consistent with the results of Aykın-Dincer and Erbas (2018).

Also, tragacanth and salep coating pre-treatments at the applied concentrations (except for 0.25% tragacanth) decreased the solid diffusion coefficient at 5% and 27% osmotic treatments, demonstrating the supportive effect of tragacanth and salep on the reduction of D_s. Therefore, the results of the diffusion model show that the pre-treatment coating with tragacanth and salep gums can limit the penetration of solids, including sodium chloride. This might be due to the structure of the coating as a restrictive membrane with a better control of solid penetration and the addition of another controlling membrane layer (thickening of layers and deceleration of solid penetration). The findings of this study are consistent with those reported by Yuan et al. (2016).

3.4. *Efficiency index of osmotic treatment*

The effects of coating pre-treatment on the efficiency index of osmotic treatment (D_w/D_s) for various concentrations of sodium chloride are tabulated in Table 3. In the osmotic treatment of meat, the water loss or gain and the permeation of solids (sodium chloride) occurs simultaneously. The permeation of salt into meat and water movement is a complex process. Several conductive forces are effective in this regard, that the concentration of salt and osmotic pressure are among the most important. (Akköse & Aktas, 2014). At 27% concentration of sodium chloride, which is used for muscle osmotic dehydration and often as a pre-process of drying, the goal is to increase water loss and reduce solid gain or achieve a higher efficiency index. At 5% sodium chloride concentration used for marinating or hydrating muscles, the goal is to increase water gain and balanced gain of solutes (depending on solute type). Based on the results, all coated samples had a higher efficiency index, compared to the control samples, except for 0.25% tragacanth treatment at 5% and 27% concentrations. The highest level of this index

Table 3
efficiency index of osmotic treatment of ostrich meat pieces.

Samples	D_w/D_s		
	5%	15%	27%
Control	0.597	3.181	0.805
Tragacanth 0.25%	0.333	12.632	0.619
Tragacanth 0.5%	0.944	2.988	0.943
Tragacanth 1%	1.094	4.036	0.901
Salep 1%	0.836	2.192	0.866
Salep 2%	1.129	3.322	0.910
Salep 3%	2.598	4.536	1.034

was related to the 3% salep treatment. In addition, a significantly high-efficiency index was obtained at a sodium chloride concentration of 15%. Nonetheless, considering the variable nature of water loss/gain and solid gain at this concentration and the subsequent difficulty of controlling this process, the efficiency index at this concentration was not important probably. In this regard, Yuan et al. (2016) reported that the application of selective coatings for scallop muscle increased the efficiency index of osmotic treatment at 20% and 30% concentrations.

4. Conclusion

Based on the findings of the current study, the coating process integrated with osmotic treatment in ostrich meat pieces was mostly affected by the concentration of the osmotic solution. Water gain/loss and solid gain are significantly affected by the concentration of the osmotic solution and coating concentration during the osmotic treatment ($P < .05$). In the present study, the parameters of kinetic, diffusion, and Azuara's models were evaluated to assess the efficiency of tragacanth and salep coatings. According to the statistical indicators, the Peleg's model had the best efficiency in the prediction of water loss at two concentrations of 5% and 27% and solid gain at 27% concentration. Similar results were obtained for the Azuara's model. On the other hand, the diffusion model had a favorable performance at 27% and 15% concentrations for water loss and solid gain, respectively. At 15% concentration of the osmotic solution, dehydration or hydration did not occur in both coated and non-coated samples, and no border could be considered for water loss/gain. The pre-treatment of meat samples during osmotic treatment at 5% concentration increased water absorption in shorter time. Therefore, this pre-treatment may have a positive effect on the low salt concentrations in order to marinate the meat and increase the tenderness and juiciness of the product.

The initial rate of water loss/gain in all treatments with coating was higher, compared to the control samples. In addition, the maximum D_w at 5% and 27% concentrations of sodium chloride were 0.597×10^{-9} and $0.578 \times 10^{-9}\,m^2/s$, respectively, belonging to 2% and 3% salep treatments (D_w of control samples: 0.456×10^{-9} and $0.537 \times 10^{-9}\,m^2/s$, respectively). On the other hand, the minimum D_s at 5% and 27% concentrations of sodium chloride were 0.171×10^{-9} and $0.540 \times 10^{-9}\,m^2/s$ belonging to the 3% salep and 1% tragacanth treatments, respectively (D_s of control samples: 0.764×10^{-9} and $0.667 \times 10^{-9}\,m^2/s$). The D_w/D_s index of coated and osmified pieces of meat was higher in most of the treatments, compared to that of the control samples. This showed the proper features of gum, which facilitate moisture transfer as a membrane layer while better preventing solid gain, which may have a positive effect on the nutritional profile of the products, and can reduce the cost and duration of the osmotic treatment process.

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