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Elektrik Potansiyeli ve Sıcaklığın Ohmik Isıtma ve Sıcak Suya Daldırma Esnasında Makarnaların Rehidrasyon Davranışları Üzerine Etkisi

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Öz

Söz konusu çalışma kapsamında, farklı elektrik potansiyelleri altında (10, 20, 30 ve 40 V/cm) ohmik ısıtma ve farklı sıcaklıklarda (75, 85 ve 95°C) suya daldırma işlemi esnasında makarna örneklerinin rehidrasyon özellikleri incelenmiştir. Makarnaların rehidrasyon davranışlarını ifade etmek için Fick'in ikinci difüzyon kanunu kullanılarak, normal daldırma denemeleri için iki ve ohmik ısıtma denemeleri için üç farklı efektif difüzyon katsayısı hesaplanmıştır. Uygulanan farklı voltaj ve sıcaklıkların difüzyon katsayıları üzerine etkisi ise Arrhenius tipi bir eşitlikte değerlendirilmiştir. Ayrıca, gıdaların rehidrasyon özelliklerinin tanımlanmasında yaygın olarak tercih edilen iki model, Peleg ve Weibull, rehidrasyon denemelerinin kinetik analizi amacıyla kullanılmıştır. Elde edilen veriler neticesinde, hem daldırma suyu sıcaklığının hem de ohmik ısıtma esnasında uygulanan voltajın artırılması, makarna örneklerinin su emilimini hızlandırıcı etki göstermiştir. Hem Peleg hem de Weibull modelleri, normal daldırma denemeleri için üst düzey bir performans ortaya koymuştur. Ancak bunlardan sadece Weibull, ohmik ısıtma esnasında gözlenen nem değişimini kabul edilebilir seviyede ifade edebilmiştir. Normal daldırma denemelerinden farklı olarak, ohmik ısıtma işleminin ilk safhalarında nem emiliminde bir gecikme dikkati çekmiştir. Ancak genel olarak ohmik ısıtmanın makarnaların nem absorpsiyonu üzerine hızlandırıcı bir etkiye sahip olduğu ifade edilebilir.

Anahtar kelimeler
Ohmik ısıtma; Makarna; Rehidrasyon; Difüzyon; Peleg; Weibull

Effects of Electrical Potential and Temperature on Rehydration Behaviour of Pasta Samples during Ohmic Heating and Soaking

Abstract

In the present study, rehydration of pasta samples was examined during soaking at different temperatures (75, 85 and 95°C) and during ohmic heating at different electrical potential levels (10, 20, 30 and 40 V/cm) as an alternative method of pasta cooking. Two effective diffusion coefficients were defined using Fick's second law of diffusion for regular soaking experiments and three diffusion coefficients were calculated to describe the rehydration behaviour during ohmic heating. The effect of applied voltage and temperature on the diffusion coefficients were evaluated using an Arrhenius type equation. Moreover, the two common models that are used to describe rehydration behaviour of food materials, namely Peleg and Weibull models, were used for kinetic analysis of rehydration experiments. It was observed that an increment both in temperature of cooking water and applied voltage for ohmic heating enhanced the water absorption rate of pasta samples then the rehydration was completed faster. The Peleg and Weibull models showed promising performance for regular soaking experiments where the first one could not describe moisture change of pasta during ohmic heating at a desired level. Different from soaking testes, a delayed moisture uptake phase was observed at the very beginning of ohmic heating experiments however it can be concluded that ohmic heating led an increment in moisture uptake rate in general.

Keywords
Ohmic heating; Pasta; Rehydration; Diffusion; Peleg; Weibull

1. Introduction

Pasta is a well-known food product that is produced by drying the dough obtained from mainly semolina (from *Triticum durum* wheat) and some other ingredients such as egg, water, spinach etc. (Manthey & Schorno, 2002). There are some reasons that may be listed explaining why it is so popular around the world, e.g. economic reasons, favourable taste, ease of preparation and also, wide options of preparing/consuming in many different ways (Kim, Petrie, Motoi, Morgenstern, Sutton, Mishra, et al., 2008). Moreover, due to its low moisture content, pasta can easily be stored for a long time at room conditions (Doster & Kahn, 1986). From the point of health, it has a lower glycemic index than many other carbohydrate based foods (Cubadda, Carcea, Marconi, & Trivisonno, 2007).

Pasta is traditionally cooked in boiling water until a desired degree of starch gelatinization and rehydration is achieved. While rehydration occurs very fast at first, the moisture concentration of pasta increases, water absorption rate of starch molecules decreases and then moisture uptake gradually slow down as time progresses (Cafieri, Mastromatteo, Chillo, & Del Nobile, 2010). Although the traditional cooking method is pretty simple to operate, possible problems/disadvantages are generally arise or experienced especially after long cooking times such as excessive cooking, dry matter loss or excessive energy consumption (Cocci, Sacchetti, Vallicelli, Angioloni, & Dalla Rosa, 2008). Apart from the time that is spent to cook pasta, in traditional method, a notable amount of time is also required before cooking to heat the cooking water to boiling temperature. As easily be conduct, one should heat the cooking pot first, then water and finally pasta pieces present in water for traditional cooking technique. Thus, these successive heat transfer between different mediums increase the time normally needed to cook pasta like products (Kanjanapongkul, 2017).

One possible and promising alternative that can be used instead of traditional method to expedite pasta cooking is ohmic heating. Ohmic heating can briefly be defined as the method where the food material behaves as a resistance itself against the electric current, and as a result the electrical energy is converted to heat in the cooking domain and the temperature is increased (İçier, 2005; Varghese, Pandey, Radhakrishna, & Bawa, 2014). Ohmic heating was invented in 1987 and it has been used for different purposes such as pasteurization, sterilization, blanching, fermentation, extraction to save times and energy substantially until today (Knirsch, Dos Santos, de Oliveira Soares, & Penna, 2010). Due to uniform and volumetric heating behaviour, ohmic heating ensures homogenous temperature distribution through the food, but it depends on the electrical property of the cooking medium. The efficiency of ohmic heating is determined with electrical conductivity of the food, applied voltage and time applied (Mercali, Schwartz, Marczak, Tessaro, & Sastry, 2014). Ohmic heating has been previously studied for cooking different food materials such as rice (Jittanit, Khuenpet, Kaewsri, Dumrongpongpaiboon, Hayamin, & Jantarangsri, 2017; Kanjanapongkul, 2017), chickpea (Loypimai, Moonggarm, & Chottanom, 2009), artichoke (Guida, Ferrari, Pataro, Chambery, Di Maro, & Parente, 2013), quince (İçier, Yıldız, Eroğlu, Sabancı, & Eroğlu, 2013), cauliflower (Eliot, Goullieux, & Pain, 1999). It was previously stated that ohmic heating can accelerate moisture diffusion to starchy foods due to increased porosity as a result of the impact of electrical field (electroporation) (Cocci, Sacchetti, Vallicelli, Angioloni, & Dalla Rosa, 2008; Jittanit, Khuenpet, Kaewsri, Dumrongpongpaiboon, Hayamin, & Jantarangsri, 2017).

Mathematical models are very important in the optimization of processes such as rehydration. With the help of mathematical models, the most suitable conditions can be determined for rehydration of a food, and one can figure out how the rehydration will be affected by process variables and how long the rehydration will take place under certain conditions (Sanjuán, Simal, Bon, & Mulet, 1999). The Peleg and Weibull models are widely used in the modelling of rehydration process (Demiray & Tülek, 2016) and they were previously used to describe the hydration of various food stuffs. For example Cocci, Sacchetti, Vallicelli, Angioloni, and Dalla Rosa (2008) used Peleg and Weibull models to predict water absorption of pasta while Dıaz, Martınez-Monzo, Fito, and Chiralt (2003) also used these two models to predict rehydration behaviour of orange slices. With Peleg's equation rehydration kinetics of firik, dovme and wheat (Maskan, 2002), amaranth grain (Resio, Aguerre, & Suarez, 2006), broccoli stem slabs (Sanjuán, Simal, Bon, & Mulet, 1999), red kidney beans (Abu-Ghannam & McKenna, 1997) were predicted adequately. However, any study investigating the water uptake behaviours of pasta during ohmic heating on pasta cooking and the performance of mentioned models on it could not found in the available literature.

Thus, the aim of this study is to (1) investigate the effect of applied voltage and time on the rehydration characteristics of pasta samples, (2) compare the rehydration characteristics of pasta samples during ohmic heating and soaking, and (3) describe and evaluate the moisture change of pasta cooking process with Peleg and Weibull equations and asses their efficiency.

2. Materials and Methods

2.1. Materials

Pasta samples (bow-tie pasta), purchased from a local market in Isparta, Turkey and they were kept under appropriate conditions at room temperature in a gas/moisture resistant plastic bags until the experiments. In order to reflect the industrial or home usage conditions, pasta samples were cooked using tap water (for further details about cooking experiments please see section 3.2). But it was thought that ionic strength of the tap water is possibly change depending on time and this may affect the results. Thus, the enough amount of water that was required for all cooking experiments were obtained at the same time as a batch. All the replicates were conducted within three days to ensure the results were not affected from any possible microbiological growth in the water.

2.2. Methods

Cooking: The pasta:water ratio (w/v) use in the experiments was 1:10 as recommended by (Alamprese, Casiraghi, & Rossi, 2011) both for ohmic heating and soaking. In order to shorten the cooking time and ensure the energy efficiency as aimed in ohmic heating process, required amount of pasta and water at room temperature were added in the ohmic cell at the same time for the ohmic heating experiments and four different voltage gradients (10, 20, 30 and V/cm) were applied. The soaking experiments were conducted using an electric heater in a cooking pot. However, in order to reflect the traditional cooking habit, the pasta samples were added into water after target temperature has reached. During cooking experiments, pasta samples were taken, drained and excess water over them were slightly removed using a tissue paper and weighed periodically. The weight change of the samples was monitored with the help of precision scale with a precision of 1/1000 g. All of the cooking experiments were carried out during the time where any noticeable change of the last four weight was not observed. A graphical summary of the study is presented in Fig. 1.

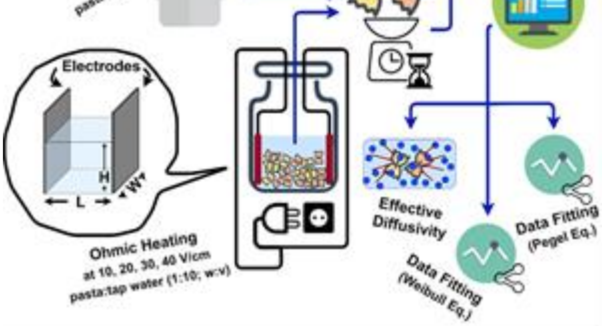

Figure 1. Graphical summary of the study

Effective water diffusivity and activation energy: Effective moisture diffusivity was determined to conduct an idea about moisture transfer mechanism and effect of different cooking procedures. Pasta pieces were assumed to be an infinite slab, since other directions were large enough compared to the thickness. The effective moisture diffusivity was defined by Fick's second law with the assumption of the diffusion is the only mechanism controlling the absorption of water molecules by the pasta samples and following the solution by Crank (1975). Irrespective of temperature, rehydration graphs (see Figs. 2 and 3) considered two straight lines for regular soaking and three straight lines for ohmic heating experiments. These lines were describing the number of stages characterising rehydration behaviour and one diffusion coefficient was calculated for every stages assuming that the diffusivity coefficients were to be constant during every step individually, initial moisture distribution was uniform, and equilibrium moisture and dry mater loss from pasta samples were negligible.

$$MR = \frac{M - M_e}{M_i - M_e} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\left[\frac{1}{(2n-1)^2} exp\left(-D\frac{(2n-1)^2\pi^2}{\delta^2}t\right)\right] \quad (1)$$

where MR is moisture ratio, M is a moisture content of the product at a time (kg/kg dry matter), M_e is equilibrium moisture content of the product (kg/kg dry matter), M_i is initial moisture content (kg/kg dry matter), δ is total thickness of the slab shaped product (m), D is diffusion coefficient of water inside the product (m^2/min) and t is time (min). For long-term cooking, only the first term of the (Eq. 1) was used to explain the rehydration process (n = 1). The M_e was accepted as the final moisture content at the end of the cooking experiments. With some simplifications, Eq. 2 were obtained, and effective diffusivity was calculated by fitting Eq. 2 to the curve of *ln(MR)* vs. time.

$$ln[MR] = ln\left(\frac{8}{\pi^2}\right) - D.t.\frac{\pi^2}{L^2} \quad (2)$$

The diffusion coefficient of water can be correlated either with temperature (see Eq. 3) or applied electrical potential (see Eq. 4) using the Arrhenius equation (Sanjuán, Simal, Bon, & Mulet, 1999):

$$D = D_0 e^{-E_a/RT} \quad (3)$$
$$D = D_0 e^{-E_a/FV} \quad (4)$$

where E_a is the activation energy (kJ/mole); R is the universal gas constant (8.314 kJ/(mole K)) for soaking experiments and F is Faraday constant (96.49 kJ/(mole V)), for ohmic heating experiments in order to endure the unit uniformity of E_a; T is the absolute temperature (K) where V describes applied voltage during ohmic heating (V) and D_0 is the pre-exponential Arrhenius factor (m^2/min).

Rehydration kinetics and model assessment: To analyse the rehydration kinetics of pasta samples during different ways of cooking as defined previously, two common models in the literature, i.e. Peleg and Weibull, were selected (Singh & Erdogdu, 2009), and moisture curves obtained from pasta samples were fitted these equations. These models were previously used to describe moisture uptake of pasta by Cunningham, McMinn, Magee, and Richardson (2007). Firstly, Peleg equation (Eq. 5) was used to fit rehydration data (Peleg, 1988).

$$M_t = M_i + \frac{t}{(k_1 + k_2 t)} \quad (5)$$

where k_1 is the Peleg rate constant (min %$^{-1}$), k_2 is the Peleg capacity constant (%$^{-1}$), M_i is the initial moisture content (kg/kg dry solid) and that was 0.1299, M_t is the moisture content (kg/kg dry solid) at time t (min).

The second mathematical model that was used to express rehydration behaviour of pasta samples was probabilistic Weibull model as described in (Eq. 6) (Machado, Oliveira, & Cunha, 1999):

$$M_t = M_i + (M_e - M_i)\left[1 - \exp\left[-\left(\frac{t}{\beta}\right)^{\alpha}\right]\right] \quad (6)$$

where α is the shape parameter (dimensionless), β is the rate parameter (min), M_i is the initial moisture content (kg/kg dry solid), M_e is the equilibrium moisture content (kg/kg dry solid), M_t is the moisture content (kg/kg dry solid) at time t (min).

The parameters of the proposed models were obtained be non-linear regression using SigmaPlot 12.0 (Chicago, IL). In order to evaluate the goodness of fit of the models, the determination coefficient (R^2), the adjusted determination coefficient (R^2_{adj}) and the standard error of the estimate (SEE) values were used (see Eq. 7).

$$SEE = \sqrt{\frac{\Sigma(y - y')^2}{n}} \tag{7}$$

where y and y' were actual and predicted data, respectively; and n was the number of pairs of scores.

3. Results and Discussion

3.1. Water absorption

The rehydration curves of pasta samples rehydrated at various temperatures (75, 85 and 95°C) and voltage gradients (10, 20, 30 and 40 V/cm) respectively during soaking and ohmic heating were presented in Figs. 2 and 3. For regular soaking experiments (see Fig. 2), water absorption was initially rapid then slowed down as the moisture content increased. That is why rehydration process may be divided into two stages, namely initial period and final stage of rehydration (Cunningham, McMinn, Magee, & Richardson, 2007). Water absorption rate, and hence soaking time, were effected from water temperature where almost the same moisture content was achieved nearly in 100, 60 and 35 mins, respectively at 75, 85 and 95°C. During these soaking times, moisture content of pasta gradually increased however did not reach equilibrium as previously reported by Hasegawa and Adachi (2014). It was relatively in a small rate but water uptake of pasta samples was ongoing when experiments were ended.

During ohmic heating, somewhat different rehydration behaviour was observed (see Fig. 3). Because one more rehydration step, defined as “delayed rehydration stage”, can be described other than two previously specified stages. In ohmic heating treatments, initial temperature of cooking water at room level which was same with pasta’s temperature but the initial water temperature in soaking experiments. Thus, moisture absorption rate of pasta samples was almost zero during the first 5 to 15 mins of ohmic heating at 20-40 V/cm. After this delayed stage were passed, the water absorption behaviour was seem to be continue as it was in the initial stage of soaking. The transition between different stages of rehydration were quite smooth at 10 V/cm so it was difficult to specify a duration for delayed stage however from Fig. 3(a), it can be seen that this stage was ended sometime between from 40 to 60 mins. For ohmic heating experiments the time required to reach the slowed down rehydration rate were 140, 35, 25 and 20 mins, respectively for 10, 20, 30 and 40 V/cm electrical potential level. From these results it can be concluded that although delayed stage of rehydration due to low initial temperature of cooking medium were exists, the rehydration of pasta samples was achieved faster compared regular soaking.

In order to understand the rehydration behaviour of pasta samples and also for design and further optimisation of the processes, effective diffusion coefficients relating the moisture transfer phenomena is an important parameter (Maroulis & Marinos-Kouris, 1996). The calculated effective diffusivity parameters and associated activation energy results were shown in Table 1. As it is seen, because of the previously stated reasons respectively two and three effective diffusivity values were calculated for soaking and ohmic heating, for further details please see Section 3.2.3. These different effective diffusivity coefficients describes different single stages observed during rehydration experiments. One can easily conduct from the results that effective diffusivity of initial stage of the rehydration (D_1 for soaking) is higher than the diffusivity found for final stage (D_2)

meaning that the rate of moisture uptake by pasta samples were decreasing in time with increasing moisture content. On the other hand, temperature have shown so sound impact on effective diffusivity that the diffusivity coefficient calculated for 95°C were found almost two fold of 75°C. Similar observations about the moisture diffusivity coefficients of pasta samples during rehydration were previously reported by Cunningham, McMinn, Magee, and Richardson (2007). For ohmic heating, three different effective diffusivity, i.e. D_1, D_2 and D_3, were calculated for every previously defined single stage of rehydration. According to the results, it was observed that the higher voltage led an increment in diffusivity indicating that moisture diffused into pasta samples easier when electrical potential were raised. As expected, after the delayed stage of rehydration has passed an important increment in diffusivity was obvious.

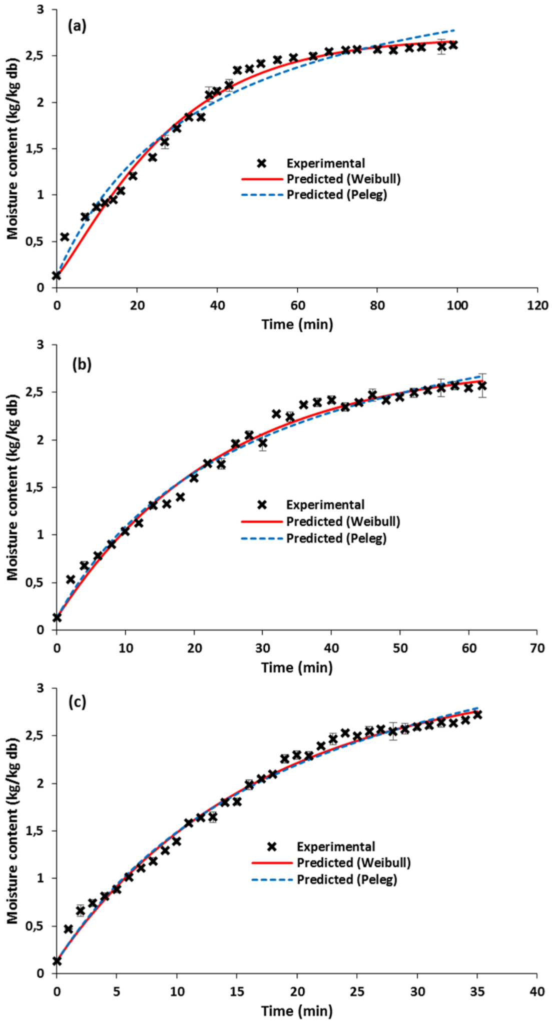

Figure 2. Experimental and predicted (Peleg and Weibull) moisture contents for rehydration behaviour of pasta samples during soaking ((a) at 75°C, (b) at 85°C, (c) at 95°C)

Surprisingly at final stage, diffusivities were found higher than that of for initial stage. However, activation energy required to achieve that diffusion was increasing in time indicating that moisture was being absorbed slower in the final stage of rehydration during ohmic heating while activation energy values for D_1 and D_2 were almost identical for regular soaking.

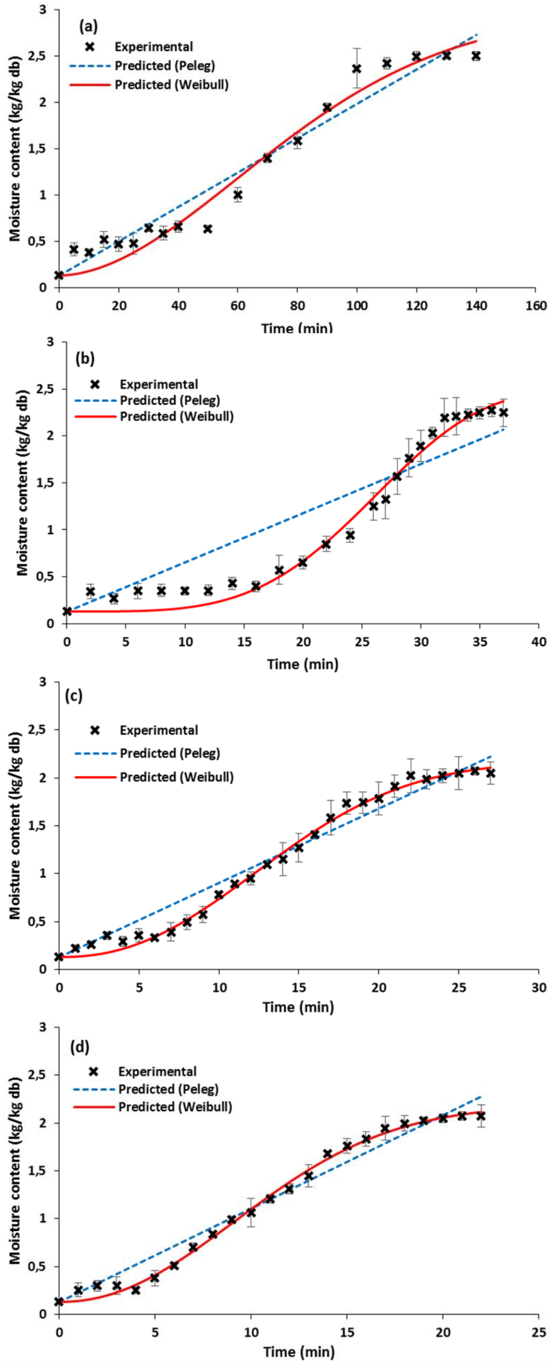

Figure 3. Experimental and predicted (Peleg and Weibull) moisture contents for rehydration behaviour of pasta samples during ohmic

heating ((a) at 10 V/cm, (b) at 20 V/cm, (c) at 30 V/cm, (d) at 40 V/cm)

Table 1. Effect of applied voltage and temperature on effective diffusion coefficient and activation energy for rehydration of pasta

Cooking method		Time	D_1 (x10^{10})	Time	D_2 (x10^{10})	Time	D_3 (x10^{10})
Ohmic heating							
10 V/cm		0-30	5.38	30-100	31.15	100-120	56.70
20 V/cm		0-12	7.24	12-32	129.61	32-36	357.91
30 V/cm		0-5	22.63	5-21	140.08	21-26	386.01
40 V/cm		0-5	27.58	5-15	165.06	15-20	427.64
	E_a	20459.20		21751.81		26940.84	
	D_0 (x10^9)	3.77		31.79		102.95	
Soaking							
at 75°C		0-65	50.53	65-96	47.14	-	-
at 85°C		0-36	62.26	36-52	51.98	-	-
at 95°C		0-25	100.65	25-30	91.62	-	-
	E_a	36.57		35.16		-	
	D_0 (x10^4)	14.84		8.21		-	

- E_a is activation energy (kJ/mole).
- D_0 is pre-exponential Arrhenius factor (m^2/min).
- Time is cooking time of pasta samples (min).
- D_1, D_2, D_3 are effective diffusion coefficients for rehydration of pasta samples during cooking (m^2/min).

Table 2. The calculated parameters of Pegel and Weibull equations at studied conditions of pasta rehydration during ohmic heating and soaking

Cooking method		Model Equations	
Ohmic heating		**Peleg**	**Weibull**
	10 V/cm	k_1 = 53.8724***	α = 2.8363***
		k_2 = 3.98E-18^{ns}	β = 90.8793***
		R^2 = 0.9505	R^2 = 0.9634
		R^2_{adj} = 0.9475	R^2_{adj} = 0.9588
		SEE = 0.2018	SEE = 0.1787
	20 V/cm	k_1 = 19.0001***	α = 2.3760***
		k_2 = 3.14E-16^{ns}	β = 28.2154***
		R^2 = 0.8396	R^2 = 0.9772
		R^2_{adj} = 0.8326	R^2_{adj} = 0.9751
		SEE = 0.3314	SEE = 0.1278
	30 V/cm	k_1 = 12.9243***	α = 2.0426***
		k_2 = 4.85E-18^{ns}	β = 15.7644***
		R^2 = 0.9582	R^2 = 0.9921
		R^2_{adj} = 0.9566	R^2_{adj} = 0.9914
		SEE = 0.1477	SEE = 0.0656
	40 V/cm	k_1 = 10.2440***	α = 2.0532***
		k_2 = 3.87E-18^{ns}	β = 12.3581***
		R^2 = 0.9659	R^2 = 0.9943
		R^2_{adj} = 0.9643	R^2_{adj} = 0.9938
		SEE = 0.1352	SEE = 0.0564
Soaking			
	at 75°C	k_1 = 10.2009***	α = 2.5659***
		k_2 = 0.2754***	β = 29.3043***
		R^2 = 0.9716	R^2 = 0.9835
		R^2_{adj} = 0.9706	R^2_{adj} = 0.9823
		SEE = 0.1283	SEE = 0.0995
	at 85°C	k_1 = 7.7448***	α = 2.6795***
		k_2 = 0.2684***	β = 23.5944***
		R^2 = 0.9833	R^2 = 0.9866
		R^2_{adj} = 0.9828	R^2_{adj} = 0.9856
		SEE = 0.0942	SEE = 0.0860
	at 95°C	k_1 = 5.0462***	α = 3.0400***
		k_2 = 0.2318***	β = 17.2290***
		R^2 = 0.9886	R^2 =0.9903
		R^2_{adj} = 0.9882	R^2_{adj} = 0.9897
		SEE = 0.0818	SEE = 0.0765

- SEE is "standard error of estimate"

*, significant at $p≤0.05$; **, significant at $p≤0.01$; ***, significant at $p≤0.001$; ^{ns}, not significant ($p>0.05$).

3.2. Kinetic analysis of rehydration process

The two common models in literature, i.e. Weibull and Peleg, were used to describe the deviation in moisture content of pasta samples as a function of time. Model parameters of fitted equations and their goodness of fit values (R^2, R^2_{adj} and *SEE*) were presented in Table 2.

Although both of the equations were found enable to explain more than 95% of the variation for regular soaking experiments, Weibull model was found to be one step ahead of Peleg equation (for fitted curves please see Figs. 2 and 3). As can be seen from Table 2, prediction capabilities of the models were found to be slightly vary depending on the temperature and both of the modes showed better performance when temperature was high.

For ohmic heating experiments, Weibull model proposed a good performance by explaining more than 95% of the variation in moisture content. Nonetheless, Peleg model was not as good for ohmic heating since it does not has the ability of explaining S shaped trends such as we obtained from ohmic heating rehydration curves.

It was previously reported that the Peleg constant k_1 is related to mass transfer rate and its reciprocal correlates with diffusion coefficient (Cunningham, McMinn, Magee, & Richardson, 2007; Maskan, 2002). From the results it can be concluded that the values of k_1 showed tendency of decrement when the processing temperature was increased indicating an enhancement in initial water absorption rate (Cunningham, McMinn, Magee, & Richardson, 2007). A similar result were also observed for ohmic heating of pasta samples since the higher voltage levels, the greater k_1 value. This result is reasonable because the increment in electrical potential would no doubt positively affect the heating rate of the cooking medium. The other Peleg constant, k_2 value, was previously announced to be a function of temperature and it decreases as the temperature increases (Cunningham, McMinn, Magee, & Richardson, 2007; Maskan, 2002). The k_2 values calculated in the present study for regular soaking were in agreement with the literature data.

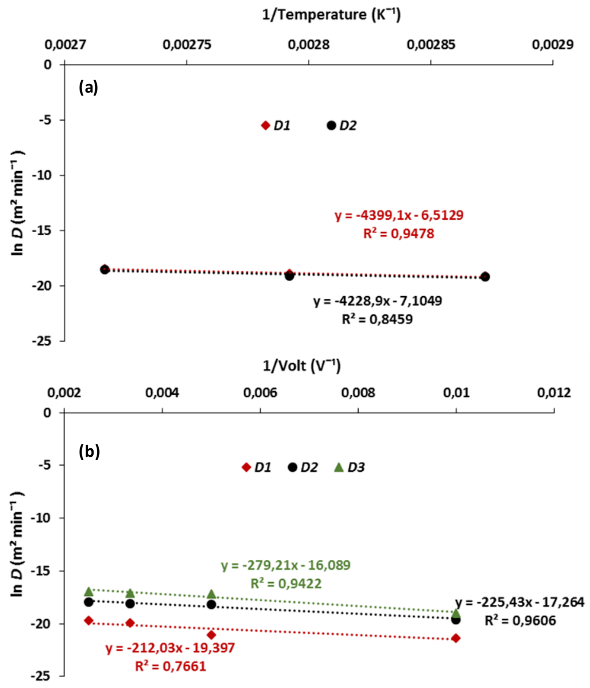

Figure 4. Effect of voltage gradient on effective diffusion coefficients (D_1, D_2 and D_3) ((a) for soaking, (b) for ohmic heating)

However for ohmic heating, any clear relation between k_2 and temperature were not observed and also k_2 value were found to be an insignificant parameter for ohmic cooking of pasta.

Regarding Weibull model parameters, the shape factor (α) could be considered as a constant value for the pasta samples, because of its limited change during rehydration experiments (Cunningham, McMinn, Magee, & Richardson, 2007). Although the variation of α was limited, a minor increment trend of it with respect to increase in applied temperature can be clearly observed. That can be related to increment of moisture transfer ratio with temperature as α was previously attributed to the existence of mass transfer where internal resistance against moisture transport prevails (García-Pascual, Sanjuán, Bon, Carreres, & Mulet, 2005). Nevertheless the variation of α for ohmic heating revealed an opposite behaviour and while the voltage increased, α were decreased as a consequence. That unexpected change may be attributed to the "delayed stage" of rehydration at the very beginning of the rehydration process. Because this stage had a retarding impact on moisture uptake and it was possibly be reflected by the Weibull model parameters. However, another study stating the opposite results, meaning faster water absorption by lower α values can also be present in the literature (García-Pascual, Sanjuán, Melis, & Mulet, 2006). Another kinetic parameter obtained from Weibull model was the rate parameter, i.e. β. Sam Saguy, Marabi, and Wallach (2005) reported that β represents the required time to accomplish approximately 63% of rehydration. Thus, β value can directly be correlated with rate of moisture uptake. In the present study, both temperature and voltage increment resulted in less β value indicating shorter rehydration time as experienced.

4. Conclusions

In the present study, rehydration of pasta samples was examined during soaking at different temperatures (75, 85 and 95°C) and during ohmic heating at different electrical potential levels (10, 20, 30 and 40 V/cm) as an alternative method of pasta cooking. It was observed that water absorption of pasta samples were started at very beginning of the soaking experiments due to high initial temperature of medium where noticeable weight change were recognized after delayed phase of the ohmic heating. That is why three different diffusion coefficient were calculated for ohmic heating, while it was two for regular soaking and furthermore, ohmic heating was superior compared to soaking in terms of rehydration rate. According to the kinetic analysis results of rehydration experiments, the Peleg and Weibull models showed promising performance for regular soaking experiments where the first one could not describe moisture change of pastas during ohmic heating at a desired level.

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