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Convective and Microwave Drying of Onion Slices Regarding Texture Attributes

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Abstract

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The textural characteristics of onion slices (*Allium cepa* L.) of 3- and 7-mm thicknesses undergoing convective drying (50, 60, and 70°C) and microwave drying (68, 204, and 340 W real effective power levels) techniques with or without pre-treatment were evaluated. Pre-treatment consisted of dipping into brine solution (8% NaCl). Texture profile analysis at 25% compression was applied and hardness, chewiness, springiness and gumminess values of onions were recorded. As the temperature (convective) or real effective power level (microwave) increased, the hardness and chewiness levels of dried onion slices were enhanced. The values of these parameters were higher in response to microwave application compared to convective drying. Pre-treatment had an additive effect on hardness and chewiness in convectively dried samples. Maximum springiness was observed in response to convective drying. Dipping in brine solution generally caused no significant changes among slices of the same thickness ($P < 0.05$). With respect to gumminess, the results were quite similar to those for hardness and chewiness, i.e., markedly higher in microwave-dried onions.

Keywords: convective drying; microwave drying; onion; texture profile analysis (TPA)

Onions (*Allium cepa* L.) ($2n = 16$) are one of the world's most significant agricultural crops and are harvested in more than 175 countries (Mitra *et al.* 2012). Global yearly production comes to nearly 640 million tons (Zhang *et al.* 2016). Fresh and dried onions (flaked, powdered, minced, etc.) are important parts of the human diet because they contain large quantities of non-essential micronutrients called phytochemicals (Lanzotti 2006; Sharma *et al.* 2015).

Consumer acceptability is affected significantly by food texture; hence, it can be regarded as one of the primary attributes of food quality (Andres-Bello *et al.* 2013). On the other hand, the texture of a dried food may affect gastric digestion, moisture absorption, shelf life, transportation and marketability. Thus, there is a great demand for understanding, controlling and optimising food texture during drying in order to obtain dried foodstuffs of high quality (Hosseinpour *et al.* 2014). Texture profile analysis (TPA) involves double-compression cycles and a large variety of textural properties like hardness, chewiness, gumminess, springiness, adhesiveness, resilience, cohesiveness, fracturability, etc., that can be determined using this technique (Jaworska & Bernas 2010).

Convective drying results in the production of high-quality products; however, drying times are longer and energy efficiency is lower. Microwave dehydration enables faster drying, but the final properties of foods, with the exception of grains and fruits, may be undesirable (Sorour & El-Mesery 2014). Reports of the impact of pre-treatment applications on drying procedures have very scarce in the current literature and results have been variable. Dipping in brine solution caused differences in the rehydration ratios of sun-dried tomatoes (Latapi & Barrett 2016).

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Nevertheless, no study in the literature has described and/or compared the effects of convective drying (CD) and microwave drying (MD) on the hardness, cohesiveness, gumminess and springiness levels of dehydrated onions. Hence, the objectives of this work were (i) to determine the effects of convective and microwave drying methods, (ii) to confirm the influence of pre-treatment with brine solution and (iii) to detect the impact of slice thickness on the textural attributes of onion slices.

MATERIAL AND METHODS

Sample preparation. Yellow onions (*Allium cepa* L.) were harvested from Ankara (Turkey) in autumn 2015 and spring 2016. Onion peels were removed. Bulbs were cut by hand after measurements were made using a digital calliper. Slices were 3 and 7 mm in thickness; the average diameter of slices was 68 mm. Onion slices were immersed in 8% (w/v) NaCl solution for 40 min in a glass petri dish at 25 ± 1°C for pre-treatment. Average solid/liquid (g/g) ratios were 1/5.05 and 1/2.65 for 3- and 7-mm-thick slices, respectively. Drying operations were performed until the final moisture content of the slice reached 0.13 for convective and 0.10 kg water/kg dry matter for microwave drying, respectively.

Drying procedures. Onion slices were dried convectively in a laboratory type natural convection oven (JSON-250; JS Research, USA) in glass Petri dishes (120 × 17 mm) in a thin layer position detailed in Süfer *et al.* (2017). Individual samples were placed in the center of the rotating plate. For microwave drying operations, a kitchen-type microwave oven (MD 574; Arçelik, Turkey) with 17 l capacity (496 × 294 × 397 mm), at real effective power levels of 68, 204, and 340 W, was used according to Süfer *et al.* (2017). All drying experiments were performed in triplicate.

Texture profile analysis (TPA). Analyses of texture were performed on onion slices using the CT3 Texture Analyzer (Brookfield, Germany) with 4500 g load cell capacity. This method incorporates two compression cycles and textural parameters such as hardness (N), gumminess (N), springiness (mm), and chewiness (N) defined by Szychowski *et al.* (2015) were measured.

The test was performed using the following parameters: trigger load 0.067 N, pre-test speed 2 mm/s, test speed 0.5 m/s, post-test speed 0.5 m/s, probe (diameter 50.8 mm, height 20 mm). All measurements were conducted at room temperature (25 ± 2°C) with ten replicates because of the heterogeneity of samples.

Design of experiments (DoE) and statistical studies. To determine the effects of T (temperature, °C) or P (microwave real effective power, W), L (slice thickness, mm) and B (brine solution, +/–) on the H (hardness), G (gumminess), Sp (springiness), and Ch (chewiness) levels of onion slices, a three-independent variable, four-level central composite rotatable design was used. Statistica software (StatSoft Inc., USA) version 13.2 was used for sketching. Also, a mathematical empirical model was suggested for each textural property by entering mean values into the computer programme.

To determine homogenous groups, the Student-Newman-Keuls test was applied on response variables using the Statistical Package for Social Sciences (SPSS Inc., USA) version 18.0. To eliminating potential sources of confusion, different lowercase letters were used in each bar chart in every figure.

RESULTS AND DISCUSSION

Hardness (H). The hardness values of convectively dried and microwave-dried onions are presented in Figure 1. The hardness levels of convectively dried samples were in the range of 0.592–6.618 N as demonstrated in Figure 1A. The highest and lowest values pertained to 7-mm-thick brined samples dried at 70°C and 3-mm-thick intact samples dried at 50°C, respectively. Intact slices always had lower softness than brined ones. In fact, Tabtiang *et al.* (2012) reported that banana that was osmotically treated with sucrose solution had a harder structure after puffing and air drying.

Figure 1B depicts the hardness values of microwave-dried samples; 7-mm-thick intact slices dried at 340 W had the highest value (28.659 N), 3 mm thick-brined slice dried at 68 W had the lowest (0.389 N). In contrast with CD, the application of pre-treatment markedly reduced the toughness of samples in MD. This is because of the lower drying times of brined samples compared with intact ones. This fact was also demonstrated by the negative sign of the saltness term (B) in the model equation of MD (Equation 1). When the duration of MD was prolonged, hardness increased. Brine solution might be expected to damage onion cells (Akgun & Doymaz 2005); heat and mass transfer occurred quickly, and, so, drying time was reduced in pre-treated samples. More heating causes rapid moisture transfer; hence, hardness rises.

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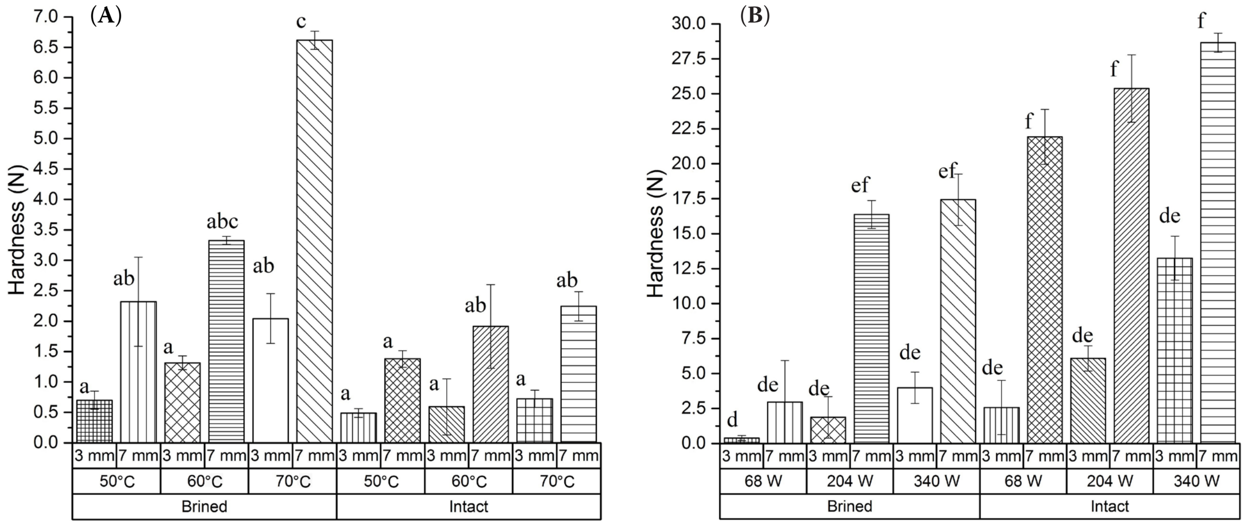

Figure 1. Hardness of samples (**A**) convective drying and (**B**) microwave drying

Shared lowercase letters indicate no significant differences between samples ($P < 0.05$)

Like temperature, the toughness did not rise as the microwave real effective power level increased. The hardness values of 7-mm-thick, intact samples dried at 68, 204, and 340 W were very close to each other and were classified in the same group statistically ($P < 0.05$). No significant differences were found between 3-mm-thick slices except for intact slices dried at 68 W ($P < 0.05$).

Application of brine solution softened control samples; the hardness of intact slices was higher than brined ones (data not shown). The hardness levels of 3-mm-thick, intact, brined samples were 24.195 and 3.856 N, and for 7-mm-thick, intact, brined slices values were 44.167 and 5.149 N, respectively. H_2O and NaCl molecules diffused into onion cells; thus, the gaps between cells and tissues increased. The softening effect of water was probably dominant over the hardening effect of salt because of the concentration of the brine solution. Similarly, Aktas *et al.* (2013) pre-treated apple slices with trehalose and sucrose solutions and reported that the hardness of samples was decreased and elasticity of samples was increased after osmotic pre-treatment. On the other hand, slice thickness had no important statistical effect on brined slices ($P < 0.05$) but caused a significant difference in intact samples ($P < 0.05$).

Response surface methodology (RSM) was used to analyse the impacts of temperature/real effective power, slice thickness and saltness on the texture of dried onion slices. In this article, for every textural attribute, only the model which had the highest determination coefficient (R^2) among the drying techniques is given. In this sense, MD was superior with respect to hardness. Response surface results are shown in Figure 5A. The model equation of MD (Equation 1) states that microwave drying has a positive effect on the hardness. MD generally provides for fast drying, and this causes cracking or warping on the surface of the product. Hence, products obtained using MD might be more rigid (Ramos *et al.* 2003).

The empirical model of hardness (H) for MD samples is as follows (R^2 = 0.975; adjusted R^2 = 0.931):

$$H = -9.276 + 0.014 \times P + 2.873 \times L - 7.145 \times B + 0.003 \times P \times L + 0.028 \times P \times B - 2.678 \times L \times B + 0.006 \times P \times L \times B \quad (1)$$

Gumminess (G). Gumminess is a parameter derived from hardness × cohesiveness (Al-Hinai *et al.* 2003); thus, anything that affects hardness will also influence gumminess in the same way. Apart from some exceptions, samples of MD were the stickiest. In CD, stickiness was in the range of 0.372–4.715 N (Figure 2A). As mentioned above for hardness, when the temperature rose, stickiness levels increased as well. Application of brine solution also enhanced this textural property. Likewise, Goksel *et al.* (2011) claimed that the gumminess of grape molasses increased with rising temperature and starch concentration.

Figure 2B describes the variation of gumminess in MD; 0.224 N was the minimum and 16.247 N was the maximum. Seven homogenous groups were identified statistically from these samples. Stickiness was positively affected by increments in microwave real effective power and temperature. Brine solution also

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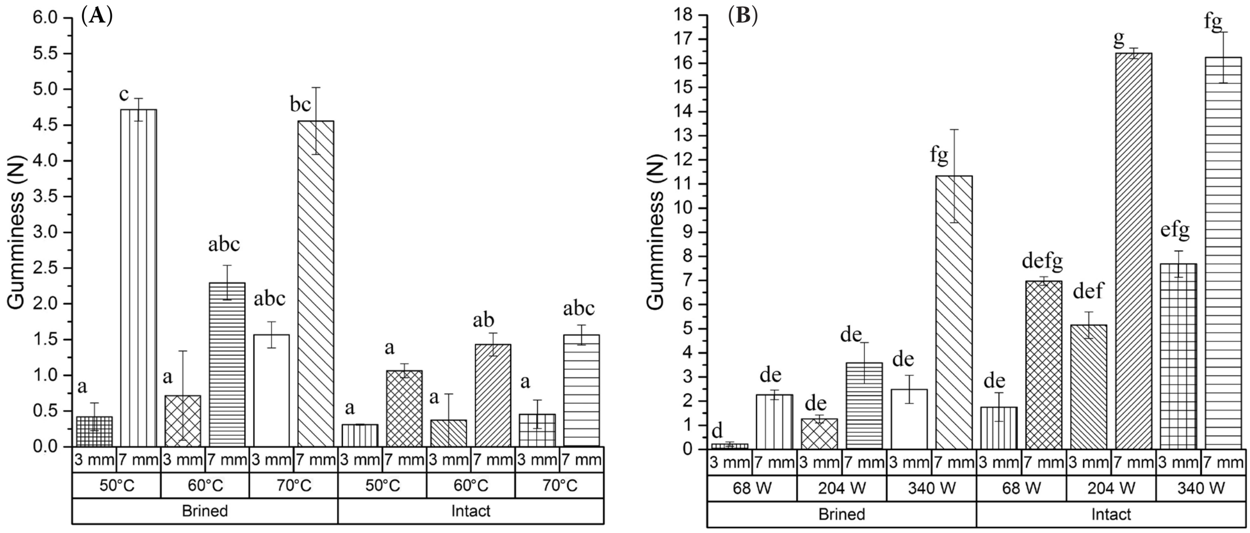

Figure 2. Gumminess of samples (**A**) convective drying and (**B**) microwave drying

Shared lowercase letters indicate no significant differences between samples ($P < 0.05$)

acted to reduce this effect with the result that the gumminess of MD samples decreased. Gumminess (hardness × cohesiveness) is a function of hardness and this characteristic of dehydrated onions is closely correlated to the toughness of dehydrated onions (Nagalakshmi *et al.* 2014). Gumminess levels ranged between 3.204–40.132 N for controls (plots not shown). Like hardness, NaCl solutions exerted a negative effect on gumminess. Only 7-mm-thick, intact slices differed statistically, however ($P < 0.05$). The response surface is given in Figure 5B.

The empirical model of gumminess (G) for MD samples is as follows ($R^2 = 0.936$; adjusted $R^2 = 0.824$):

$$G = 1.908 + 0.001 \times P + 0.643 \times L + 2.063 \times B + 0.004 \times P \times L - 0.010 \times P \times B - 0.819 \times L \times B + 0.001 \times P \times L \times B \quad (2)$$

Chewiness (Ch). Gumminess × cohesiveness gives chewiness (Al-Hinai *et al.* 2003), and factors influence gumminess and accordingly hardness play important roles in influencing this property.

Values of MD samples were clearly greater than those of CD ones (Figure 3A and B). All 3-mm-thick samples were in the same homogenous group ($P < 0.05$). Increases in temperature elicited positive changes in slices with respect to chewiness and these

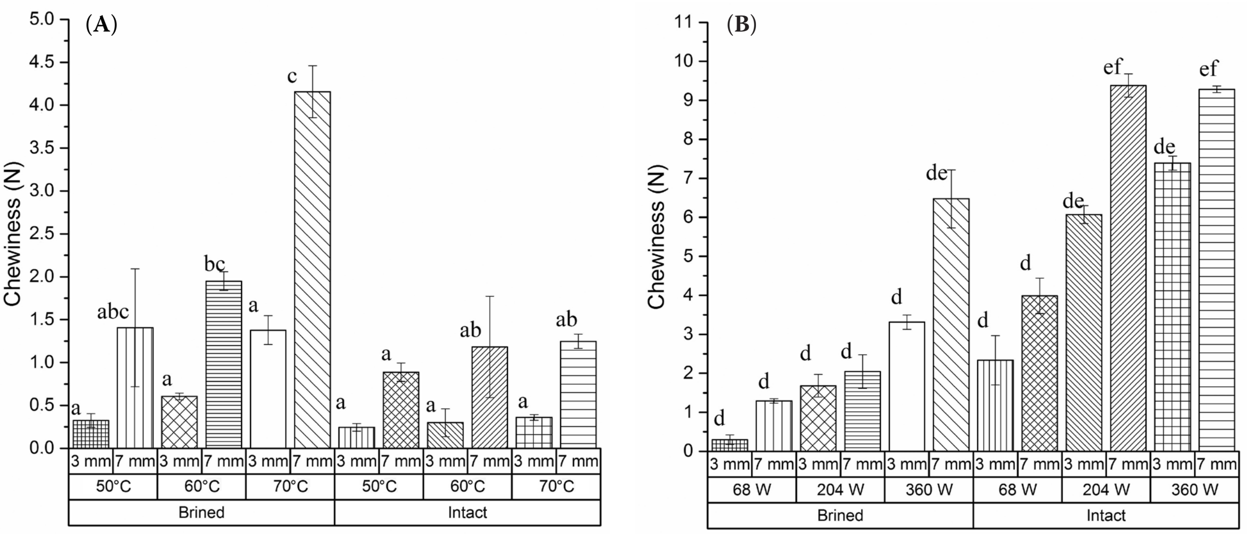

Figure 3. Chewiness of samples (**A**) convective drying and (**B**) microwave drying

Shared lowercase letters indicate no significant differences between samples ($P < 0.05$)

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increments were larger in brined samples than in intact ones. Chong *et al.* (2008) dried chempedak fruit both under sun and hot air and reported that the chewiness of slabs in hot air drying increased with increasing temperature, which is in line with the results of this study. Pre-treatment application was found to have a more pronounced effect on 7-mm-thick slices ($P < 0.05$) with respect to chewiness.

We obtained interesting statistical outcomes for MD, which are presented in Figure 3B. Both brined and intact samples of 7-mm thickness dried at 340 W and 7-mm-thick intact samples dried at 204 W (9.381 N, maximum value) were statistically significantly different from the others ($P < 0.05$), while the remainder of the samples were classified in the same homogenous group ($P < 0.05$). The minimum value, 0.298 N, was observed for 3-mm-thick brined samples dried at 68 W. The value of 7-mm-thick intact samples dried at 340 W was 9.284 N and this was very close to samples dried at 204 W (maximum value). The chewiness values of control samples (data not shown) in N and the results of one-way ANOVA demonstrate that 3-mm-thick slices differed significantly from 7-mm-thick ones, and 7-mm-thick slices were also significantly different from each other ($P < 0.05$). The response surface is shown in Figure 5C.

The empirical model of chewiness (Ch) for CD samples is as follows ($R^2 = 0.940$; adjusted $R^2 = 0.869$):

$$\text{Ch} = 7.846 - 0.132 \times T - 0.759 \times L + 5.222 \times B + 0.012 \times T \times L - 0.083 \times T \times B - 0.233 \times L \times B \quad (3)$$

Springiness (Sp). The springiness was 1.516 mm in CD and 1.417 mm in MD. The lowest springiness values were observed for MD. All 3-mm-thick CD slices were classified into the same homogenous group by SPSS software ($P < 0.05$) (Figure 4A), which means that no close relation or direct correlation between temperature increase and springiness could be detected. The average springiness levels of 3-mm and 7-mm slices were 0.65 and 1.55 mm, respectively, and were independent of drying air temperature. Kotwaliwale *et al.* (2007) studied the drying of mushrooms using hot air and determined the textural properties of the dried product. They emphasised that at the initial stage of drying, springiness increased. Surprisingly, however, in the final stage, springiness decreased. The increase in springiness was attributed to the migration of moisture inside the mushroom body at the initial stage and the decrease in this attribute was linked with the creation of capillary voids. In the current study, however, it was obvious that an increase in slice thickness caused an increase in springiness (Figures 4A and 4B).

In MD, all 3-mm-thick slices were in the same statistical group and all 7-mm-thick samples were classified together in another homogenous group ($P < 0.05$) (Figure 4B). Increases in microwave real effective power caused a slight decrease in springiness values of all samples, which was, however, non-significant ($P < 0.05$). The values of 7-mm-thick slices were obviously greater than those of 3-mm-thick slices, but the effect of brine solution could not be seen clearly from the bar chart. The springiness values of intact and brined

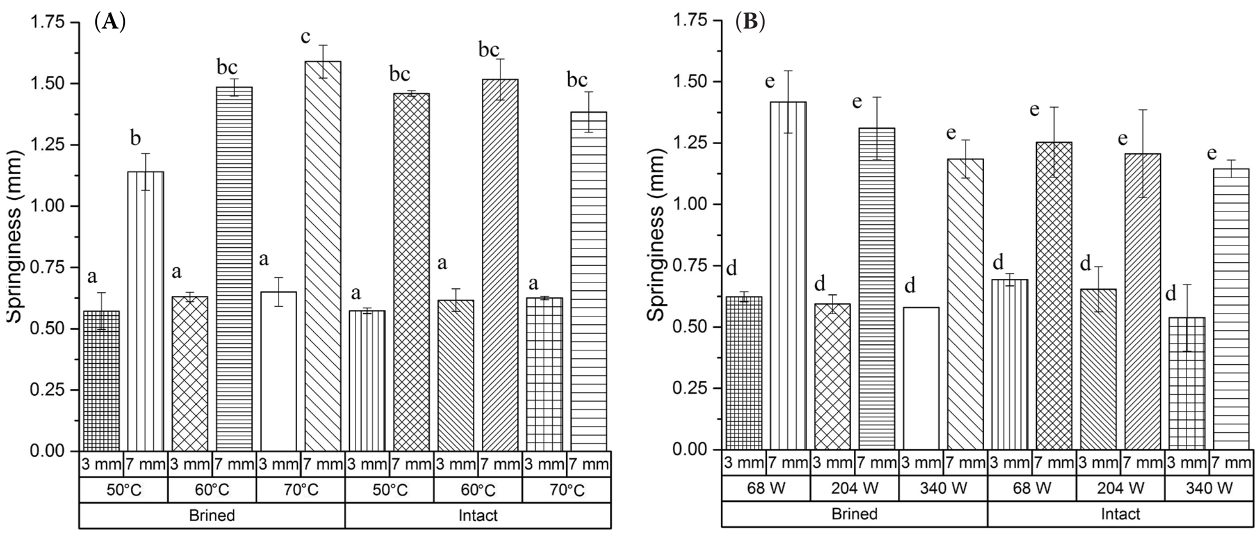

Figure 4. Springiness of samples (**A**) convective drying and (**B**) microwave drying

Shared lowercase letters indicate no significant differences between samples ($P < 0.05$)

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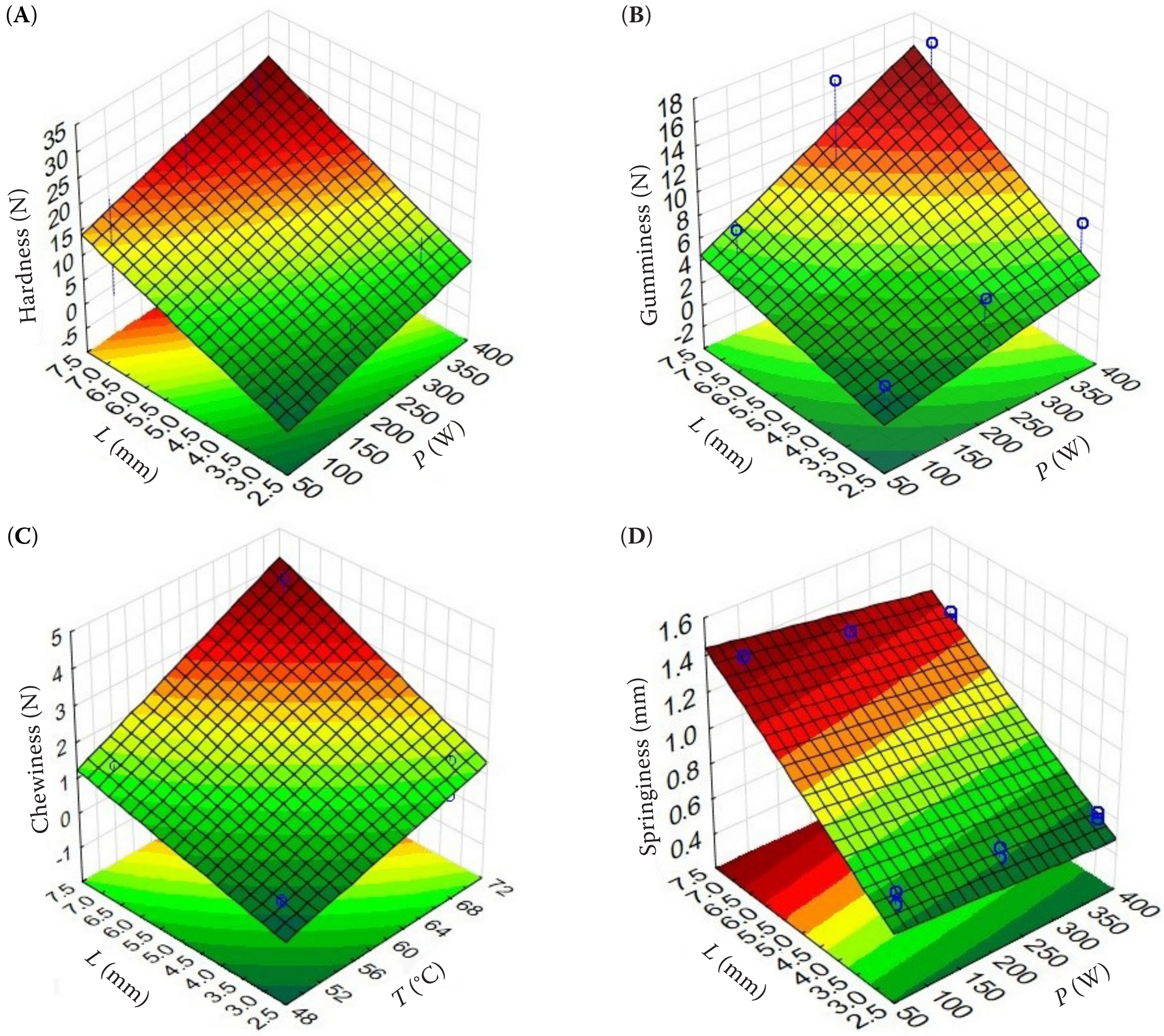

Figure 5. Response surfaces of dried samples (**A**) hardness (microwave drying), (**B**) gumminess (microwave drying), (**C**) chewiness (convective drying), and (**D**) springiness (microwave drying)

controls were 0.680–1.523 mm and 0.692–1.798 mm for 3- and 7-mm-thick slices, respectively (plots not shown). There were significant differences between 3-mm-thick slices and 7-mm-thick samples ($P < 0.05$). The response surface is given in Figure 5D.

The empirical model of springiness (Sp) for MD samples is as follows ($R^2 = 0.999$; adjusted $R^2 = 0.998$):

$$Sp = 0.1687 - 0.000 \times P + 0.173 \times L + 0.173 \times B - (5.55 \times 10^{-5}) \times P \times L - 0.000 \times P \times B + 0.039 \times L \times B - (9.225 \times 10^{-5}) \times P \times L \times B \quad (4)$$

CONCLUSIONS

In this study, the textural properties of dried onion slices were examined and simple empirical models for hardness, gumminess, chewiness and springiness with high determination coefficients were suggested. Response surfaces made it easier to understand the effects of process variables on onion texture in these experiments, in which we used different dehydration techniques with or without pre-treatment on onion slices of 3-mm and 7-mm thicknesses.

Overall, onion slices dried by microwave had higher hardness, gumminess and chewiness values. Relatively high determination coefficients were generally observed when deriving the empirical models in MD; hence, model developing was more successful in MD. We believe that this study contributes to closing the gap in detailed information regarding the texture of dried onion slices, since previously reported studies were usually focused on colour and browning indexes of dried products. However, together with colour and other properties, texture is one of the primary attributes playing a significant role in consumer acceptability.

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