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Full Length Research Paper

Textural properties of infra red dried apple slices as affected by high power ultrasound pre-treatment

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Drying is a process frequently used in food industry, often based on the use of conventional methods using heat exchange by conduction or convection. This kind of method may lead to quality loss in structure, texture and sensory characteristics of final products. Consequently, the need for research of new drying methods arises. One of such methods is power ultrasound aided drying. The aim of this work was to investigate the impact of high power ultrasound pre-treatment on drying rate and textural properties of the infra red dried apple slices. Ultrasound device working at a frequency of 24 kHz with a power capacity of 200 W was used for ultrasound pre-treatment. The amplitudes used for ultrasonic pre-treatment were 50 and 100%. The results showed that the use of different amplitudes of ultrasound reduces the time of drying and allows elimination of more water from the apple slices. Usage of 50 and 100% of ultrasonic amplitude in great extent shortened the duration of drying (up to 40%). The results showed that hardness of samples gradually increases (50% amplitude – 97.260 N; 100% of amplitude – 217.90 N) with increase of ultrasound intensity. As a result, hardness of untreated apple slices (41.037N) was significantly lower ($p < 0.05$).

Key words: High power ultrasound, amplitude, drying, apple.

INTRODUCTION

One of the oldest methods of food preservation is by drying. Consumption of dried foods is still in growth, hence the increase in demands of the market (Singh and Heldman, 1993; Bankole et al., 2005). Conventional methods of drying, using hot air (convection) or hot surface (conduction), are processes that cannot be replaced for extension of shelf life of various fruits, but their disadvantage lies in quality loss of the final product such as lower texture, colour and nutritional value (Nacheva and Tsvetkov, 2007; Ježek et al., 2008; Jimoh et al., 2009). Dried foods could be stored for long periods without demand for cooled transport and specific storage as well (Ježek et al., 2006; Nacheva et al., 2007). This is achieved with the decrease of available moisture or activities of water (within material) until the level that inhibits growth and progress of pathogen microorganisms might have influenced the decaying. On the other hand, this mechanism diminishes enzyme activity and rapidity of chemical changes (Brennan, 2006; Márquez and De Michelis, 2009).

Ultrasound could be recognised as sound signals with frequencies that are above the upper human hearing range (Suslick, 1988; Dolatowski et al., 2007). With frequencies above 2-3 MHz, until it gets to 10 MHz in food technology, ultrasound is utilized as a non-destructive technique with various applications like: determination of foreign bodies (Haegstrom and Luukkala, 2001; Zhao et al., 2003), leveling of liquid in tankers (Gan et al., 2002), characterization (McClements, 1995), measuring of liquid flow properties (Choi et al., 2002), in line monitoring of foodstuffs (Choi et al., 2006) and rheology measurements of foods (Saggin and Coupland, 2004).

On the other hand, high intensity ultrasound or power ultrasound is determined with low frequencies that start from 18 kHz up to 2 MHz. High intensity ultrasound is generally divided as high power ultrasound from 18 until 100 kHz and has an extended range with frequencies from 100 kHz to 2-3 MHz dependable on various processing conditions (Herceg et al., 2009; Brnčić et al., 2009; Guan et al., 2010). High power ultrasound provides enough energy for intermolecular ties splitting, and intensity above 10 W/cm^2 creates cavitations which are,

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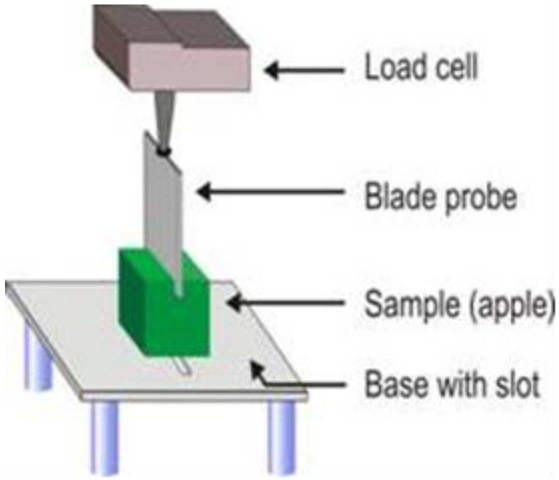

Figure 1. Experimental setup of texture analysis measurements – blade set approach.

namely, the main reason for physical properties' changes during sonication and various chemical reaction occurrences (Povey and Mason, 1995). Cavitations are micro scale bubbles filled with gas that are created within the liquid which is propagated by ultrasonic wave (Wambura and Yang, 2010). When the cavitation bubble reaches its critical size and when the processes within the bubble are critical, it collapse by spreading the energy throughout the environment. The temperature inside the bubble could rise up to 5500 K and pressures of 50 MPa.

High intensity ultrasound is recognised as non-thermal technology with various advantages and is applicable within various foodstuffs (Povey and Mason, 1995; Knorr, 2004; Herceg et al., 2004; Barbosa Canovas et al., 2005; Balachandran et al., 2006; Cucheval and Chow, 2008; Patist and Bates, 2008). Propagation of ultrasonic wave or sonication could be used for enhanced extraction (Wambura et al., 2010), ultrasonic assisted freezing (Zheng and Sun, 2005), improved blanching (Cruz et al., 2010), meat processing (Chang et al., 2010), cleaning (Fuchs, 1999), homogenization and emulsification (Canselier et al., 2002; Bosiljkov et al., 2009), enhanced membrane separation processes (Muthkumaran et al., 2006), inactivation of microorganisms (Pitt and Rodd, 2003) and sonocrystalization (Luque de Castro and Priego Capote, 2007).

One of the promising applications of ultrasound within food technology is the treatment of fruits and vegetables before drying (Fuente-Blanco et al., 2006). This kind of pre-treatment has got an important impact on dried foodstuffs and advantages in physico-chemical and textural properties as well (Carlos and De Michelis, 2009).

Sensory perception of foods (taste, texture, appearance and colour) is one of the most important consumers demand (Brnčić et al., 2008a; Adejumo and Oje, 2009). Loss of water, which occurs during drying, results in structural changes that leads to textural and sensory characteristics different from the fresh product. Texture, as parameter of sensory quality, also plays an effect which is known as taste modulation release. To feel these taste components, it must be released from the food matrix to the suitable receptors. Release of the taste is narrowly tied with the way the food is broken up in the mouth. Consequently, it is also tied with the initial texture and change of the texture during chewing (Brnčić et al., 2006; Makri, 2009a). Texture is a feature of quality that is closely related with structural and mechanical properties of foodstuffs (Burubai et al., 2007; Brnčić et al., 2008b; Makri, 2009b). Relationship force/deformation is time dependable, while force (F), deformation (D) and time (t) represents 3 basic variables that are used in mechanical, that is, textural properties studies of various foods (Lu and Abbott, 2004).

MATERIALS AND METHODS

Preparation of samples

Apples (*Zlatni delises*) were obtained from Fragaria in Croatia. Apples were hand-peeled and cut to the rectangular shaped slices, with dimensions 30 x 20 x 5 mm.

Ultrasound pre-treatment

Pre-treatment of the apple samples was conducted with an ultrasonic device, "UP200S" ("Hielscher", Teltow, Germany) with declared maximal output power of 200 W. Ultrasonic frequency was 24 kHz. Amplitudes used in work were 50 and 100%. Cycle of ultrasound was put up to 1, which is the full time period. Probe that was mounted on the device was 35 mm in diameter. A 100 ml of distilled water was poured into laboratory glass of 250 ml in volume and apple samples were thrown in. Ultrasonic probe was immersed by 1 cm below the surface and sonication was performed for 8 min. After the ultrasonic treatment samples were gently wiped out, the control sample was not treated with ultrasound and was placed directly into the dryer.

Drying

Drying of the samples was carried out in infrared dryer "LJ 16" (Mettler-Toledo, Switzerland). Temperature of drying was adjusted on 85°C and a change in mass of the samples was read off every 5 min. Drying was conducted until constant mass of the sample was achieved. Three samples were dried inside the device, that is, 3 parallel measurements for each of the treatment.

Texture analysis

Hardness, elasticity and work were measured with TA.HDPlus texture analyzer ("Stable Micro Systems", Great Britain) and obtained curves were analyzed with software "Texture exponent". The blade set setup was used. Sample was placed on the base and was cut into two slices (Figure 1). From obtained curves, achieved values were read off. Work is calculated as the total area under force-distance curve and it is expressed in mJ. Apparently, it is equivalent to the work needed for the first bite into sample during sensory analysis.

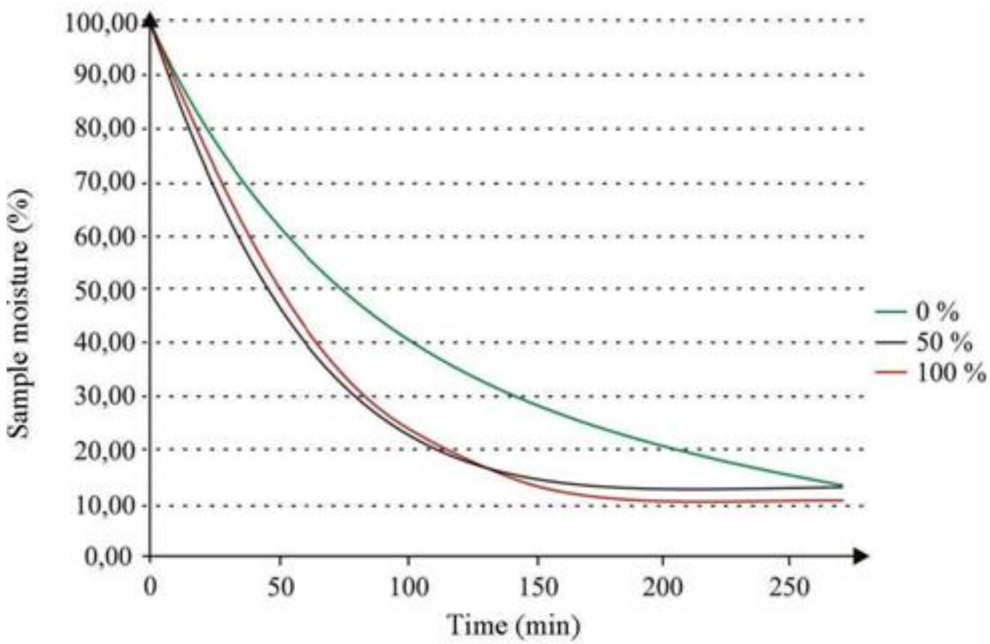

Figure 2. Influence of ultrasonic pre-treatment on drying rate of apple slices.

RESULTS AND DISCUSSION

Drying

The goal of this work was to investigate influence of ultrasonic pre-treatment on drying rate and textural properties of apple slices. Apple samples were sonicated under 50 and 100% amplitude of ultrasonic power and investigated as well. Moisture content of samples was measured gravimetrically every 5 min during drying. Consequently, data were recorded and curves were obtained. Drying rate for each treatment and procedure were compared (Figure 2). It can be observed that drying rate is significantly shortened with increase of ultrasonic amplitude. Drying in infra-red dryer lasted for 270 min for apple slices that were not submitted to ultrasonic pre-treatment. On the other hand, sonication of samples under 50% of amplitude shortened drying rate on 150 min. Similar results for samples treated with 100% amplitude ultrasonic power were obtained. Ultrasonication, as pre-treatment before drying, is helpful in removing moisture from the samples due to sponge effect that is created by the principle of compression and rarefaction, while wave is propagated throughout the liquid medium in which the samples are placed. Researches on this agenda showed that ultrasonic pre-treatment should be conducted up to 10 min. Changes in effective diffusivity after 20 min could be very low and even more insignificant after 30 min of ultrasonic treatment (Rodrigues and Fernandes, 2008). Treatment could be conducted using ultrasonic bath with sonotrodes mounted at the bottom of the device or with sonotrode which is directly immersed in liquid from above, in which samples are submerged. According to Fernandes and Rodrigues (2007), ultrasonic frequency should be between 20 until 100 kHz (very aggressive cavitations) or from 100 until 500 kHz (less aggressive cavitations).

Higher amplitude and consequently, higher intensities of ultrasound had considerable larger effect on tied moisture in samples; while for the same time of drying, increased diffusion of water, throughout the samples, was enabled. This could be explained with the formation of small microscopy in size channels on the surface, but also inside the samples, created by cavitational mechanical forces. This channel enables the relieved release of moisture from the samples during drying, but also improves the final texture. Fernandes and Rodrigues (2007) explained this mechanism in their work with drying of bananas. However, they used ultrasonic bath of 25 kHz frequency without direct mechanical agitation, while in this work, direct immersed sonotrode was applied. Moreover, various authors (Dheng and Zhao, 2008; Fernandes et al., 2008) show pronounced efficiency of ultrasonic treatment on cells and structure of the samples as well.

Textural properties

Texture was measured using instrumental empirical method and the obtained data are shown in Figure 3. Force-time setup was used to present force needed for cross sectional cutting of the apple slices. Maximum force needed for the break down of the sample that was selected represents hardness of the sample (N), while distances from the beginning till the maximum force represent

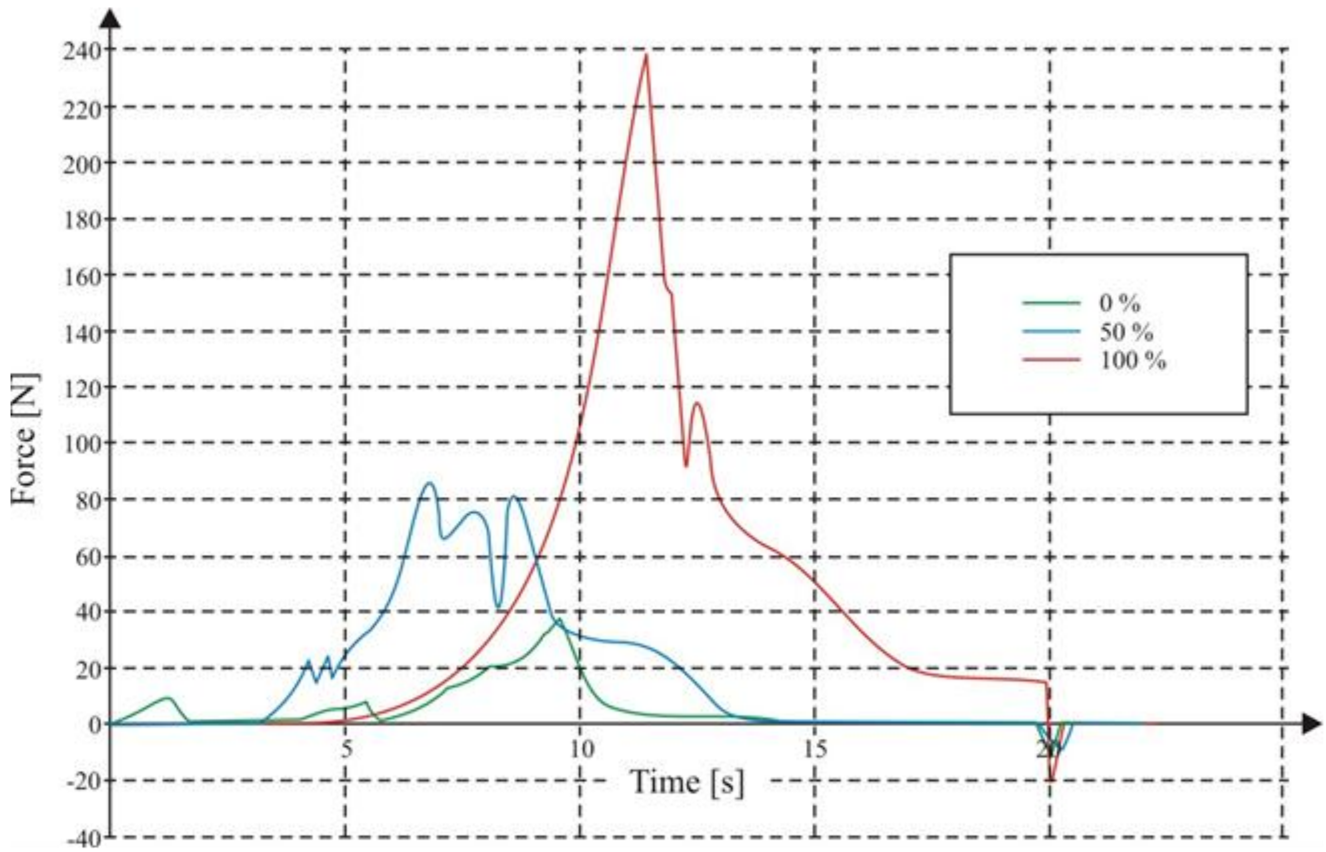

Figure 3. Curves of textural properties for untreated and ultrasonicated apple slices.

Table 1. ANOVA – Influence of process parameters on hardness, elasticity and work required for chewing of the apple slices ($p < 0.05$*).

Process parameter	p - Value		
	Hardness (N)	Elasticity (mm)	Work (mJ)
A [%]	0.000083	0.295600	0.000008
US treatment	0.027567	0.875012	0.004228

*Statistical significance ($p < 0.05$).

elasticity (mm).

Influences of ultrasound treatment and amplitude on textural properties of apple slices are presented on 3-D diagrams and results were analysed with Statistica 8 software. Performed analysis included analysis of variance (ANOVA) and post-hoc analysis (Tukey test) by which the influencing importance of amplitudes and time of treatment on hardness, elasticity and work required for chewing of the apple slices is expressed. Influence on drying rate is presented in Table 1 by correlation of treatment and applied amplitude.

Achieved results show a significant influence of ultrasound treatment and amplitude on hardness and work, while both (ultrasound treatment and amplitude) show no significant influence on elasticity of samples.

Hardness

Interdependence of changeable amplitude and ultrasonic treatment as pre-treatment for drying on hardness of apple slices is shown in Figure 4, while post-hoc statistical analysis for apple slices hardness after ultrasonic pre-treatment is presented in Table 2.

Results of post-hoc analysis indicate that hardness of the samples in dependence of maximal force required for breaking out of untreated samples was (1) 41,037 N compared with sonicated samples of (2) 97,260 N and (3) with 21,790 N. Significant influence on the rise of the force is noticed for both applied amplitudes of ultrasound, with special review on how amplitude of 100% had a stronger influence that could be observed from p-values

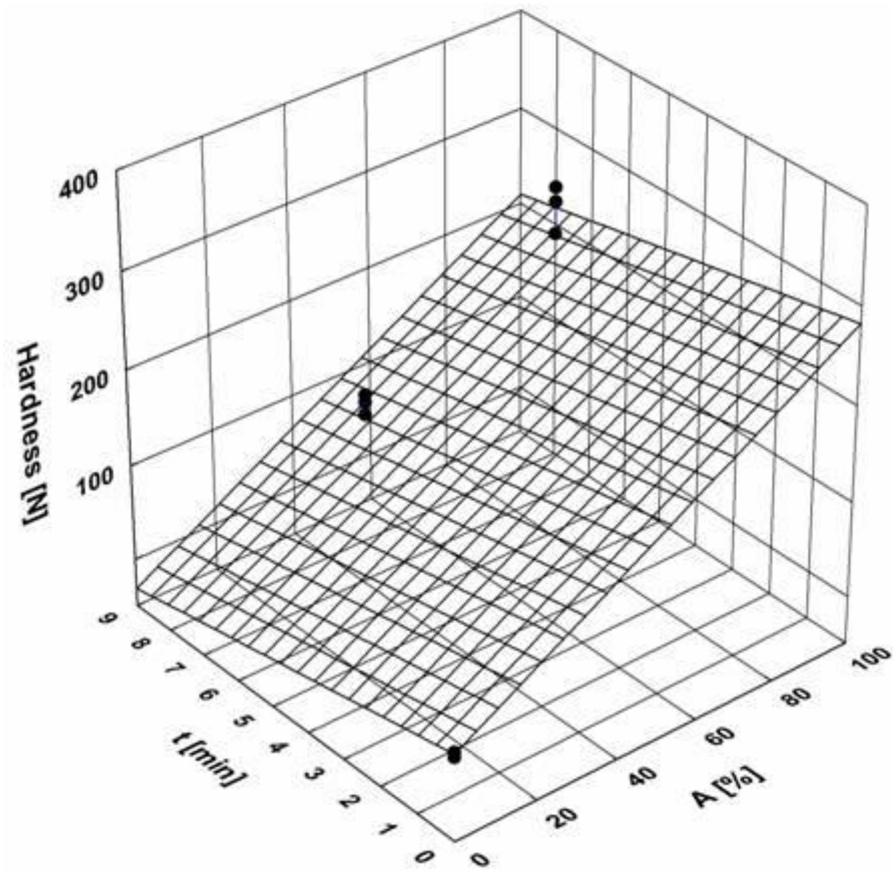

Figure 4. Influence of processing parameters on hardness of apple slices.

Table 2. Post–hoc analysis (Tukey – test) – Influence of ultrasonic amplitude on apple slices hardness compared with untreated apple slices ($p < 0.05$)*.

Hardness [N]	p – Value			
Cell number	**A (%)**	**(1) 41,037 (N)**	**(2) 97,260(N)**	**(3)217,90(N)**
1	0		0.011284	0.000233
2	50	0.011284		0.000402
3	100	0.000233	0.000402	

* Statistical significance ($p < 0.05$).
(1) – Mean value of hardness (N) for unsonicated apple slices.
(2) – Mean value of hardness (N) for ultrasonically treated apple slices under 50% of amplitude.
(3) – Mean value of hardness (N) for ultrasonically treated apple slices under 100% of amplitude.

data presented in Table 2 ($p_{A100\%}<p_{A50\%}$). Likewise, by comparing the p-value influences of untreated samples with the sample sonicated under 100% of amplitude on a mean value of maximal applied force (for the sample sonicated with 50% of amplitude), there is an indicated influence again of maximal amplitude on increase of the sample hardness ($p_{A100\%} < p_0$). Comparison of p-values of post-hoc analysis, between amplitudes ($p_{A100\%} < p_{A50\%}$) of work required for chewing, is in accordance with the achieved p-values for post-hoc analysis of hardness which indicate that hardness of the samples increased with higher amplitude. Obtained influence of ultrasonic amplitude could be compared with elasticity of the newly arisen sample presented in Figure 5, where from bland curvature of the flat surface, influence of applied amplitude is observed (that is, there is a proportional decrease of elasticity of apple slices with increase of hardness). These are advisable and preferable properties for the

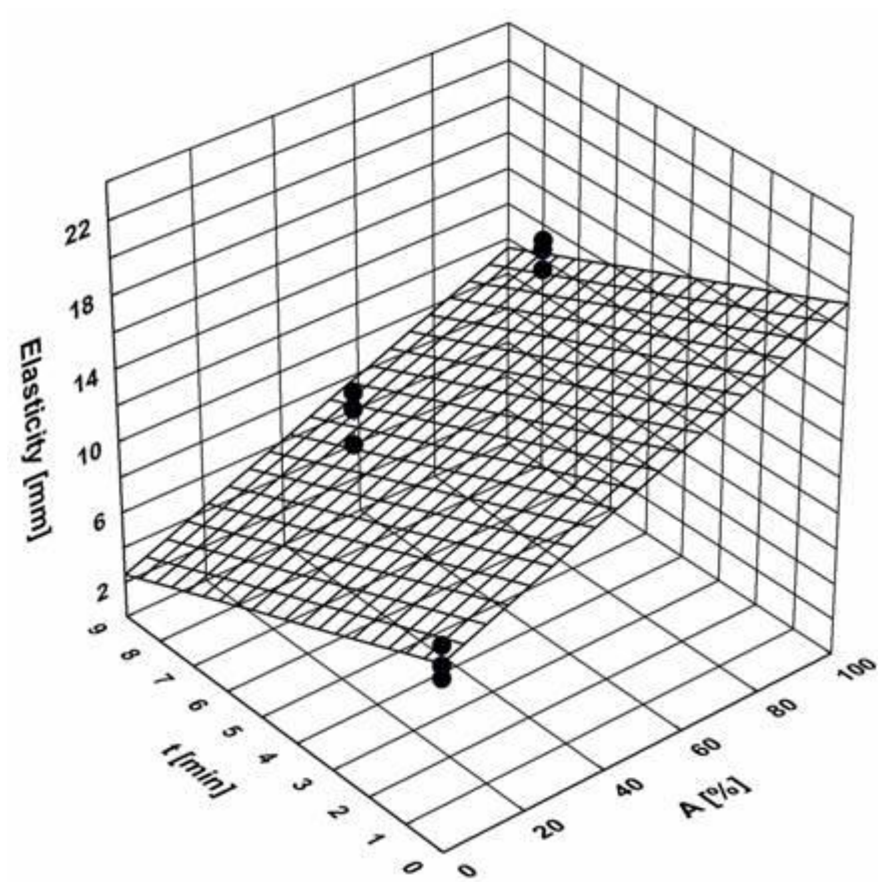

Figure 5. Influence of processing parameters on elasticity of apple slices.

Table 3. Post – hoc analysis (Tukey – test) – Influence of ultrasonic amplitude on apple slices elasticity compared with untreated apple slices ($p < 0.05$).

Elasticity (mm)	p – Value			
Cell number	**A(%)**	**(1)41,037(mm)**	**(2)97,260 (mm)**	**(3)217,90(mm)**
1	0		0.075832	0.159308
2	50	0.075832		0.006716
3	100	0.159308	0.006716	

* Statistical significance ($p < 0.05$).
(1) – Mean value of hardness (N) for unsonicated apple slices.
(2) – Mean value of hardness (N) for ultrasonically treated apple slices under 50% of amplitude.
(3) – Mean value of hardness (N) for ultrasonically treated apple slices under 100% of amplitude.

food product, which are similar to that of the apple slices.

Elasticity

Interdependence of changeable amplitude and ultrasonic treatment as pre-treatment for drying on elasticity of apple slices is shown in Figure 5, and post-hoc statistical analysis for apple slices elasticity after ultrasonic pre-treatment is presented in Table 3.

There is no significant influence of any amplitude of ultrasonic treatment on elasticity of ultrasonically treated apple slices compared with untreated apple slices. Significance for this characteristic is visible only in inter-relationship of applied amplitudes, where a more significant effect is observed with maximal (100%) amplitude in comparison to minimal amplitude (50%) (Table 3). It could also be observed, from the results of post-hoc

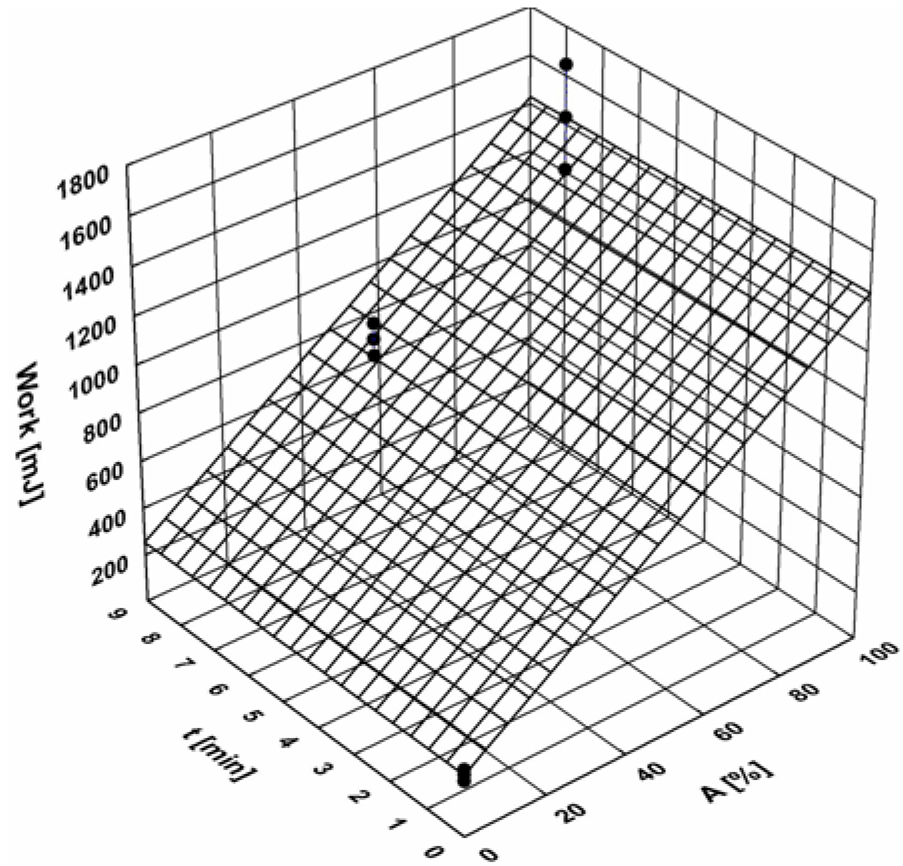

Figure 6. Influence of processing parameters on work required for chewing of apple slices.

Table 4. Post – hoc analysis (Tukey – test) – Influence of ultrasonic amplitude on apple slices work required for chewing compared with untreated apple slices ($p < 0.05$).

Work [mJ]	p – Value			
Cell number	**A (%)**	**(1) 258.26 (mJ)**	**(2) 841.63 (mJ)**	**(3) 1428.2 (mJ)**
1	0		0.004142	0.000280
2	50	0.004142		0.004034
3	100	0.000280	0.004034	

* Statistical significance ($p < 0.05$).
(1) – Mean value of hardness (N) for unsonicated apple slices.
(2) – Mean value of hardness (N) for ultrasonically treated apple slices under 50% of amplitude.
(3) – Mean value of hardness (N) for ultrasonically treated apple slices under 100% of amplitude.

analysis, how possible increase of amplitude (by stronger ultrasonic devices) would not influence additional elasticity of the samples.

Work

Figure 6 represents interdependence of changeable amplitude and time of ultrasonic treatment as pre-treatment for drying on work required for chewing of apple slices. Likewise, post-hoc statistical analysis for apple slices work required for chewing after ultrasonic pre-treatment is presented in Table 4.

Both applied amplitudes of ultrasound had significant influence on work required for chewing compared to untreated apple samples. Applied maximal amplitude of 100% had much stronger influence in relation to amplitude of 50%. This is visible from the data presented in Table 4, in which significance is noticeable over p-value ($p_{A100\%} < p_{A50\%}$). This could lead to further (in future) increase of ultrasonic amplitude in way of different device with larger nominal output power (400 W). However, increased hardness could be an undesirable property. Therefore, sensory evaluation of achieved product with increased hardness should be performed.

Conducted texture analyses indicate that ultrasound pre-treatment influenced sample hardness. By increase of ultrasonic amplitudes and intensities, hardness of the samples increases as well as a consequence of higher amounts of water removal. By itself, increase of hardness is a positive attribute that leads to improved crispiness of dried fruit slices which is one of the main factors for the final consumer judgement. However, treatment with maximum applied amplitude add up to an oversized increase of hardness and therefore is not recommendable for pre-treatment before drying under the mentioned setup of the device. It could be observed in Table 4, where work required for chewing is presented. Values for this property significantly arise with an increase of the amplitude; while for the maximum (100%) of this parameter, the required work is 5.5 times higher when compared with ultrasonically untreated samples. Since the amplitude of 50% triply increases the work when compared to untreated samples, it is an adequate result. Such a treatment is most applicable for pre-treatment, while all benefits are taken into consideration.

Conclusions

Ultrasonic treatment of apple slices before drying enables shorter time of drying. Increase of ultrasonic intensity, additionally lead to more time shortening of drying process. Increase of ultrasonic intensity increases hardness of the dried samples because of higher water removal due to creation of micro channels within and at the surface of apple slices formed by cavitation. Amplitude of 50% was adequately indicated with achieved results for ultrasonic pre-treated apple slices. Maximum ultrasonic amplitude resulted in large hardness of the samples where those parameters of pre-treatment were not suitable. Elasticity of the samples is improved for both amplitude of ultrasound as compared to untreated samples. Ultrasonic pre-treatment assured drying process with shorter duration which led to a reduced quality loss of dried samples.

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