Convective drying of potato assisted by ultrasound

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Abstract: The aim of this paper was to study the influence of ultrasound on convective drying of potato (Solanum tuberosum L.) in stationary conditions. A hybrid dryer equipped with an ultrasound generator was used for this purpose. The effect of different powers of ultrasound on kinetics has been investigated. The effect of ultrasound on potato quality was analyzed by total color change, water activity change, and rehydration. The material used in the experiment was the potato tuber slices, which were cut to a certain size. Drying kinetics and energy consumed for different drying conditions were compared. The results of the experiment indicate that ultrasound assisted process is characterized by lower energy consumption and better quality parameters.

1. Introduction

Food conservation by drying is a well-known method of extending shelf-life. It is known that food, especially fruits and vegetables are particularly sensitive to thermal treatment. Relevant changes are observed both in physical aspects (strength parameters) and chemical composition of the product. Especially adverse changes occur in vitamin and other nutrients content (Sagar and Suresh Kumar, 2010; Tunde-Akintunde et al., 2005; Chou and Chua, 2001; Patel and Kar, 2012). For that reason, scientists are interested in new technological solutions. For some time now, the use of ultrasound, as a factor intensifying the drying process has raised considerable interest among researches. Ultrasounds give the possibility to lower the temperature of the process, and shorten the time of the process.

Ultrasound assisted drying may be carried out in various ways. The most popular is osmosis assisted by ultrasound (as a pre-treatment) (Kek et al., 2013; Fernandes, 2009; Nowacka et al., 2012; Azoubel et al., 2010; Xin et al., 2013), but there are also papers about contact ultrasound drying (Schössler et al., 2012), fluidized-bed drying with ultrasound (García-Pérez et al., 2006), freeze-drying with ultrasound (Rawson et al., 2011) and convective drying assisted by ultrasound (Buntle and Eikevik, 2014). Process intensification using liquids is explained by the cavitation effect and leads to

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significant changes in the structure of dried material (Fernandes et al., 2006; Aday et al., 2013). The main problem of processing conducted in gases is to obtain a high frequency wave, which is characterized by high efficiency (Cárcel et al., 2012). Such efficiency was achieved in the new hybrid dryer used to carry out the experiment described in this paper.

2. Materials and methods

The material for experiment was potato tubers (*Solanum tuberosum* L.) ‘Denar’, purchased from the local market. The initial water content was about 78%. The material was stored at 4 °C without light. Before each experiment, potatoes were washed in cold water and cut into slices of: $D = 0.053 \text{ m}$ (diameter) and $h = 0.005 \text{ m}$ (thickness). Samples were dried in stationary conditions as presented in Tab. 1.

<table>
<thead>
<tr>
<th>Flow rate of hot air [m/s]</th>
<th>Inlet air temperature [°C]</th>
<th>Ultrasound power [W]</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>50</td>
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<tr>
<td>4</td>
<td>50</td>
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<tr>
<td>4</td>
<td>50</td>
<td>200</td>
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Experiments were carried out in the new hybrid dryer. Ultrasounds with frequency 25 kHz were generated constantly using Airborne Ultrasound System (AUS), produced by Pusonics S.L. (Spain). The hybrid dryer was equipped with a pyrometer, which measured temperature of the material during the process, with accuracy of 0.1 °C. The initial moisture content in potatoes was determined on the basis of a moisture analyzer model XM120 PrecisaGravimetrics AG, CH – Dietikon (Switzerland). For each experiment six slices were cut and placed concentrically on the tray in the dryer. The tray was situated on the rotary shaft, which was attached to the balance (Radwag PS 6000.R2). The accuracy of weight loss measurements was at 0.01 g. The measurements were read-out and saved automatically every minute by the computer. Each experiment was conducted twice, to check if the result is recurrent. The scheme of the experimental setup is shown in Fig. 1.

The determinants of the dried material quality were the color change and the water activity. Color change was determined as the difference between fresh sample color value and dried sample color value. Color was measured using colorimeter CR-400 Konica Minolta Sensing, INC. (Japan). The colorimeter was connected to the computer, equipped with SpectraMagic NX QC software. Before the color measurement, the sample was grounded in a basic analytical mill IKA A11 (Werke GmbH & Co. KG, Germany). The color of the potato was indicated by CIELab color scales L, a, b. The value of total color change ($\Delta E$) was calculated using formula (1).

$$\Delta E = \sqrt{(\Delta L)^2 + (\Delta a)^2 + (\Delta b)^2}$$ (1)
Fig. 1. The experimental setup: 1 air pump; 2 dryer chamber; 3 converter; 4 microwave generator; 5 balance; 6 control system; PC; 7 ultrasound generator.

$L$ — lightness,

$a$ — color parameter in the space from red to green,

$b$ — color parameter in the space from yellow to blue.

Water activity ($a_w$) was determined for each experiment before and after drying. The $a_w$ value was measured with the use of Testo 650/0628.0024. The outcome was obtained as an equilibrium of temperature and moisture content. Before the measurement, a piece of potato tuber was fragmented and put into the chamber of the device.

Rehydration was conducted for two slices from each experiment. Dried slices were immersed in distilled water at a temperature of 17.2 °C. The overall time of rehydration was 5 h. The samples were weighted after 0.5, 1, 2, 3, 4 and 5 hours. Before weighing samples were withdrawn from the water and drained. The proportion between the dried material and distilled water was 1:50, and water amount did not change.

3. Results

The first stage of the experiment was a convective drying (CV) test, at a temperature of 50 °C and hot air flow rate of 4 m/s. The drying kinetics of this process and the temperature of the material are shown in Fig. 1. As shown in Fig. 1, the temperature of the material rises during the process and reaches a constant value in the fourth hour. The time of the process was 5.13 [h].

The next step of the experiment was to examine the influence of ultrasound on convective drying. For that purpose, at the same hot air conditions, ultrasound with powers 100 W and 200 W was added. Drying curves are shown in Fig. 2 and Fig. 3.

The ultrasound assisted process was conducted until the moisture content of sam-
ple reached 0.02 kg/kg wb, as in the CV process. The time of the process shortened by about 28 % for 100 W ultrasound power, and 32 % for 200 W ultrasound power, respectively.

Fig. 5 shows total electrical energy consumption during the experiments. The ultrasound assisted process, although it is more energy-intensive per time unit, requires less energy than the CV process.

3.1. Total color change ($\Delta E$)

Because of enzyme content (especially polyphenol oxidase), vegetables, darken in contact with oxygen (Malinowska-Pańczyk and Kołodziejska, 2010). Fig. 6 demonstrates
samples dried in different conditions (a, b, c) and a fresh sample (d).

Fig. 7 demonstrates total color change ($\Delta E$) on potato slices during the experiment. The maximal $\Delta E$ was obtained for samples dried in the convective process, but $\Delta E$ measured for samples dried in an US assisted process was comparable. As already mentioned, potato is sensitive to oxygen and any violation of the structure causes progressive changes.

### 3.2. Water activity change

According to Lewicki, the growth of most fungi, molds and bacteria is inhibited when water activity value is less than 0.7 (Lewicki, 1999).

Results from water activity examination are shown in Fig. 8. Water activity values
Fig. 6. Samples: a) CV; b) CV+US 100W; c) CV+US 200W; d) fresh sample.

Fig. 7. Total color change in potato samples.

are similar for both the convection process sample and the ultrasound assisted process sample. The $a_w$ value is high compared to e.g. Nowacka, but it is within the safe limit (Nowacka et al., 2010).

3.3. Rehydration

Drying causes irreversible changes in the material. Even if the time of rehydration would be infinite, the material does not absorb as much moisture, as it lost during
drying (Witrowa-Rajchert, 2004). However, from the viewpoint of consumption, dried material should be characterized by the greatest return to initial weight. Fig. 9 indicates that the ratio of return to initial weight is higher for samples dried with US. The difference between samples dried with US power 100 W and 200 W is about 4 % in favor of 200 W power.

Fig. 9. Relationship between the ratio of current mass ($m_t$) to initial mass ($m_0$) of time for samples dried in different conditions.
4. Conclusion

The influence of ultrasound on convective drying of potato was analyzed. According to research, ultrasound usage improves potato quality. Results from rehydration show that the structure of biomaterial dried with ultrasound is characterized by minor changes. From the viewpoint of its application in industry, ultrasound significantly reduces the time of the process, from about five hours to three hours. This makes it possible to reduce energy consumption and total costs of the process, which is crucial, because drying is one of the most energy-intensive process in food industry.

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References


