Scientific quarterly journal ISNN 1429-7264
Agricultural Engineering
2014: 2(150):219-228
Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2014.150.048

IMPACT OF DRYING PARAMETERS AND METHODS ON THE VOLUME INCREASE OF DRIED APPLES DURING THEIR REHYDRATION[1]

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ARTICLE INFO

Article history:
Received: September 2013
Received in the revised form: December 2013
Accepted: January 2014

Keywords:
manner of grinding,
temperature,
velocity of drying air,
drying,
rehydration,
volume,
apple

ABSTRACT

The objective of this paper was to analyse the impact of parameters and drying method on the increase of the volume of dried apple slices and cubes during their rehydration. Ligol apples (cut into 3 and 10 mm slices and 10 mm cubes) were dried with the following methods: natural convection (temperature of drying 60°C), forced convection (a tunnel drier, parameters of drying air: 50, 60, 70°C and 0,5, 2 $m \cdot s^{-1}$), fluid drying (60°C and 6 $m \cdot s^{-1}$). Dried fruit were rehydrated in the distilled water of 20°C temperature. Determination of volume was carried out with an uplift pressure method in petroleum ether. Tests proved the impact of ground dried particles and the impact of drying method on the increase of the volume of dried apples during their rehydration. The final volume of the rehydrated dried fruit increased along with the reduction of drying temperature, these differences in numerical values were low, but statistically significant.

Introduction

Drying is a frequent method of preserving food products. Its purpose is to remove water, which causes, inter alia, limitation of the growth and development of putrefactive micro-organisms and limits biochemical reactions, due to which the period of storing the product at the maintenance of proper storage conditions, may be considerably elongated (Jayaraman and Das Gupta, 1992). Simultaneously, however, in food products unfavourable quality changes take place during drying, which include both optical properties (colour), sensory (smell, taste), structural (volume, porosity, density), textural, rehydration properties and losses in nutritious elements, in particular vitamins, the intensity of which depends on the type of the dried product and the applied drying method (Krokida and Maroulis, 2001; Marabi et al., 2006).

[1] *The article was written as a part of a research grant no N N313 780940 financed from the National Science Centre funds*

Reduction of volume is one of the most disadvantageous physical changes during the process of drying food. The loss of water and heating causes formation of stresses in the cell structure of food products which leads to drying shrinkage, the change of the product shape and the decrease of its dimensions (Mayor and Sereno, 2004). The phenomenon of shrinkage also negatively influences the process of rehydration of the dried product, decreasing ability of tissues of the dried material to absorb water (Krokida and Marinos-Kouris, 2003; Mayor and Sereno, 2004). At the same time, many dried products is consumed or industrially processed after previous hydration. Thus, it is important to obtain dried fruit in such conditions, which enable in the highest degree a later return of the rehydrated material to properties, which characterized the raw material.

Impact of drying parameters and methods on rehydration of fruit and vegetables was investigated and presented in literature. Rehydration of banana, carrot and potatoes dried by means of microwaves was faster and particles absorbed more water than samples dried by means of convection (Drouzas and Schubert, 1996; Prabhanjan et al., 1995). Witrowa-Rajchert and Radecka-Wierzbicka (2005) did not find any explicit impact of the drying technique (convection drying with the air flow along the material layer, convectional drying with a perpendicular air flow, fluid drying) on the ability of dried carrot and potatoes to rehydrate. The increase of the microwaves power caused deterioration of the rehydration of the dried beetroot pulp (Figiel et al. 2006). Stępień (2007) investigated rehydration of the dried celery, which was dehydrated by means of sublimation, microwave and vacuum and convection. Celery dried by means of sublimation was characterised with the highest kinetics of the increase of the sample mass and the increase of the water mass and the lowest loss of the dry substance mass. The increase of mass of the jujube fruit wholly dried (*Zizyphus jujuba* Miller) was higher if the temperature of drying air was higher (Fang et al., 2009). Investigating the impact of the drying method (convectional, sublimation, microwave-vacuum) Stępień (2009) proved that from the dried carrot obtained with convectional method from the material dehydrated by means of osmosis, during hydration, the biggest amount of dry substance diffuses to the solution, whereas Aversa et al. (2012) proved the impact of convectional drying parameters (temperature and the drying air velocity) on the increase of water mass during rehydration of dried carrot. If convectional drying will be preceded with microwave drying, then dried fruit and strawberries will absorb more water during rehydration. In such manner, dried mushrooms will absorb less water and in case of dried tomatoes, no impact of such drying on the course of rehydration was reported (Askari et al., 2009). Stępień et al. (2011) determined a significant impact of the drying method (convectional, sublimation, microwave-vacuum) on the ability to rehydrate dried parsley. Taking into consideration the results of the quality research of convectional dried fruit and freeze drying agent and in particular the course of rehydration Lis et al. (2011) reported their considerable variability, the bigger, the lower water content was in dried fruit (from a sublimation drier).

The impact of parameters and the drying methods on the increase of the volume of dried fruit and vegetable during their rehydration was researched less frequently and presented in literature. Bilbao-Sáinz et al. (2005) performed microwave drying of apples before convectional drying and determined that the increase of the volume of dried fruit during hydration is higher for a higher power of microwaves. The increase of volume during rehydration of apples dried by means of sublimation was higher than apples dried by means of convection (Lewicki and Wiczkowska, 2006). Markowski et al. (2009) proved the impact of the drying method of potatoes (microwave – vacuum, convectional) on the increase of the volume of dried fruit during rehydration. Górnicki et al. (2009) stated that temperature of drying influences the relative increase of the volume of dried parsley roots during rehydration.

The objective of this paper was to analyse the impact of parameters and drying method on the increase of the volume of dried apples during their rehydration.

Material and methods

Ligol apples were used for the research. Their initial temperature was approx. 85% (5.7 kg $H_2O \cdot kg^{-1}$ d.m.). The raw material was washed and sliced and cut into cubes. Slices were 3 and 10 mm and cubes 10 mm. The raw material was dried with the following methods:

- natural convection, temperature of drying air in a drier (KCW-100, PREMED, Marki) was 60ºC,
- forced convection, temperature of drying air in a tunnel drier was 50, 60 and 70ºC, whereas the velocity of drying air was 0.5 and 2 $m \cdot s^{-1}$, the air flow was horizontal, the initial load of meshes was 10 $kg \cdot m^{-2}$,
- fluidized drying, temperature of drying air was 60ºC and the drying air velocity was 6 $m \cdot s^{-1}$.

drying lasted to the moment a fixed value of the dried fruit mass was set. The final moisture of dried apples was approx. 9% (0.1 kg $H_2O \cdot kg^{-1}$ d.m.).

Dried fruit obtained in given conditions from three independent experiments were mixed and stored in a tightly closed container for approx. a week in temperature of 20ºC. Afterwards samples for further research were collected. A container, where dried fruit were stored was placed in a cardboard, so the dried apples were exposed to sun's rays effect. The process of rehydration was carried out for 6 hours in distilled water of a fixed temperature 20ºC. The relation of the dried fruit mass to water mass was 1:20. During the process of moistening water was not stirred. The initial mass of dried fruit subjected to rehydration was approx. 10 g. Determination of the volume was carried out with the uplift pressure method in petroleum ether (Kaleta (red.), 2013; Mazza, 1983). Measurements were carried out for dried fruit and during the process of rehydration. During rehydration volume was determined after 10, 20, 30, 50, 90, 180 and 360 min of the duration of moistening. Each sample was subjected to rehydration to a single measurement of volume. Designation was carried out in three repeats. The maximum relative error of designating the volume calculated with the total differential method was 5%.

Pelega model (1988) in the following form was applied for description of the volume of dried apples in the process of rehydration

$$\frac{V}{V_0} = 1 + \frac{\tau}{k_1 + k_2 \tau} \tag{1}$$

where:
k_1, k_2 – constant,
V – volume (ml),
V_0 – initial volume (volume of dried fruit) (ml),
τ – time (h).

This model was very frequently used for description of the rehydration process including inter alia for modelling the volume increase (Bilbao-Sáinz et al. 2005). For determination of the model parameters the method of non-linear estimation by Lavenberg-Marquardta was applied. Coefficients of correlation *r* were also calculated. Significance of the impact of methods and parameters of drying on the increase of the volume of dried apples during their rehydration was determined with the use of analysis of variance (ANOVA) after accepting the uniformity test of Levene's variance. Tukey's test HSD was applied for division into uniform groups (at the significance level of α=0.05). Calculations were carried out with the use of IBM® SPSS® Statistics 21 application.

Results and discussion

Results of experiments were presented in figures 1-5. Figure 1 presents an exemplary diagram of the increase of the volume of dried material (apple cubes of a 10 mm side, dried in a fluidized drier in temperature of 60ºC and the drying air velocity of 6 $m \cdot s^{-1}$) during rehydration in distilled water of temperature of 20ºC. This figure presents measurement points. It is visible, that the fastest increase of volume takes place in the initial period of rehydration, in the further stage of the process, water absorption slows down, because hydrated samples get close to the state of balance. A similar character of volume changes during rehydration was reported by Bilbao-Sáinz et al. (2005) for apples, Markowski et al. (2009) for potatoes and Witrowa-Rajchert (1999) for apples, carrot, parsley and potatoes. Fast initial water absorption is related the most probably with filling with water capillaries at the surface of a sample (Bilbao-Sáinz et al., 2005).

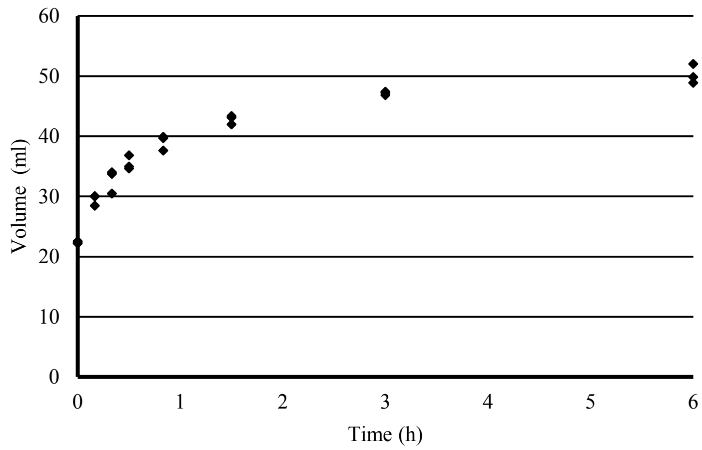

Figure 1. The increase of the volume of dried material (apple cubes of a 10 mm side, dried in a fluidized drier in temperature of 60ºC and the drying air velocity of 6 $m \cdot s^{-1}$) during rehydration in distilled water of temperature of 20ºC

Figures 2-5 present functions approximating the results of three repeats of measurements of volume changes during the process of rehydration (Pelega model). The calculations prove that Pelega model describes well the increase of volume of dried apples during their rehydration since the value of the coefficient of correlation *r* is within 0.956 to 0.996 (fig. 2-5).

Statistical analysis of the impact of drying methods and parameters on the increase of volume during rehydration of dried apples (division into uniform groups) was presented in table 1. In this table, numbers mean average values from three repeats of measurements of the relations of present volume of rehydrated dried fruit to the initial volume of dried fruit, whereas uniform groups for each time of rehydration were determined with the same letters. On account of transparency of diagrams in figures 2-5, measurement points and confidence regions were not marked.

Table 1
Average values of the relation of the volume of rehydrated dried fruit to the initial volume of dried fruit in the rehydration process

Form of raw material	Drying method and parameters	Time (min)						
		10	20	30	50	90	180	360
3 mm slice	tunnel drier 60ºC, 0.5 $m \cdot s^{-1}$	1.98^{a}	2.22^{a}	2.41^{a}	2.76^{a}	2.89^{a}	3.18a	3.12^{a}
10 mm slice	tunnel drier 60ºC, 0.5 $m \cdot s^{-1}$	1.19^{b}	1.43^{b}	1.36^{b}	1.50^{b}	1.60^{b}	1.96b	2.22^{b}
10 mm slice	natural convection, 60ºC	1.14^{b}	1.31^{c}	1.27^{c}	1.53^{b}	1.56^{b}	1.83c	2.02^{c}
cube 10 mm	fluidized drying, 60ºC, 6 $m \cdot s^{-1}$	1.32^{cdg}	1.47^{bd}	1.59^{dg}	1.75^{cgh}	1.92^{c}	2.11^{dh}	2.25^{b}
cube 10 mm	natural convection, 60ºC	1.37^{cdegh}	1.50^{bd}	1.62^{dg}	1.85^{defgh}	2.06^{d}	2.43^{e}	2.62^{d}
cube 10 mm	tunnel drier 50ºC, 0.5 $m \cdot s^{-1}$	1.42^{defgh}	1.55^{d}	1.71^{eg}	1.90^{defh}	2.15^{e}	2.32^{fg}	2.51^{efh}
cube 10 mm	tunnel drier 60ºC, 0.5 $m \cdot s^{-1}$	1.48^{efh}	1.68^{f}	1.80^{f}	1.93^{def}	2.16^{e}	2.24^{fg}	2.45^{efgh}
cube 10 mm	tunnel drier 70ºC, 0.5 $m \cdot s^{-1}$	1.39^{cdegh}	1.46^{bd}	1.64^{deg}	1.79^{cdgh}	1.92^{c}	2.18^{gh}	2.38^{fg}
cube 10 mm	tunnel drier 60ºC, 2 $m \cdot s^{-1}$	1.41^{defgh}	1.52^{bde}	1.65^{deg}	1.83^{cdegh}	2.02^{d}	2.24^{fgh}	2.48^{fh}

a, b, c, d, e, f, g, h – the same letters in columns indicated uniform groups

Figure 2 presents the impact of slices thickness and in figure 3, the impact of the shape of a particle on the increase of the volume of rehydrated dried fruit. For the same time of process duration the increase of the volume of rehydrated dried fruit increased with the reduction of slices thickness and dependent on the shape of a particle (increase of volume for a cube is higher than for a slice with the same thickness). The higher degree of grinding of dried apples particles, the higher are the increases of volume in the rehydration process.

Such impact of grinding of particles on the increase of the volume of rehydrated dried fruit is statistically significant (table 1). A similar character of the impact of grinding was reported by Aversa et al. (2012) for carrot particles.

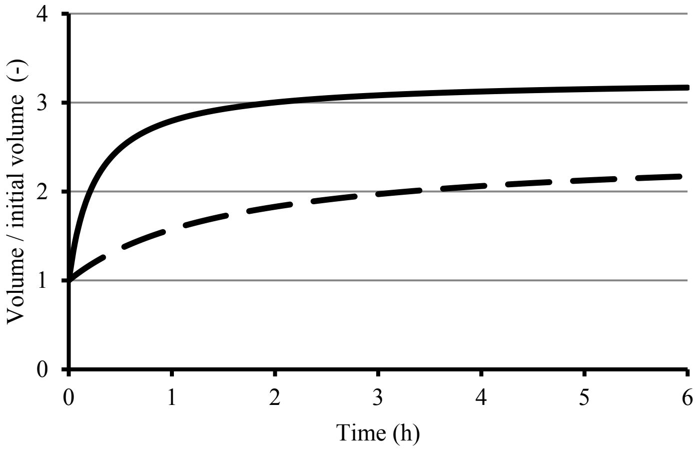

Figure 2. The increase of volume of dried apple slices (tunnel drier, drying air temperature 60ºC, drying air velocity 0.5 m·s^{-1}) of thickness: (——) 3 mm (r=0.986), (— —) 10 mm (r=0.956) during rehydration in distilled water

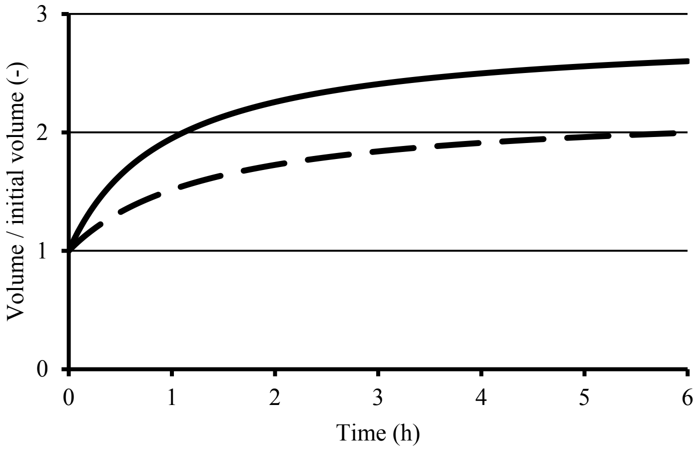

Figure 3. The increase of the volume of dried material (natural convection, drying air temperature 60ºC) during rehydration: (——) apple cubes of 10 mm side (r=0.992), (— —) apple slices of 10 mm thickness (r=0.956) in distilled water

The next figure presents the impact of convectional drying on the increase of volume of dried fruit during rehydration. The final volume of the rehydrated dried fruit increases along with the reduction of drying temperature, these differences for numerical values are low, but statistically significant (tab. 1). A similar character of the impact of drying temperature was reported for potatoes by Markowski et al. (2009).

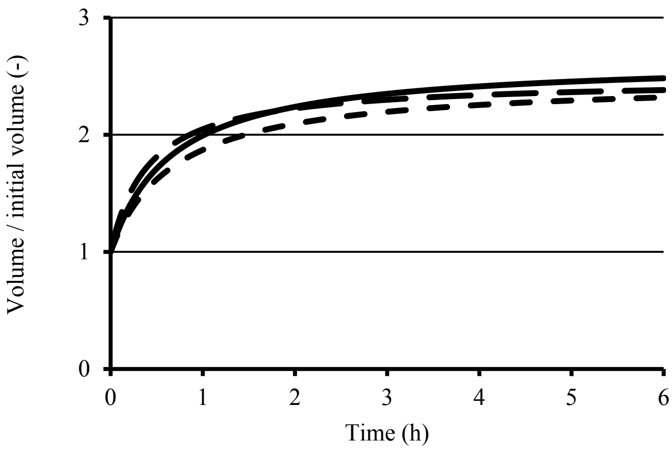

Figure 4. The increase of the volume of dried material (apple cubes of a 10 mm side, dried in a tunnel drier in temperature: (——) 50ºC (r=0.996), (— —) 60ºC (r=0.986), (- - -) 70ºC (r=0.990), drying air velocity 0.5 m·s^{-1}) during rehydration in distilled water

Figure 5 presents the impact of convectional drying on the increase of volume of dried fruit during rehydration. The highest final volume have dried fruit obtained in natural convection conditions and the lowest the one obtained with fluidized drying method and the difference is statistically significant (tab. 1). Drying air velocity in a tunnel drier ceased to have a statistically significant impact on the increase of dried fruit volume as soon as after three hours of rehydration (table 1). Analysis of results of research presented in figure 5 gives basis to state that drying in natural convection conditions damages the plant tissue structure the least, and fluidized drying the most. The research carried out by Witrowa-Rajchert and Radecka-Wierzbicka (2005) on carrot and potatoes drying shows that although many advantages of fluidized drying, which characterizes with very good conditions of heat and mass exchange, this method negatively influences the structure of plant tissue.

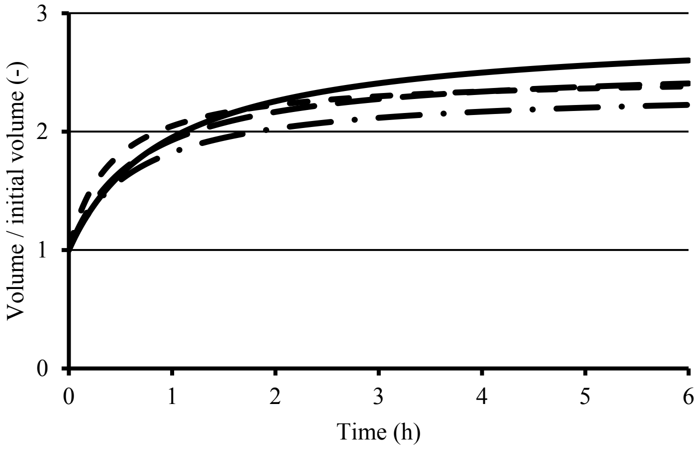

Figure 5. The increase of dried material (apple cubes of 10 mm side, dried in temperature 60ºC: (——) natural convection (r=0.992), (— —) tunnel drier, drying air velocity 0.5 m·s^{-1} (r=0.986), (– – –) tunnel drier, drying air velocity 2 m·s^{-1} (r=0.986), (— · —) fluidized drying (r=0.993) during rehydration in distilled water

Conclusions

1. The higher degree of grinding of dried apples particles, the higher is the increase of their volume in the rehydration process.
2. The final volume of the rehydrated dried fruit increases along with the reduction of drying temperature, these differences for numerical values are low, but statistically significant.
3. Drying method affects the increase of the volume of dried fruit of apples particles during their rehydration. The highest final volume is assumed by dried fruit (cubes) obtained in natural convection conditions and the lowest the one obtained with fluidized drying method.

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WPŁYW PARAMETRÓW I METODY SUSZENIA NA WZROST OBJĘTOŚCI SUSZONYCH JABŁEK PODCZAS ICH REHYDRACJI

Streszczenie. Celem pracy była analiza wpływu parametrów i metody suszenia na wzrost objętości suszonych plastrów i kostek jabłek podczas ich rehydracji. Jabłka odmiany Ligol (plastry o grubości 3 i 10 mm, kostki sześcienne o boku 10 mm) suszono następującymi metodami: konwekcja naturalna (temperatura suszenia 60ºC); konwekcja wymuszona (suszarka tunelowa, parametry powietrza suszącego: 50, 60, 70ºC oraz 0,5, 2 $m \cdot s^{-1}$); suszenie fluidalne (60ºC i 6 $m \cdot s^{-1}$). Susz rehydrowano w wodzie destylowanej o temperaturze 20ºC. Oznaczenie objętości wykonano metodą wyporu w eterze naftowym. Badania wykazały wpływ rozdrobnienia suszonych cząstek i wpływ metody suszenia na wzrost objętości suszonych jabłek podczas ich rehydracji. Końcowa objętość rehydrowanego suszu rosła z obniżeniem temperatury suszenia, różnice te w wartościach liczbowych były niewielkie, ale statystycznie istotne.

Słowa kluczowe: sposób rozdrobnienia, temperatura, prędkość powietrza suszącego, suszenie, rehydracja, objętość, jabłko