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KINETICS OF DRYING AND QUALITY OF THE APPLE CULTIVARS GRANNY SMITH, IDARED AND JONAGOLD

Dragana M. Paunović[*], Branislav P. Zlatković and Dušica D. Mirković

University of Belgrade, Faculty of Agriculture, Nemanjina 6,
11080 Belgrade-Zemun, Serbia

Abstract: Apple is nutritionally valuable and present as fresh fruit in human nutrition throughout the year. Also apple is a raw material in food processing, primarily in the production of juices, nectars, refreshing soft drinks, marmalades, jams, compotes, apple cider vinegar and dried fruits. In the last decade on the world market there is a great interest in dried apple products (commercially called apple chips). During preservation by drying the technological process aimed at the final product of optimal quality is required. The subject of this paper is the kinetics of the apple cv. Granny Smith, cv. Idared and cv. Jonagold drying in laboratory dehydrator for the purpose of pinpointing at which level of humidity the maximum speed of evaporation is achieved and at which level of humidity apple slices begin to change in colour and geometric shape. Parameters of the drying process were the same for all three cultivars, 3hrs at air temperature of 70^{o}C and 5hrs at air temperature of 50^{o}. The amount of evaporated water is expressed in relative and absolute units of measure. The purpose of this paper is to determine which one of the three tested cultivars provides the best properties for drying, i.e. in terms of oxidation of polyphenolic compounds to find the cultivar which will provide that the final product is technologically and organoleptically the most acceptable. The results showed that the sample cv. Granny Smith expressed the least oxidation of polyphenolic compounds (browning), curved edges and shrivelled apple slices. After that the sample cv. Jonagold followed. The sample cv. Idared showed the worst results. Following the drying kinetics of all three samples, it can be concluded that the cultivars Granny Smith and Jonagold were achieving the lower maximum speed of evaporation, unlike the cultivar Idared. The cultivars Granny Smith and Jonagold have attained consistent drying and in this way the technological process was finished with a smaller temperature stress for plant tissue, resulting in a much better quality of the final product.

Key words: apple, cultivar, Granny Smith, Idared, Jonagold, drying process, the kinetics of the drying process.

[*]Corresponding author: e-mail: draganap@agrif.bg.ac.rs

Introduction

Nutritional and medicinal properties of apple fruits have been known since ancient times of human civilisation. Apple makes a very important part of nutrition as a good source of dietary fibers, pectin, potassium, vitamin C and vitamin A. It also contains a significant amount of different classes of phenolic compounds (Veličković, 2006). The most important are flavonoides, heterogeneous group of polyphenolic compounds (Milić et al., 2000) that have multiple functions and in dependence on the subgroup they can be coloured matters, precursors of coloured matters and antioxidants. Besides the antioxidants characteristics, flavonoides are manifesting anti-allergic, anti-inflammatory and anticancer properties (Đorđević et al., 2000). The cultivar Granny Smith is an old Australian variety, launched in Serbia (Institute of Pomology in Čačak) in the mid-seventies of the twentieth century (Mišić, 1994). The fruit contains 3.0% of glucose, 5.1% of fructose, 1.2% of sucrose, 0.94% of total acid (Mišić, 1994), pectin, tannin, vitamin C, minerals and significant amount of carotenoids, amino acids and other biologically valuable substances (Veličković, 2006). The content of phenolic compounds, antioxidants and antiproliferative activity were analysed by spectrophotometry, HPLC, DPPH, ESR methods and it is confirmed that the apple cv. Granny Smith is a valuable source of antioxidants and anticancer nutrients (Savatović et al., 2008).

The cultivar Idared originates from the United States and the production in Serbia began in 1961. The fruit contains 13.2% of soluble solids, 1.3% of glucose, 5.9% of fructose, 2.1% of sucrose, 0.37% of total acid, vitamins, pectin, minerals and other biologically valuable substances and pH value is 3.57 (Mišić, 1994).

The cultivar Jonagold originates from the United States and the production in Serbia began in 1973. The chemical composition is similar to the one of the cultivar Golden delicious, it has a dominant amount of sugar: 1.5% of glucose, 6.8% of fructose and 2.2% of sucrose. Total acid content is 0.26% (Mišić, 1994).

The Granny Smith variety of apple behaves differently in comparison to other apple cultivars, that is, it needs an abnormally long time to ripen at room temperature (Pérez-Ilzarbe et al., 1997). The phytochemical composition of apples varies greatly among different varieties of apples, and there are also small changes in phytochemicals during the maturation and ripening of the fruit. Storage has little to no effect on apple phytochemicals, but processing can greatly affect apple phytochemicals (Boyer and Hai Liu, 2004).

Preserving by drying is one of the oldest methods of preserving foods in the technological, microbiological and nutritional terms. The convective drying method is drying by flow of heated air under controlled and adjusted conditions (Niketić-Aleksić, 1994). Serbia has a significant potential for industrial drying of fruits and vegetables.

The purpose of this paper is to determine which of the three cultivars is showing the best options for drying, determining the rate of water loss from apple slices, not just in a function of time (such analysis can only indicate to the dryer), but how to change the speed of evaporation of water in relative and absolute units of measure (in % and g) depending on the apple current humidity (Paunović et al., 2006). The purpose is also to determine which of the three tested cultivars technologically and organoleptically is providing the most acceptable final product.

Materials and Methods

In the experiment apple cultivars Granny Smith, Idared and Jonagold supplied by the Institute of Pomology and Viticulture, Faculty of Agriculture, University of Belgrade were used. Apples were not peeled, but cut into slices of 6 mm thickness, and the seed lodge was retained and seeds were mechanically removed. The apple slices were laid out on three mesh trays of the laboratory dehydrator Stöckli, Switzerland (Figure 1). On the each mesh tray 500 g of sample was placed. The drying process was done three times because each cultivar was dried separately. Dehydrator has its own thermostat which controls the heater of 600 watts and maintains a given air temperature.

Figure 1. Laboratory dehydrator Stöckli, Switzerland with three mesh trays.

One of the initial assumptions is that in the dryer there is always the same weight of fresh apples (for each cultivar). For this reason the care of this was taken, as well as of the quantity of apples on the mesh trays for uniform air flow and relation of apple:air amount. Another important initial assumption is that the characteristics of air (T, φ, V) during the experiment do not change.

The experiment was conducted to follow the speed of drying of apple slices and to be expressed as speed changes in the ratio of humidity in the moist material depending on the current humidity ($\frac{dW}{d\tau}$: W). The kinetics of drying was monitored by a temperature treatment: 3hrs at air temperature of 70°C and 5hrs at air temperature of 50°C.

Every 60 minutes the apple sample was taken (each sample was selected by random sampling, where in order to reduce experimental error from each mesh tray a certain amount of sample has been taken). The humidity content in each sample is determined by gravimetric method, by which the following were measured:

m_1 - mass of the empty vegeglas (small vessel for measuring with lid);

m_2 - mass of the vegeglas with moist sample;

m_3 - mass of the vegeglas with sample after drying in dryer at 105°C until constant weight.

Humidity content was expressed as the rate of humidity in moist apple slices (w) Eq. (1) and as humidity content in grams which binds 1 g dry matter of sample (u) Eq. (2). These values are calculated through the relations:

$$w = \frac{(m_2 - m_3)}{(m_2 - m_1)} \times 100 \tag{1}$$

$$u = \frac{m_2 - m_3}{m_3 - m_1} \tag{2}$$

where: w-the rate of humidity in moist apple slices (%); u-humidity content which binds 1 g dry matter of the apple sample (g/g).

The actual loss of humidity from 100 g of the apple slices is calculated Eq. (3):

$$W = G\left(1 - \frac{C_1}{C_2}\right) \tag{3}$$

W-amount of evaporated humidity (g); G-initial amount of fruit (g); C_1-dry matter content in fresh sample (%); C_2-dry matter content in the sample after drying (%).

Results and Discussion

The results of determination of the humidity content (w) in the apple during drying and the speed of water evaporation expressed as a decrease in humidity content over time (Δw/Δτ) are shown in Table 1.

Table 1. Humidity content in apple slices and speed of water evaporation during drying.

Time (h)	Granny Smith		Idared		Jonagold	
	w (%)	Δw/Δτ (%/h)	w (%)	Δw/Δτ (%/h)	w (%)	Δw/Δτ (%/h)
0	86.8	0	84.6	0	85.0	0
1	74.6	12.2	80.2	4.4	76.8	8.2
2	61.1	13.5	67.3	12.9	59.4	17.4
3	35.9	25.2	38.9	28.4	48.0	11.4
4	17.6	18.3	34.5	4.4	28.2	19.8
5	16.5	1.1	21.2	13.3	20.6	7.6
6	9.5	7.0	12.3	8.9	10.9	9.7
7	9.0	0.5	9.8	2.5	10.4	0.5
8	7.6	1.4	8.5	1.3	7.7	2.7

w (%)-humidity content; Δw/Δτ (%/h)-speed of water evaporation.

Based on these results, the graphics on speed of drying depending on the current humidity of the apples for each cultivar are given (Figures 2, 3 and 4).

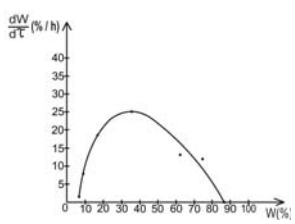


Figure 2. Changes in speed of drying depending on apple humidity of cv. Granny Smith.

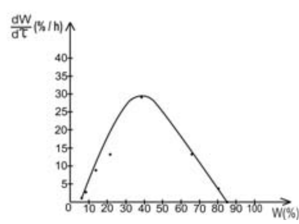


Figure 3. Changes in speed of drying depending on apple humidity of cv. Idared.

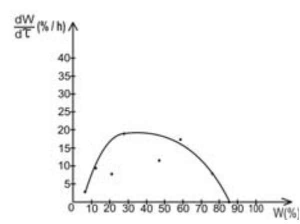


Figure 4. Changes in speed of drying depending on apple humidity of cv. Jonagold.

It is concluded from the Figures that the speed of drying increased and the maximum was achieved at the current humidity of 35.9% (cv. Granny Smith), 38.9% (cv. Idared) and 28.2% (cv. Jonagold), after that the speed of drying decreased. The cultivars Granny Smith and Jonagold achieved lower maximum speed of drying compared to the cultivar Idared. The decrease after reaching the maximum speed of drying was moderate (consistent drying) resulting in a much better quality of the final product. The cultivar Idared achieved a maximal speed of drying and after reaching the maximum, the speed of drying rapidly decreased, which represented a temperature stress for the plant tissue, inevitably resulting in worse quality of the final product.

It is significant to determine the actual loss of humidity from 100 g of the apple slices. The fresh apple sample of cv. Granny Smith had 13.2% of total dry matter and the dried one had 92.4% of total dry matter. The fresh apple sample of cv. Idared had 15.4% of total dry matter and the dried one had 91.5% of total dry matter. The fresh apple sample of cv. Jonagold had 15% of total dry matter and the dried one had 92.3% of total dry matter. From 100 g of fruits 85.714 g of water evaporated during drying cv. Granny Smith; 83.169 g of water during drying cv. Idared and 83.749 g of water during drying cv. Jonagold, according to the relation Eq. (3).

$$W = 100 \text{ x } (1 - \frac{13.2}{92.4}) = 85.714\text{g (cv. Granny Smith);}$$

$$W = 100 \text{ x } (1 - \frac{15.4}{91.5}) = 83.169\text{g (cv. Idared);}$$

$$W = 100 \text{ x } (1 - \frac{15.0}{92.3}) = 83.749\text{g (cv. Jonagold).}$$

Since the drying lasted 8 hours, this means that the average humidity loss per hour was approximately 10.7 g (cv. Granny Smith), 10.4 g (cv. Idared) and 10.5 g (cv. Jonagold).

From the point of this paper it is necessary to define in some way the distribution of water according to its activity, i.e. the binding energy to dry matter.

To effectuate the percentage distribution of the evaporated amount of humidity over time, its content is expressed in relation to dry matter. Table 2 shows data for the calculated values of amount of humidity in relation to dry matter (u) and evaporated humidity (in g) during each hour of drying (the initial assumption is that there was 100 g of apples in the dryer).This relation shows that in the batch conditions of convective drying the largest amount of free water was lost in the first three hours of drying, and during the continuation of the technological process, that amount was significantly reduced. Table 2 shows that after the first hour of drying even 48.03 g of free water which makes 56.0% of total free water evaporated in drying the cv. Granny Smith.

Table 2. Mass of evaporated humidity from 100 g of apple during drying.

Time (h)	Granny Smith		Idared		Jonagold	
	Humidity (g/g)	Evaporated humidity (g)	Humidity (g/g)	Evaporated humidity (g)	Humidity (g/g)	Evaporated humidity (g)
0	6.5757	0	5.4935	0	5.6667	0
1	5.6515	48.03	5.2078	22.22	5.1200	35.34
2	4.6288	18.04	4.3701	30.69	3.9600	27.71
3	2.7197	13.34	2.5260	21.89	3.2000	8.1
4	1.3333	4.57	2.2402	1.69	1.8800	7.96
5	1.2500	0.21	1.3766	3.97	1.3733	2.00
6	0.7197	1.22	0.7987	1.98	0.7267	2.05
7	0.6818	0.08	0.6364	0.49	0.6933	0.10
8	0.5757	0.22	0.5519	0.24	0.5133	0.49
Σ	-	85.71	-	83.17	-	84.75

The largest amount of water (36.9%) in drying the cv. Idared evaporated after two hours of drying and 42.2% after the first hour of drying the cv. Jonagold. After the first 2 hours of drying, the loss of free water in relation to the total evaporated water was 77.08% (cv. Granny Smith), 63.62% (cv. Idared) and 74.39% (cv. Jonagold). In the next 2 hours of drying, the loss of free water was 20.90% (cv. Granny Smith), 28.35% (cv. Idared) and 18.95% (cv. Jonagold). After the fourth and fifth hours of drying the amount of evaporated water was 1.67% (cv. Granny Smith), 7.15% (cv. Idared) and 4.78% (cv. Jonagold). In the last two hours of drying, the amount of evaporated water was 0.35% (cv. Granny Smith), 0.88% (cv. Idared) and 0.70% (cv. Jonagold). The amount of evaporated humidity in every two hours of drying for all three cultivars is shown in the histogram (Figure 5). As the drying parameters (temperature and time) were the same for all three cultivars, and that the loss of humidity was the most in cv. Granny Smith, then in cv. Jonagold and the least in cv. Idared, it can be concluded that the humidity loss is proportional to the initial humidity content.

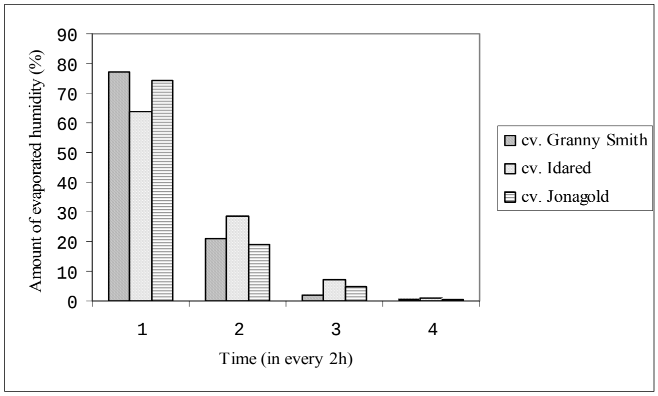
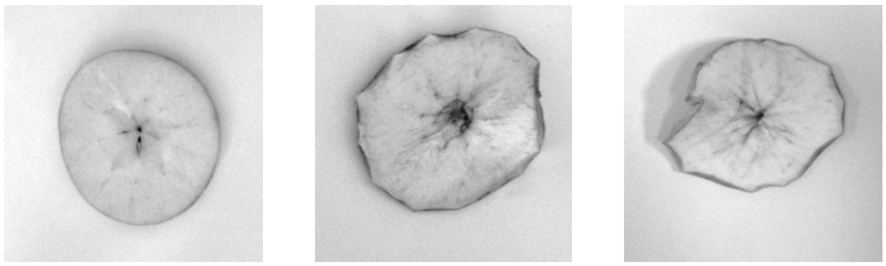


Figure 5. Amount of evaporated humidity every 2 hrs of drying for all three cultivars.

The Figures 6, 7 and 8 show the changes in colour and geometric shape of the apple slices during drying. The apple sample of cv. Granny Smith began browning and changed the geometric shape at the humidity content of 35.9% during drying and during further drying (temperature was lowered to 50°C) the sample was slightly browning. The apple sample of cv. Idared began browning and changed the geometric shape at the humidity content of 38.9%. The apple sample of cv. Jonagold began browning and changed the geometric shape at the humidity content of 48.0%. The apple cv. Idared succumbed to the reactions of browning faster and more intensive than the other two cultivars. The edges of the apple slices of cv. Idared were more curved and the apple slices were more shrivelled (due to water loss and movement of soluble constituents under the heat effect) than the other two cultivars.

The browning kinetics of the Granny Smith apple and the influence of temperature and humidity content on browning reaction were researched by Voegel-Turenne et al. (1999). They observed the apple browning (cut into 0.5 x 1 x 1 cm parallelepipeds) in temperatures from 40^{o}C to 90^{o}C and concluded that the temperature between 55^{o}C and 72^{o}C is a critical zone for apple browning (which is in accordance with the results obtained in this paper) and the induction period (initial phase without any browning) is very dependent on temperature (decreasing with increasing temperature). The same authors also concluded that the influence of humidity on the apple browning is more complex: very weak at temperature zone between 55^{o}C and 72^{o}C, positive in temperatures above and negative in temperatures below. Heating treatments for apple slices dipped in 1% ascorbic acid caused a reduction of enzymatic browning, optimum temperature for inactivation of the enzyme phenol oxidase was between 60-70°C for 15 minutes (El-Shimi, 1993).

The convective drying of apple could be conducted at a temperature of 60°C which would reduce the browning, and higher loss of humidity would be achieved by increasing the airflow velocity (Velić et al., 2004).

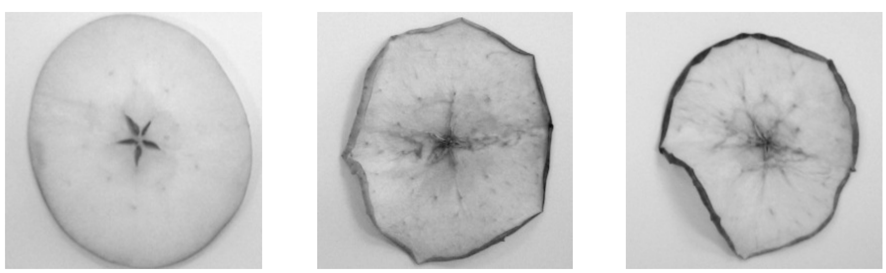


A B C

Figure 6. A) Apple sample of cv. Granny Smith before drying; B) after 3hrs of drying at 70°C; C) after 8hrs of drying (3hrs, 70°C and 5hrs, 50°C).

A B C

Figure 7. A) Apple sample of cv. Idared before drying; B) after 3hrs of drying at 70°C; C) after 8hrs of drying (3hrs, 70°C and 5hrs, 50°C).



A B C

Figure 8. A) Apple sample of cv. Jonagold before drying; B) after 3 hrs of drying at 70°C; C) after 8 hrs of drying (3 hrs, 70°C and 5 hrs, 50°C).

Structural changes in apple rings during convection, air-drying with controlled temperature and humidity by measuring porosity and using electron microscopy were researched by Bai et al. (2002). They concluded that the porosity of the apple rings increased linearly when the moisture content decreased during drying and then reached a constant value. In all dried apple slices, a degree of cellular collapse occurred.

The apple cv. Granny Smith also had the best taste (harmoniousness of sugar and acid) and aroma, while the apple cv. Idared had the worst in which the sugars are the dominant taste.

As all samples had the best organoleptic characteristics after 6 hours ofdrying and in the last two hours the primary aroma of apple has been lost, it can be concluded that these 6 hours are enough time for drying. The drying time could be even shortened which would increase the possibilities of great sensoryevaluation. The suggestion is to reduce the thickness of the cut apple slices from 6 mm to 4 mm.

Conclusion

Out of the three apple cultivars tested, the best quality was shown by the cultivar Granny Smith, which showed the least oxidation of polyphenolic compounds (browning) and the least curved edges and shrivelled apple slices. The apple Granny Smith also demonstrated the best taste (harmoniousness of sugar and acid) and aroma, while the apple cv. Idared had the worst taste in which the sugars are the dominant taste.

The largest amount of free water evaporated in the first 3 hours of drying. Following the drying kinetics of the apple slices, it can be concluded that the speed of drying increased and achieved its maximum at the current humidity of 35.9% (cv. Granny Smith), 38.9% (cv. Idared) and 28.2% (cv. Jonagold), after that the speed of drying decreased.

As all samples demonstrated the best organoleptic characteristics after 6 hours of drying and in the last two hours the primary aroma of apple has been lost, it can be concluded that this 6 hours are enough time for drying. The drying time could be even shortened which would increase the possibilities of great sensory evaluation and the suggestion is to reduce the thickness of the cut apple slices from 6 mm to 4 mm. These indications will definitely be re-tested and more precise modelled to accurately optimise the conditions of convective drying of apples.

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KINETIKA SUŠENJA I KVALITET JABUKE SORTI GRANNY SMITH, IDARED I JONAGOLD

Dragana M. Paunović[*], Branislav P. Zlatković i Dušica D. Mirković

Univerzitet u Beogradu, Poljoprivredni fakultet, Nemanjina 6,
11080 Beograd-Zemun, Srbija

R e z i m e

Nutritivno vredni plodovi jabuke se koriste kao stono voće tokom cele godine, ali i kao sirovina u prehrambenoj industriji za proizvodnju sokova, nektara, osvežavajućih bezalkoholnih pića, marmelada, džemova, kompota, jabukovog sirćeta i sušenih plodova. Poslednjih decenija na svetskom tržištu postoji veliko interesovanje za sušene proizvode od jabuke (marketinški nazvane čips od jabuke). Pri konzervisanju sušenjem od tehnološkog postupka se zahteva da obezbedi gotov proizvod optimalnog kvaliteta. U radu je izučavana kinetika sušenja jabuke sorti Granny Smith, Idared i Jonagold u laboratorijskom dehidratoru sa ciljem da se uoči pri kojim sadržajima vlage dolazi do postizanja maksimalne brzine isparavanja i pri kojoj vlažnosti kolutovi jabuke počinju da menjaju boju i geometrijski oblik. Parametri procesa sušenja su isti za sve tri sorte, 3 h na temperaturi vazduha od 70^{o}C i 5 h na temperaturi vazduha od 50^{o}C. Količina isparene vode je izražena u relativnim i apsolutnim jedinicama mere. Cilj rada je da se utvrdi koja od ispitivane tri sorte pruža najbolje mogućnosti za sušenje, tj. da se sa aspekta oksidacije polifenolnih jedinjenja pronađe sorta koja omogućava da gotov proizvod bude tehnološki i organoleptički najprihvatljiviji. Rezultati su pokazali da je uzorak sorte Granny Smith pored najmanje izražene oksidacije polifenolnih jedinjenja (tamnjenje) imao i najmanje izraženo povijanje ivica i smežuravanje kolutova, potom sledi sorta Jonagold, a najlošije rezultate je pokazao uzorak sorte Idared. Prateći kinetiku sušenja sva tri uzorka zaključuje se da su sorte Granny Smith i Jonagold postigle manje maksimalne brzine isparavanja, za razliku od sorte Idared. Sorte Granny Smith i Jonagold su imale ravnomerno sušenje i na taj način tehnološki postupak se vršio sa manjim temperaturnim stresom za biljno tkivo što je rezultiralo mnogo boljim kvalitetom gotovog proizvoda.

Ključne reči: jabuka, sorta, Granny Smith, Idared, Jonagold, sušenje, kinetika sušenja.

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[*]Autor za kontakt: e-mail: draganap@agrif.bg.ac.rs