CONVECTIVE DRYING OF ORGANIC PEAR PULP IN A THIN STAGNANT LAYER

KONVEKTIVNO SUŠENJE KAŠE OD ORGANSKE KRUŠKE U TANKOM NEPOKRENOM SLOJU

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ABSTRACT

The aim of this paper is to present the influence of convective drying of organic pear pulp and adding ascorbic acid on changes in color, the difference in vitamin C content and also show the kinetics of convective drying. It was a two-factor experiment. The first factor was the air temperature needed for drying, between 45 °C and 65 °C, with a constant speed of drying air of 1.5 m/s; the second factor of the experiment was the adding of ascorbic acid to the pear pulp in the amount of 1 % and 2 % of the full prepared mass.

The lowest change in color was achieved by adding ascorbic acid in the amount of 2 % of the full mass of the pulp and drying air temperature of 45°C (ΔE= 23.981). The highest change was accomplished at the air temperature of 65 °C and by adding ascorbic acid in the amount of 1% (ΔE= 30.039).

With samples where ascorbic acid was added reduction of vitamin C was over 99 % with all samples. By examining the kinetics of convective drying based on statistical indicators R, X2, RMSE, models Page and Logistic are the best in representing convective drying of pear pulp at air temperatures of od 65 °C and 45 °C respectively.

Key words: organic pear, convective drying kinetic, mathematical modeling, vitamin C, color change, fruit leather-rolls.

REZIME

U centrima za sušenje često se prehramanjem javlja određeni udeo voća koje je "prezrelo" za ovakav vid prehrane. Jedan od novijih metoda prerade prezrelih voćnih plodova jeste sušenje voća kojim se povećuje tranzitivnost rolnica od sušene voćne kaše.

U radu je predstavljen uticaj konvektivnog sušenja kaše od kruške proizvedene po organskim principima sorte "Kiferov sejanac". Eksperiment je izveden kao dvo faktorski sa dva nivoa faktora. Prvi faktor je temperatura vazduha za sušenje od 45°C i 65°C, pri bezn vazduha za sušenje od 1.5 m/s, a drugi faktor eksperimenta je dodatak askorbinske kiseline u količini od 1% i 2%, od mase pripremljene kaše.

Cilj rada je da se ispita uticaj konvektivnog sušenja na promene voća i da se definišu matematički modeli kinetike konvektivnog sušenja kaše od kruške. Najniža promena voće ostvarena je kod kaša sa dodatkom askorbinske kiseline u vrednosti 2% od mase kaše i temperaturi vazduha za sušenje od 45°C (ΔE= 23,981). Najviša promena voće ostvarena je pri temperaturi vazduha za sušenje od 65°C i dodatkom askorbinske kiseline u vrednosti od 1% (ΔE= 30,039).

Zabeležena je razgrada vitamina C u svim uzorcima. Kod kontrolnih uzoraka razgradnja vitamina C je ≈ 77-80%. Kod uzoraka sa dodatkom askorbinske kiseline razgradnja vitamina C prelazi preko 99%, kod svih uzoraka.

Page model najbolje prikazuje konvektivno sušenje kaše od kruške pri temperaturi vazduha od 65°C. Koeficijent korelacije iznosi R= 0,9998, vrednost of the reduced X² = 0,000262 i RMSE= 0,02.

Konvektivno sušenje kaše od kruške, vazduhom temperature 45°C, najbolje prikazuje Logarithmic model. Koeficijent korelacije iznosi R= 0,999660, vrednost of the reduced X² = 0,000066 i RMSE= 0,01.

Ključne reči: organska kaša, kinetika konvektivnog sušenja, matematički modeli, sadržaj vitamina C, promena boje, voćne rolnice.

INTRODUCTION

Fruit produced by organic principles and production of products based on the principles of organic production comprises a set of advantages, particularly in health, ecological and economic terms.

Fruit needs to be processed, stored in cold storage, frozen and dried right after harvest. Convective drying of fruit, as the most common method of drying, affects the chemical-physical changes that occur during the process of drying, changes in the color, deconstruction of vitamin C, etc. (Lutovska et al., 2015; Vakula 2015; Tepić, 2012; Radojičin, 2010; Ratti 2011).

One of the newer products that can be found on the market is fruit leather rolls. Order of processing is that fruit is first blended into a pulp and set on drying trays in fixed thin-layers, 4-5 mm thick. After the drying process, it is cut in ribbons that are then used to form rolls. The downside of these products is a high level of oxidation and darkening during the preparation of the fruit pulp and during the process of convective drying. In addition, there is a loss in the content of vitamin C, which is especially noted with fruit that is susceptible to these changes.

Silvana M. Demarchi (2012), examines, in her paper, the effect of air temperature on convective drying, on antioxidant capacity in apple leather. Apple pulp, with the addition of potassium metabisulfite as antioxidant, was dried convectively at air temperatures of 50, 60 and 70 °C. The result of their research confirms that air temperature has a significant effect on antioxidant capacity during convective drying, where with an increase in temperature there is a decrease in antioxidant capacity in apple leather products.

The color of such products is seen as one of the important factors that influence customers to buy the product. Air temperature for convective drying and the length of drying reciprocally influence the darkening of fruit tissue. Tomtul et. al (2017) have examined the effect of different drying techniques on the physical-chemical changes during the production of pomegranate leather. Convective drying was done at temperatures of 50, 60 and 70 °C, with the speed of drying air at 1.5 m/s. The result of their research confirms that air temperature has a significant effect on antioxidant capacity during convective drying, where with an increase in temperature there is a decrease in antioxidant capacity in apple leather products.

Vakula 2015; Lutovska et al., 2015; Tepić, 2012; Radojičin, 2010; Ratti 2011)
for designing new drying systems as well as selection of drying process important procedure describing the behavior of the thin-layer simultaneous heat and mass transfer phenomena during the optimum drying conditions and for accurate prediction of convective drying of pear pulp in a thin, static layer defined.

The samples was measured at 10 different measurable surfaces. The color was represented in a CIE L*(whiteness/brightness), a* (redness/greenness) and b* (yellowness/blueness) color system. The color difference (ΔE), hue angle (h') and chromaticity (C') were expressed in Eqs. 1, 2, 3 and 4.

\[ \Delta E = \sqrt{(L' - L_0)^2 + (a' - a_0)^2 + (b' - b_0)^2} \]  
\[ h' = \arctan \left( \frac{a'}{b'} \right) \]  
\[ h_{\text{fresh}} = 180 + \arctan \left( \frac{a_{\text{fresh}}}{b_{\text{fresh}}} \right) \]  
\[ C' = \left( \sqrt{a'^2 + b'^2} \right) \]

where \( L_0, a_0, b_0 \) are the color values before drying, while \( L', a', b' \) are the color values after drying.

A standard volumetric method was used to determine the content of vitamin C in fresh samples and the samples collected after the drying process.

The kinetics of convective drying was measured with the use of a laboratory convective dryer “IVA-2”, which has the ability to continuously measure mass of the sample during the process of drying (Pavkov 2012). The changes in mass of the fruit pulp during the process of drying and the changes in air temperature were recorded onto a computer in 5min intervals, with the use of the laboratory acquisition National Instrument. Every experiment lasted until there was the moisture of the pulp reaching \( \omega_{eq} = 0.111 \) g/g d.w.

The drying data from air drying test were then expressed as moisture radio (MR), calculated according to the following equation:

\[ MR = \frac{X_t - X_{eq}}{X_0 - X_{eq}} \]  

where \( X_t, X_0, X_{eq} \) are moisture content at time \( t \) (kg/kg d.b.); initial moisture content (kg/kg d.b.) and equilibrium moisture content (kg/kg d.b.), respectively.

The drying curves (MR) were fitted by means of four different moisture ration models that are widely used in most food and biological materials (Table 1.).

The results of the statistical importance of the influence of the factor as well as the interaction of influence of the factor were shown in table 2. The analysis of the measured values established that the lowest change in color was accomplished by adding ascorbic acid in the amount of 2 % of the pulp mass and by using the drying temperature of 45 °C, that resulted in the total change of color \( \Delta E = 23.981 \).

The highest change in color was accomplished at the drying air temperature of 65 °C and by adding ascorbic acid in the amount of 1% and it equals \( \Delta E = 30.039 \). The change of color in the control sample, with no ascorbic acid added, equals \( \Delta E = 40.536 \), at the temperature of 45 °C while the total change in color is \( \Delta E = 36.054 \) at the temperature of drying air of 65 °C. The results of the statistical importance of the influence of the factor as well as the interaction of influence of the factor were shown in table 3. Based on the analysis of the variance, the content of ascorbic acid has a statistically important influence on the conservation of color in the sample during convective drying.

However, there is no statistically important influence of the drying air temperature on the sample. Based on visual control, there is no significant difference in conservation of color between samples where 1 % of ascorbic acid was added and those with 2 %.
and drying time.

After convective drying, there was a marked reduction in ascorbic acid, or 1000-1100 mg/100g db with 2% of ascorbic acid compared to the air temperature of 65 °C. In control samples, the increase in time of the drying process when 45 °C is air temperature of 45 °C. This occurrence can be explained by the addition of ascorbic acid). The C vitamin content measured in the pulp prepared for the drying (with the addition of the ascorbic acid). The C vitamin content measured in fresh pear (without adding ascorbic acid) amounted to cca. 24 mg/100g db. Similar results, when it comes to the content of vitamin C in a pear, were measured by the group of authors Guo, et al., 2003; Chen, et al., 2007 and Sanchez, et al., 2003.

The content of vitamin C in samples after adding ascorbic acid was measured in fresh pear samples. However, it is important to note that by adding ascorbic acid the sample was significantly enriched with vitamin C before the drying process, therefore the remaining vitamin C, after the drying process, is higher than the content of vitamin C measured in fresh pear samples.

Drying kinetics

Statistical parameters for four mathematical models of convective drying of pear pulp R, X^2, RMSE, are shown in Table 5. The Page model best shows the convective drying of pear pulp in a thin layer at air temperatures of 65 °C. The correlation coefficient for the Page model is R = 0.998. Furthermore, this model has the lowest value of the reduced X^2 = 0.000262 and the lowest value of RMSE = 0.02. Convective drying of pear pulp, at air temperature of 45 °C is best shown by the Logarithmic model. The correlation coefficient is R = 0.999660, value of the reduced is X^2 = 0.000066 and RMSE = 0.01. The whole drying process of the pear pulp at temperature of 65 °C took around 350 min, and during that the moisture of the pulp was reduced from the starting α_{dm} ≈ 4.88 g/g_{dm} (cca. 83 % moisture relative to the moisture base) to α_{df} ≈ 0.111 g/g_{dm} (cca. 10 % moisture relative to the moisture base). The experimental results of the kinetics of drying and the results predicted by the Page model of convective drying of the pear pulp are shown in picture 2. Table 6. Shows the constants and the coefficients of the mathematical models Page and Logarithmic, for the kinetics of convective drying of the pear pulp at temperatures of 65 °C and 46 °C.

The content of vitamin C in samples after adding ascorbic acid amounts to between 5000 and 5500 mg/100g_{dm}, with 1% of ascorbic acid, or 10000-11000 mg/100g_{dm}, with 2% of ascorbic acid. After convective drying, there was a marked reduction in vitamin C, in all samples. However, it is important to note that by adding ascorbic acid the sample was significantly enriched with vitamin C before the drying process, therefore the remaining vitamin C, after the drying process, is higher than the content of vitamin C measured in fresh pear samples.

**Drying kinetics**

Table 1. Mathematical models applied to the drying curves

| No. | Model | Name of model | References |
|-----|-------|---------------|------------|
| 1. | MR = exp(-kt) | Newton | Bon et al., 2007 |
| 2. | MR = exp(-kt^n) | Page | Hassan-Beygi et al. 2009 |
| 3. | MR = aexp(-k_a t) | Hend. and Pabis | Hend. and Pabis, 1961 |
| 4. | MR = aexp(-k t) + c | Logarithmic | Bon et al., 2007 |

* k - drying constant, n - model exponent, a, b, c - model coefficients and t - drying time

Table 2. Color change results

| Experiment factors | Measured values |
|--------------------|----------------|
| Drying air temperature [°C] | Amount of ascorbic acid [%] | L*, a*, b*, ΔE, k*, C* |
| 45 | 1 | 58.293 | 9.389 | 41.729 | 29.169 | 77.319 | 42.77 |
| | 2 | 65.154 | 5.364 | 40.338 | 23.981 | 82.425 | 40.69 |
| Control sample | 35.101 | 15.110 | 18.432 | 40.536 | 50.656 | 23.83 |
| 65 | 1 | 55.263 | 14.011 | 27.607 | 30.039 | 69.566 | 40.13 |
| | 2 | 65.005 | 6.872 | 40.148 | 27.014 | 80.236 | 40.73 |
| Control sample | 42.062 | 16.474 | 26.929 | 36.054 | 58.543 | 31.56 |
| Color of the fresh pear | L_0 = 71.676, a_0 = -2.262, b_0 = 18.712, k = 96.893, C = 18.84 |

Table 3. Statistical results of the influence of the factor on color change

| Effect | SS | DF | MS | F | p |
|--------|----|----|----|---|---|
| Intercept | 77540.46 | 1 | 77540.46 | 2589.279 | 0.00000 |
| Air temp. | 0.74 | 1 | 0.74 | 0.025 | 0.87521 |
| Ascorbic acid cont. | 2277.10 | 2 | 1138.55 | 38.019 | 0.00000 |
| Air temp. * Asc. acid cont. | 199.53 | 2 | 99.77 | 3.331 | 0.04052 |
| Error | 2515.53 | 84 | 29.95 |

Table 4. Vitamin C content

| Experiment factors | Content of vitamin C in samples prepared for the drying process [mg/100g db] | Vitamin C in samples after the drying process [mg/100g] | Level of vitamin C reduction [%] |
|-------------------|---------------------------------------------|---------------------------------------------|---------------------------------|
| Drying air temperature [°C] | Amount of ascorbic acid [%] | | |
| 45 | 1 | 5332.02 | 28.55 | 99.46 |
| | 2 | 10640.16 | 81.83 | 99.23 |
| Cont. Samp. | 23.88 | 5.48 | 77.04 |
| 65 | 1 | 5630.92 | 41.08 | 99.27 |
| | 2 | 11236.61 | 116.80 | 98.94 |
| Cont. Samp. | 25.22 | 4.79 | 80.97 |
| Fresh sample | 24.53 |

Fig. 2. Experimental and predicted moisture ratio for convective drying of organic pear pulp at 45 °C air temperature
**CONCLUSION**

This paper shows the influence of convective drying of the pear pulp produced in accordance with the organic principles of the “Kieffer Seedling” (Kiferov sejanac) with the aim of producing pear leather-rolls.

It has been established that the least amount of color change occurs during drying with the addition of ascorbic acid in the amount of 2%, relative to the mass of the pulp, and the highest change was noted on the control sample, without ascorbic acid. With the use of dispersive analysis, it has been established that the amount of ascorbic acid within the sample significantly affects the conservation of color in the sample, while the air temperature used for the drying process does not have a statistical influence, based on the range of 45-65 °C, in given experimental conditions. By the use of analysis of the total color difference ΔE, it has been established that there is no significant difference in conservation of color when adding 1% in comparison to the addition of 2% of ascorbic acid relevant to the mass of the sample.

In samples with the addition of ascorbic acid, the largest reduction of vitamin C was achieved at drying air temperatures of 45 °C. This occurrence can be explained by the longer time needed for the drying process than with the temperatures of 65 °C. In samples where ascorbic acid was added, the reduction of vitamin C amounts to approximately 99 %, in all drying regiments. However, the ascorbic acid, as an antioxidant supplement, considerably raises the total content of vitamin C in the end product. The process of drying pear pulp at air temperatures of 65 °C, lasted for around 350 min, while the drying process at the temperature of 45 °C took around 480 min and resulted in the decrease of the moisture of the pulp from the starting value from ω₀,wb ≈ 4.88 g/gwb (cca. 83% moisture relative to the moist base), to ω₀,wb ≈ 0.111 g/gwb (cca. 10% moisture relative to the moist base). By examining the four, most frequently used models for convective drying based on the statistical indicators $R$, $X^2$, RMS, it has been determined that the Page and Logarithmic models best show the convective drying of pear pulp in a thin layer at temperatures of 65 °C and 45 °C respectively.

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Received: 15. 11. 2018. Accepted: 28. 11. 2018.

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**Table 5. Statistical results of four mathematical models for pear pulp convective drying**

| Name of model | Air temperature | Statistical coefficients | $R$ | $X^2$ | RMSE |
|---------------|-----------------|--------------------------|-----|------|------|
| Newton        | 65°C            | 0.981130                 | 0.003078 | 0.06   |
| Page          | 65°C            | 0.995280                 | 0.000804 | 0.03   |
| Henderson     | 45°C            | 0.998685                 | 0.000262 | 0.02   |
| Pabis         | 45°C            | 0.999660                 | 0.000066 | 0.01   |

**Table 6. Constants and coefficient for Page and Logarithmic mathematical model of organic pear pulp convective drying**

| Name of model | Air temp. | $k$ | $n$ | $a$ | $c$ |
|---------------|-----------|-----|-----|-----|-----|
| Page          | 65 °C     | 0.00106 | 1.40103 | -   | -   |
| Logarithmic   | 45 °C     | 0.00244 | -   | 1.50465 | -0.51307 |