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INFLUENCE OF CONSTANT AND VARIABLE PRESSURE ON WATER ABSORPTION CAPACITY OF DRIED STRAWBERRIES*

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Abstract. This work presents the influence of the method used for vacuum drying on the dry matter content and water absorption capacity of dried strawberries. Calibrated frozen and defrosted strawberries variety Senga Sengana were used in the research. Vacuum drying was carried out twice at preset temperature of 70°C under pressure of 4 and 16 kPa and with a step change of pressure from 4 to 16 kPa. Pressure was changed, as well as the dryer, through either the vacuum-convective or the convective-vacuum drying method, after 4 and 5 hours respectively. The dry matter content and water absorption capacity were determined in strawberries. The dry matter content of strawberries after drying processes with the step change of pressure from 4 to 16 kPa and both fixed levels of pressure did not differ significantly. However, vacuum-convective drying resulted in statistically lower dry matter content. In spite of the introduction of step increase of pressure from 4 to 16 kPa the water absorption capacity was comparable for dried fruits under 4 kPa pressure. The lowest water absorption capacity of vacuum-convective dried strawberries in relation to absorption results of dried fruits obtained under 4 kPa pressure or by convective-vacuum method indicated the existence of structural differences between products.

Keywords: vacuum drying, variable pressure, combined drying, statistical analysis

INTRODUCTION

For the preservation of strawberries vacuum drying, freeze-drying or combined (e.g. convective and vacuum) drying are applied much more frequently than convective drying. Vacuum drying permits the process to be conducted in a much

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milder manner, selecting suitable process parameters (temperature and pressure) (Piotrowski *et al*. 2011). As a result, much lesser changes in the quality of the product are obtained as compared to drying under atmospheric pressure.

Estimation of the quality of dried products is performed with the use of various traits and properties, among which assays of water absorption capacity (PN-A-75101-19:1990) have been used for years in relation to dried fruits and vegetables. However, no uniform criterion has been developed for the estimation of the water absorption capacity (Lewicki 1998, Wesołowski 2009, Ciurzyńska *et al.* 2011a).

The objective of the study was to determine the effect of the vacuum and combined drying methods on the content of dry mater and water absorption capacity of dried strawberries.

MATERIAL AND METHOD

The experimental material consisted of whole frozen strawberries cv. Senga Sengana, with diameter of 29 mm, stored at temperature of –18°C. The strawberries were defrosted at temperature of about 25°C for 2.5h, and the freezing effluent was determined that, with relation to the mass of the frozen fruits, varied in the range of 8.7 to 12.8% by mass.

Drying of the experimental material was carried out with the use of two laboratory dryers, vacuum and convective, until the moment of achieving a state of equilibrium was confirmed by balance readings. Within the scope of the study, two replications were made for the constant preset parameters of temperature and pressure, from the level of a computer application operating in the programming environment VisiDAQ, i.e.: temperature of 70°C and pressure of 4 and 16 kPa. Moreover, two kinds of drying were performed in two replications for variable pressure conditions, and two kinds of combined drying (i.e. convective drying combined with vacuum drying, in both sequential orders), in one replication. Pressure change, as well as the change of the dryer, in the combined drying process (vacuum-convective and convective-vacuum), were made after 4 and 5 hours, respectively. Due to the fact that the preset temperature in the vacuum dryer was regulated relative to the wall temperature, and above the strawberries it was lower, for convective drying the preset temperature of drying air was adopted as 65°C.

The properties of the strawberries were estimated on the basis of dry matter content (mass %) in the raw and dried material with the method of vacuum drying at temperature of 68-70°C, and of the water absorption capacity of dried strawberries (PN-A-75101-19:1990). The water absorption capacity X of dried fruits was assayed after 6 hours of rehydration in and expressed in ml of water per 100 g of dried strawberries:

$$X = \frac{100 - V - 2}{m} \cdot 100 \quad (1)$$

where:

100 – volume of water used for the rehydration of dried fruits (ml),

V – volume of filtrate obtained (ml),

2 – conventional volume of water absorbed by the filter (ml),

m – mass of sample taken for the assay (g).

Statistical analyses were conducted through the application of the standard statistics, one sample and independent samples t-tests. Prior to the one-factor analysis of variance ANOVA (F ratio or Welch's test) and the multiple comparison tests (Tukey's or Tamhane's T2 test for identification of homogeneous groups) the hypotheses of equality of variance were verified by means of Levene's test. Statistical analyses were carried out at significance level of 0.05, using the program SPSS 14.0 PL (SPSS Inc.) (Górniak and Wachnicki 2004). On error bar charts (Fig. 1-3) with a particular mean value the standard deviation was presented as a vertical line (T-bar).

RESULTS AND DISCUSSION

Analysis of dry matter content in defrosted and dried strawberries

Table 1 presents the symbols used and process parameters applied to obtain dried strawberries.

Table 1. Designations of symbols and codes used to denote drying methods

No.	Code	Drying pressure (kPa)	Descriptive notation of experiments	Methods of drying
1A 1B	4 kPa_A 4 kPa_B	4	70°C 4 kPa	vacuum drying, constant pressure
2A 2B	4/16 kPa_A 4/16 kPa_B	4/16	70°C 4/16 kPa	vacuum drying, increase of the pressure
3A 3B	16 kPa_A 16 kPa_B	16	70°C 16 kPa	vacuum drying, constant pressure
4A	100\4 kPa	100\4	65&70°C100\4 kPa	convective-vacuum drying
5A	4/100 kPa	4/100	70&65°C4/100 kPa	vacuum-convective drying

Table 2 and Figure 1 present the content of dry matter in defrosted strawberries before drying and in the product after drying. Statistical analysis with the use of one sample t-tests at significance level of 0.05 did not reveal significant differences in dry matter contents of raw material (9.9 mass %) and dried material (97.8 mass %). However, the application of Welch's test for the parameter under consideration revealed variation of the parameter (Tab. 3). As an example, differentiation between the lowest dry matter content for vacuum convective dried strawberries (ca. 94 mass %), and the highest (ca. 99 mass %) for vacuum dried strawberries obtained at drying pressure of 16 kPa, led to the rejection of the hypothesis of equality of average values by Welch's and Tamhane's T2 tests. This confirms the difficulty involved in the removal of water from soft tissue of fruits dried in the final stage of convective drying (drying 4A: 4/100 kPa) (Tab. 3, Fig. 1).

Table 2. Dry matter content of defrosted strawberries; the same letters (a, b) show homogeneous groups

No	Average dry matter content (mass %)	Standard deviation (mass %)
1A, 1B	9.34 [a]	0.368
2A, 2B	9.47 [a]	0.077
3A, 3B	10.22 [b]	0.390
4A	10.46 [b]	0.240
5A	10.72 [b]	0.087

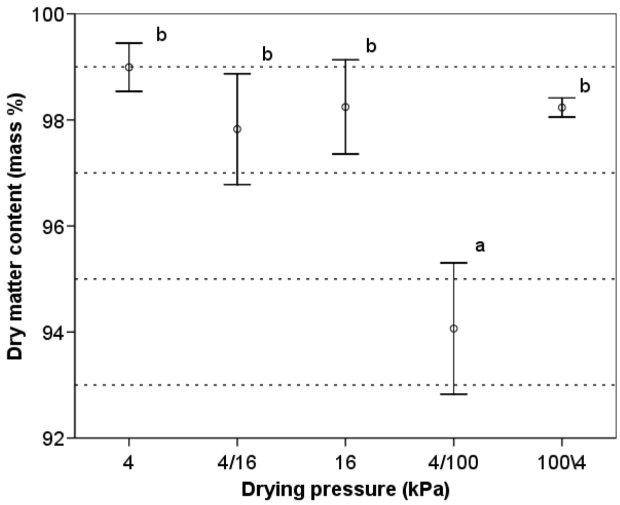

Fig. 1. Dry matter content of dried strawberries; the same letters (a, b) show homogeneous groups

Table 3. Results of statistical analysis for average values dry matter content of dried strawberries

Drying pressure (kPa)	Levene's test	F ratio	Welch's test
4, 4/16, 16, 100\4, 4/100	0.033	Assumption not fulfilled	0.004

Analysis of the effect of vacuum drying method on water absorption capacity of dried strawberries

The results of independent samples t-tests for average values of water absorption capacity from replications A and B of three parallel series of determinations, revealed a lack of differences for the presented replications (Tab. 4).

Table 4. Statistical comparison of replications of water absorption capacity X of dried strawberries (designations as in Tab. 1)

Kod Code	Average X (ml (100 g)$^{-1}$)	Standard deviation (ml (100 g)$^{-1}$)	Significance	
			Levene's test	t-test
16 kPa_A	427.4 **a**	69.8	0.220	0.108
16 kPa_B	522.8 **a**	39.3		
4/16 kPa_A	599.2 **b**	111.9	0.100	0.710
4/16 kPa_B	572.6 **b**	28.7		
4 kPa_A	636.7 **c**	59.0	0.707	0.819
4 kPa_B	649,2 **c**	66,1		

No statistically significant difference for rows A and B is indicated by the same letters (a, b, c).

Figure 3 presents the effect of pressure and of step increase of pressure in the dryer chamber on the water absorption capacity of dried strawberries. The average value of water absorption capacity of strawberries dried under conditions of variable pressure (4/16 kPa) during the drying was 586 (ml (100 g)$^{-1}$), while for dried strawberries obtained at constant drying pressure of 16 kPa the average value of water absorption capacity was lower, at 475 (ml (100 g)$^{-1}$). Analysis revealed significant statistical differences between the values of water absorption capacity in the dried materials compared (Tab. 5, Fig. 2). For the above differentiation of values, using the Tukey's test at significance level of $\alpha = 0.05$, two homogeneous groups were distinguished, where the values of water absorption capacity of material obtained through drying at 4 kPa as well as with pressure change from 4 to 16 kPa fell into a single homogeneous group. The lowest water absorption capacity of dried material obtained at drying pressure of 16 kPa would be easier to explain if the process of drying was conducted at a lower temperature (e.g. 50°C), as under those conditions greater axial shrinkage of whole strawberries was obtained than at drying pressure of 4 kPa (Piotrowski *et al*. 2011). Nevertheless, the results of water absorption capacity obtained are in agreement with published results of other studies. Studies on vacuum drying of chilli peppers with the use of an installation with a heat pump (Artnaseaw *et al*. 2010) at temperature of 60°C showed that with pressure reduction within the range from 40 to 10 kPa the values of shrinkage decreased, and the hydration of dried materials (estimated through the values of rehydration coefficient) increased. The effect of constant pressures on the water absorption capacity of dried materials as stated in this paper, is in conformance with studies on rehydration of dried strawberries cv. Bounty and Pandora, carried out by Ciurzyńska *et al*. (2011b), regardless of the differences in methodological approach in both studies of water absorption. For the two strawberry cultivars, vacuum drying at lower pressure of 4 kPa caused the attainment of higher water contents and greater mass increments of whole dried fruits after rehydration than those achieved at drying pressure of 16 kPa. It should be mentioned that mean values of water absorption capacity for dried material obtained based on row Senga Sengana and Bounty cv. were statistically insignificant (Ciurzyńska *et al*. 2011a).

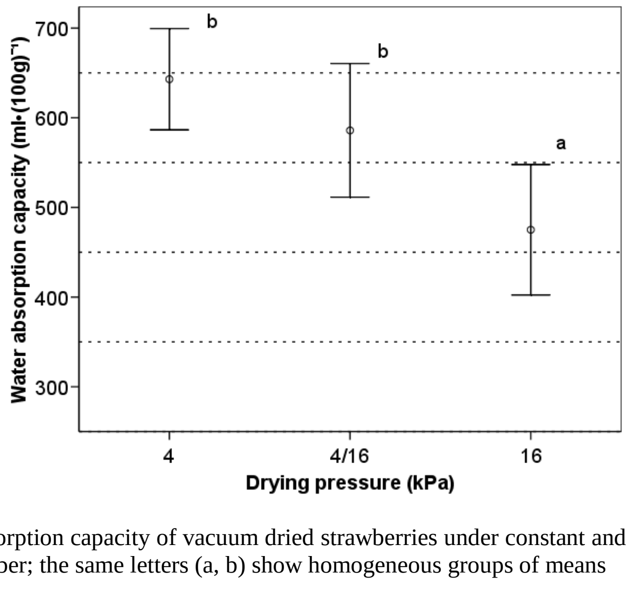

Fig. 2. Water absorption capacity of vacuum dried strawberries under constant and variable pressure in the dryer chamber; the same letters (a, b) show homogeneous groups of means

Table 5. Results of statistical analysis for average values of water absorption capacity of dried strawberries

Drying pressure (kPa)	Levene's test	F ratio	Welch's test
4, 4/16, 16	0.972	0.002	0.005
4, 100\4, 4/100	0.179	0.000	0.001

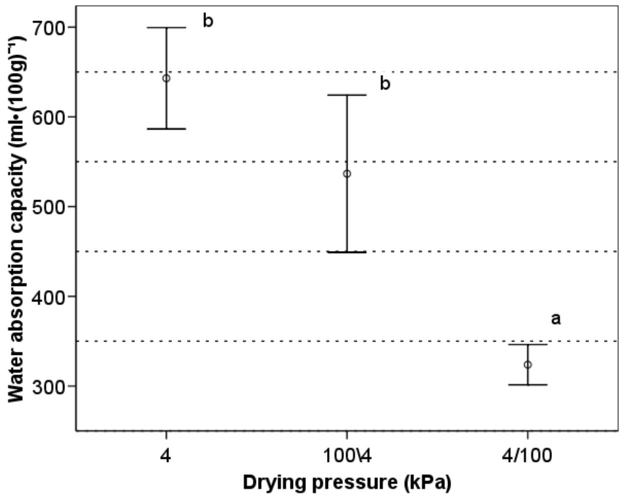

Fig. 3. Water absorption capacity of strawberries dried by vacuum, convective-vacuum or vacuum-convective method; the same letters (a, b) show homogeneous groups of means

The effect of the combined drying method on water absorption capacity is presented in Figure 3. The average water absorption capacity of dried strawberries obtained with the convective-vacuum drying was 537 (ml (100 g)$^{-1}$) and was similar to the average water absorption capacity of dried material obtained with the vacuum method – 643 (ml (100 g)$^{-1}$). The lowest average value of water absorption capacity was obtained for vacuum-convective dried fruits (Fig. 3). Statistical analysis revealed significant differences, at significance level of $\alpha = 0.05$, among the water absorption capacity values for the drying methods under analysis (Tab. 5). The lowest water absorption capacity of the vacuum-convective dried material (statistically significant difference) relative to the values obtained for the vacuum dried material (4 kPa) or convective-vacuum dried material (Fig. 3) suggests the existence of structural differences between indicated products from various homogeneous groups. The removal of water in the final stage of drying with the convective method is more difficult than in the case of vacuum drying, and therefore its evaporation to achieve the state of equilibrium at its low content in the final stage contributes to greater shrinkage. Apart from the visually observable range of changes in microstructure, increased water absorption capacity may be indicated by the state of equilibrium water content in the dried material attained at the end of drying.

Cunningham *et al.* (2008), analysing the effect of drying method and preliminary processing on rehydration of dried samples of potato at temperature of 60°C, obtained lower equilibrium water contents in convective dried material than in microwave-convective dried samples. However, microwave-convective dried potatoes, with increased porosity, were characterised by higher level of water absorption.

With rehydration of dried carrots that was not subjected to preliminary processing, freeze-dried material, compared to vacuum-microwave and convective dried materials, attained the state of equilibrium much faster. After five hours of rehydration, lyophylisate of carrot attained an amount of absorbed water closest to the state of equilibrium, each kind of dried materials achieving the state of equilibrium at a different level (Stępień 2008).

CONCLUSIONS

1. Strawberry drying with the vacuum and combined methods to the point of attainment of the state of equilibrium permits obtaining of dried materials with dry matter content in the range from 94 to 99%.
2. Water absorption capacity of dried strawberries decreases with increase in pressure during drying, and is the lowest for vacuum-convective drying at a pressure of about 100 kPa. Whereas, increase of the pressure in the dryer chamber from 4 to 16 kPa during vacuum drying causes a statistically significant increase of water absorption capacity of dried strawberries in relation to the value of that index for dried material obtained at 16 kPa.
3. Fruits dried with the vacuum-convective method attain the lowest values of water absorption capacity. Whereas, the convective-vacuum drying method causes the achievement of higher values of that index, though still lower than those obtained for vacuum dried material at drying pressure of 4 kPa.

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WPŁYW STAŁEGO I ZMIENNEGO CIŚNIENIA SUSZENIA NA ZDOLNOŚĆ POCHŁANIANIA WODY WYSUSZONYCH TRUSKAWEK

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Streszczenie. W pracy przedstawiono wpływ sposobu suszenia próżniowego i kombinowanego na zawartość suchej substancji oraz zdolność pochłaniania wody przez wysuszone truskawki. Do badań użyto skalibrowane mrożone i rozmrożone truskawki odmiany Senga Sengana. Suszenie próżniowe przeprowadzono w dwóch powtórzeniach, w temperaturze zadanej 70°C, przy ciśnieniu 4 i 16 kPa oraz ze zmianą skokową ciśnienia z 4 do 16 kPa. Zmianę ciśnienia, jak i suszarki, przy suszeniu metodą próżniowo-konwekcyjną lub konwekcyjno-próżniową wprowadzano odpowiednio po 4 i 5 godzinach. W truskawkach oznaczano: zawartość suchej substancji i zdolność pochłaniania wody. Zawartość suchej substancji w truskawkach po procesach suszenia ze skokową zmianą ciśnienia z 4 do 16 kPa lub przy obu stałych ciśnieniach nie różniła się istotnie. Natomiast suszenie próżniowo-konwekcyjne dało statystycznie niższe wartości zawartości suchej substancji. Pomimo wprowadzenia skokowego wzrostu ciśnienia z 4 do 16 kPa zdolność pochłaniania wody suszu była porównywalna ze zdolnością suszu uzyskanego przy stałym ciśnieniu 4 kPa. Najniższa zdolność pochłaniania wody przez susz próżniowo-konwekcyjny względem wyników pochłaniania przez susze uzyskane przy ciśnieniu 4 kPa lub sposobem konwekcyjno-próżniowym wskazuje na istnienie strukturalnych różnic między produktami.

Słowa kluczowe: suszenie próżniowe, zmienne ciśnienie, suszenie kombinowane, analiza statystyczna