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SHRINKAGE AND MECHANICAL PROPERTIES OF DEFROSTED STRAWBERRIES DRIED BY CONVECTIVE, VACUUM AND CONVECTIVE-VACUUM METHODS

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A b s t r a c t. The mechanical properties are among the most important indicators of the quality of food. They are the most important criteria for acceptance of the raw material by the consumer. Texture of fruits and vegetables is affected by the drying process – closely related to the composition and structure of cell walls – and its parameters. Research material for the study was strawberries of the variety SengaSengana. Axial shrinkage in the vertical plane was determined by linear measurements for 4 strawberries before drying and for the same strawberries after drying, using an electronic caliper. The mechanical properties of dried strawberries were analysed by compression tests (compression curves and maximum compression force). The test was carried out on texture analyser TA-TX2 2i (Stable Micro Systems). In this paper three methods of strawberry drying: convection, vacuum, convection-vacuum in various temperatures are presented. It was found that the largest shrinkage appears in convection drying and the lowest in vacuum drying. Increase of vacuum and convection drying temperature caused lower shrinkage. The curves of maximum compression and the compressive force showed that convection dried strawberries and convection-vacuum dried strawberries are more crisp and hard than strawberries dried by the convection method which are characterised by the lowest values of compression force.

K e y w o r d s: drying temperature, drying methods, strawberries, shrinkage, compression curves, maximum compression force

INTRODUCTION

Many factors, such as variety or pre-treatment of raw material, drying method and applied parameters, have an effect on mechanical properties of dried fruits (Askari*et al.* 2009, Ciurzyńska and Lenart 2010, Sitkiewicz*et al.* 2011, Oikonomopoulou and Krokida 2012). Therefore, it is important to use the appropriate technological processing and method of drying which will preserve the most favourable mechanical properties (Peinadoet*et al.* 2013). Convective drying, due to the use of an extensive range of temperature, causes a sagging of the structure of strawberries and adversely affects their mechanical properties (Contreras *et al.* 2008, Szumny *et al.* 2010, Ciurzyńska *et al.* 2011, Joardder *et al.* 2014). In order to obtain dried strawberries with better mechanical properties, drying methods such as vacuum drying or combined drying with a stage carried out under lowered pressure and at a lower temperature range are used (Artnaseaw *et al.* 2010, Huang *et al.* 2011).

The study of the mechanical properties of fruits is often treated as complementary to biochemical tests to allow the appraisal of individual varieties and their storage stability. The test most commonly used to determine the mechanical properties of food is the compression test which consists in measuring forces and deformations and is performed also by using machine testing. During the compression test, a sample is placed between two parallel plates, one of which is biased at a constant speed, which causes deformation of the sample. The data recorded represent the value of compression force as a function of deformation and time (Ramos *et al.* 2003, Sitkiewicz 2010, García-Martínez *et al.* 2013). The mechanical properties of agricultural raw materials depend on their humidity and the phase of physiological development. The state of the cell wall is an essential element in the structure of plant tissue, determining the formation of the mechanical properties (Stępień 2009A).

The aim of the study was to investigate the influence of temperature and drying methods on shrinkage and mechanical properties of dried strawberries. The scope of the study included obtaining strawberries dried by convective, vacuum and convective-vacuum methods in a comparable range of ambient temperatures. Shrinkage, compression curves and the maximum compression force of dried strawberries were determined.

MATERIAL AND METHOD

Raw material for the study comprised strawberries of the variety SengaSengana, with diameter of 27±1 mm, frozen and stored at –18°C. Before experiments the strawberries were defrosted at 25±1°C for 2.5 hours. Strawberries were dried by convective, vacuum and convective-vacuum methods until a constant weight was reached, as indicated by a balance. Drying experiments (Piotrowski 2009) were carried out in (1) laboratory vacuum dryer (Mensor), (2) laboratory convective dryer (built by DFEPM-KIŻiOP, chamber capacity of approx. 10 dm^3) with parallel way of air feed to sieves, with a microprocessor based electronic balance A 2000 (Axis). Process parameters or balance indications were registered by computer software applications for vacuum and convective dryers. Drying parameters and duration of convective drying stages are shown in Table 1. Convective drying was employed to determine the duration of convective stage in the combined drying process down to 50% for three temperature levels. However, convective-vacuum drying was studied more precisely for the middle temperature of 55°C. The two-stage drying concept included the removal of 30, 50 and 70% of the initial water content at the first stage by convective drying method. Before and after the drying process, water content of strawberries was determined as a rule in 4 replicates by the drying method under atmospheric pressure (Jittanit *et al.* 2006, Worobiej 2009).

Axial shrinkage (Piotrowski *et al.* 2011) in the vertical plane was determined by linear measurements for 4 strawberries at the beginning of the defrosting process and for the same strawberries after drying, using an electronic caliper with an accuracy of 0.01 mm. The mechanical properties of dried strawberries were analysed by compression tests in 8 replications, using the standard methods. The test was carried out on texture analyser TA-TX2 2i (Stable Micro Systems) to deformation of 25% of each individually measured strawberry height at the cross-head velocity of 0.3 mm s^{-1} (Bondaruk *et al.* 2007). The data recorded during the above-mentioned test allowed us to draw compression curves and to determine the maximum compressive force for dried fruits.

Table 1. Drying codes, parameters of convective, vacuum, convective-vacuum drying and final water content of dried fruits

Drying methods	Drying code	Pressure P (kPa)	Time of convective drying / a stage (min)	Final water content of dried fruits ± standard deviation (mass %)
Convective	c45	100	1070	10.45 ± 0.27
	c55	100	881	9.31 ± 0.18
	c65	100	652	6.56 ± 0.48
Vacuum	v45	4	–	2.68 ± 0.17
	v55	4	–	1.62 ± 0.12
	v65	4	–	1.82 ± 0.12
Convective – vacuum	50%c45v45	100\4	stage: 110	2.20 ± 0.20
	30%c55v55	100\4	stage: 60	0.65 ± 0.11
	50%c55v55	100\4	stage: 115	0.94 ± 0.11
	70%c55v55	100\4	stage: 178	2.06 ± 0.05
	50%c65v65	100\4	stage: 80	0.68 ± 0.04

Statistical analysis of the results was carried out using IBM SPSS Statistics version 21 (IBM Corp.). The effects of temperature and method of drying on axial shrinkage and mechanical properties of dried strawberries were analysed by the Brown-Forsythe test and post hoc procedures for multiple comparisons (Games-Howell test detected homogeneity subsets) at a given level of significance of 0.05 applied in situations where the variances could be unequal.

RESULTS AND DISCUSSION

Figure 1 shows the curves of the convection drying process at temperatures of 45, 55 and 65°C used to determine the transfer point dried to an appropriate level of water content in strawberry fruits obtained by the convective-vacuum method.

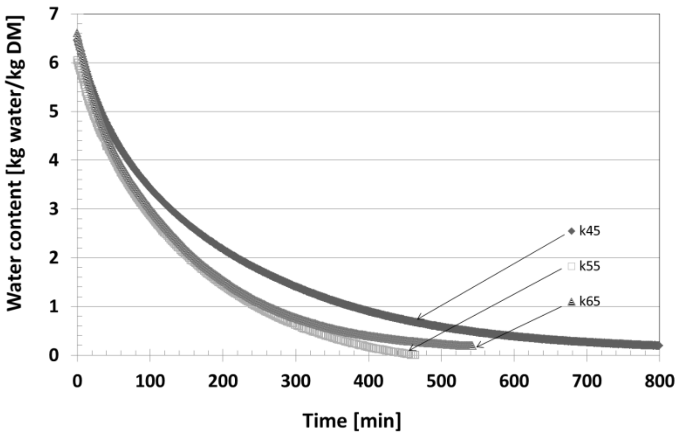

Fig. 1. Influence of drying temperature on course of drying curves of convective dried strawberries at temperatures of 45, 55 and 65ºC

The Games-Howell test, at a significance level of 0.05, revealed significant differences in the shrinkage of dried strawberries (Fig. 2). The largest axial shrinkage was observed for material dried by the convective method. Average values of shrinkage for the convective dried fruits formed a homogeneous group (the highest shrinkage for the lowest temperature – c45: 68.1%). The smallest axial shrinkage was obtained for vacuum dried strawberries (v65: 19.4%). Both for convective drying and vacuum drying with decreasing temperature the shrinkage was larger. Presumably, at higher temperature the drying time was shorter and the material was less exposed to the effect of temperature. Strawberry shrinkage during convection-vacuum drying was similar to the value obtained by vacuum drying.

Szarycz *et al*. (2006), who dried strawberries of the SengaSengana variety by convective and vacuum-microwave methods, found that definitely larger shrinkage characterised dried samples obtained by convective methods. The drying method which leads to the largest shrinkage is convective drying. During vacuum and microwave drying shrinkage of the dried material is less than during convective drying. This is due to a shorter time and a lower drying temperature and expansion of water vapour from the interior of the tissue, which was demonstrated by Giri and Prasad (2007) who investigated the effect of convective drying and microwave-vacuum drying on the structure of mushrooms. It was found that temperature has an influence on the formation of shrinkage during convective and vacuum drying. In a study carried out by Wang and Brennan (1995), shrinkage of potato slices dried by convective method was higher during drying at lower temperatures than during drying at higher temperatures. However, in a study carried out by Mauro *et al.* (2004), shrinkage of apple slices was smaller at a lower temperature, both during convective and vacuum drying. Also Piotrowski *et al.* (2011) demonstrated that increasing the temperature from 50 to 70°C resulted in a reduction of shrinkage of vacuum dried strawberries.

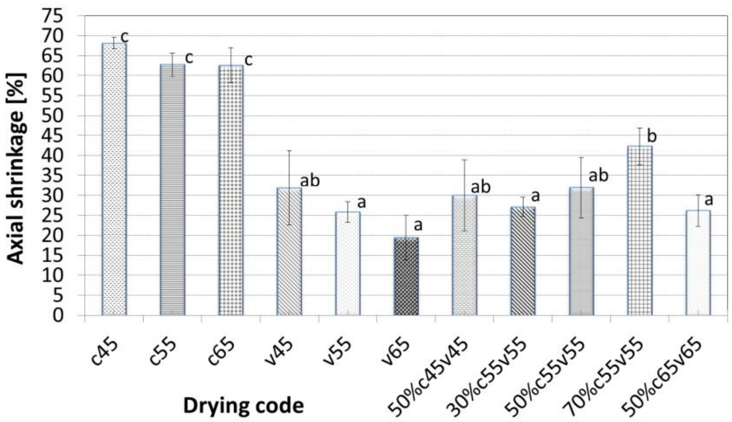

Fig. 2. Influence of drying temperature on axial shrinkage of convective, vacuum and convective-vacuum dried strawberries at temperatures of 45, 55 and 65ºC

Figure 3 shows compression curves of convective dried strawberries. All strawberries dried by the convective method, irrespective of the applied temperature, were characterised by large drying shrinkage and small volume. All compression curves are mild, which proves that the fruits are soft and have high water content at the level 6-10%. The increase of drying temperature caused lowering of the water content in convectively dried fruits. The greatest values of compression force were observed for dried fruits obtained at 55°C and the smallest ones at the temperature of 45°C. The course of the compression curves indicates that convective dried strawberries at 55°C were characterised by higher hardness and higher maximum compression force than strawberries dried at 45 and 65°C. The softest strawberries were dried at the lowest temperature, as evidenced by the course of compression curves and the lowest maximum compression force. This is the result of the fact that at 45°C the drying time was the longest, which caused sagging of the delicate structure of strawberries and the largest shrinkage of all the drying methods.

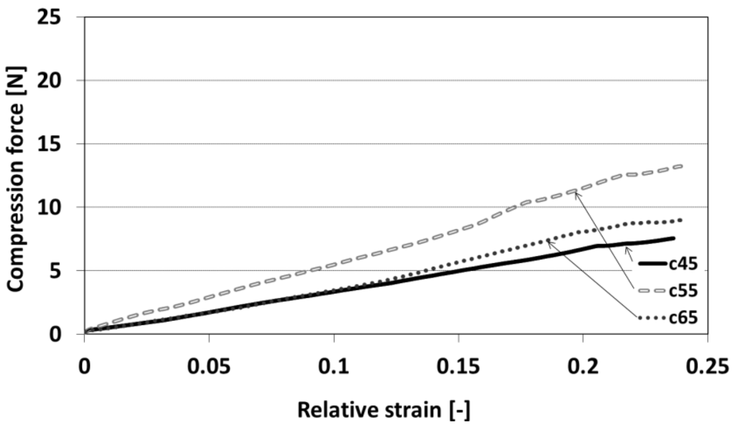

Fig. 3. Influence of drying temperature on course of compression curves of convective dried strawberries at temperatures of 45, 55 and 65°C

Figure 4 shows compression curves of vacuum dried strawberries. All vacuum dried strawberries were characterised by greater hardness and crispness than convective dried fruits because of the greater value of compression force and larger break curves. Strawberries dried by the vacuum method had a lower water content, about 2% (Tab. 1), and their structure was open and porous. At the temperature of 45°C the water content was the highest. However, with the temperature increasing by 10 or 20°C the water content decreased, remaining at comparable levels. The increase of drying temperature caused an increase of compression force values. Strawberries dried at 65°C had the lowest water content, and therefore they were harder than fruits dried at the lowest temperatures, as evidenced by the course of the compression curve and the highest maximum compression force.

The lowest compression force was exhibited by strawberries dried at 45°C, and it was related to the highest water content for all drying methods.

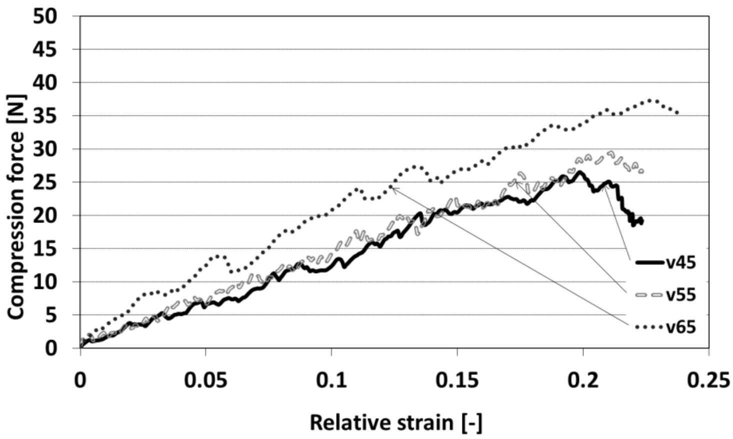

Fig. 4. Influence of drying temperature on course of compression curves of vacuum dried strawberries at temperatures of 45, 55 and 65ºC

Figure 5 shows compression curves for dried strawberry obtained by convective-vacuum drying at the same temperature. Strawberries dried by the combined method had similar compression curves to those obtained by vacuum drying, because they were also crispy, hard and had a low water content below 2%. Strawberries dried at lower temperatures had milder compression curves and little shrinkage, due to the higher water content (Tab. 1) and, therefore, softer tissue. During convective-vacuum drying an increase of temperature caused lowering of the water content. The extension of the convective drying stage caused an increase of the water content. The increase of the drying temperature caused a faster rate of water evaporation, shortening the drying time at any stage and a subsequent increase of compression forces. The shortening of the convective drying stage caused an increase of compression force values. Their maximum compression force was the lowest, as well as the compression force of strawberries dried at medium temperature to 70% water evaporation. The shorter the convection stage, the smaller was the shrinkage (Fig. 2) and the lower was the water content. Therefore, strawberries dried to 30% water evaporation had a maximum compression force at a high level (Fig. 6) and a compression curve characterised by much refraction (Fig. 5). When the drying temperature was higher, the maximum compression force was higher, which means less destruction of the structure and a lower level of drying shrinkage, due to a shorter drying time.

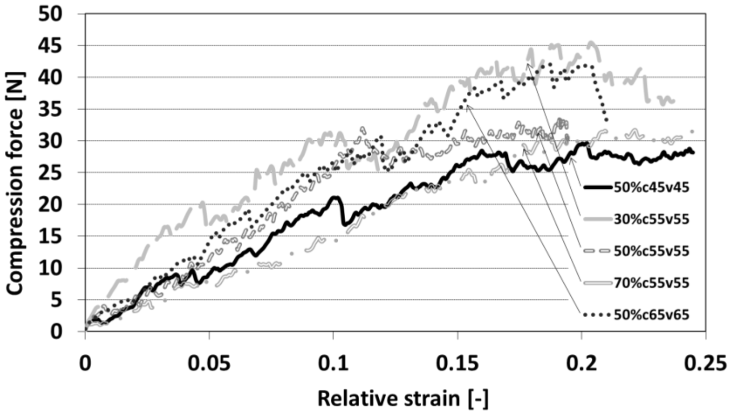

Fig. 5. Influence of drying temperature on course of compression curves of convective-vacuum dried strawberries at temperatures of 45, 55 and 65°C

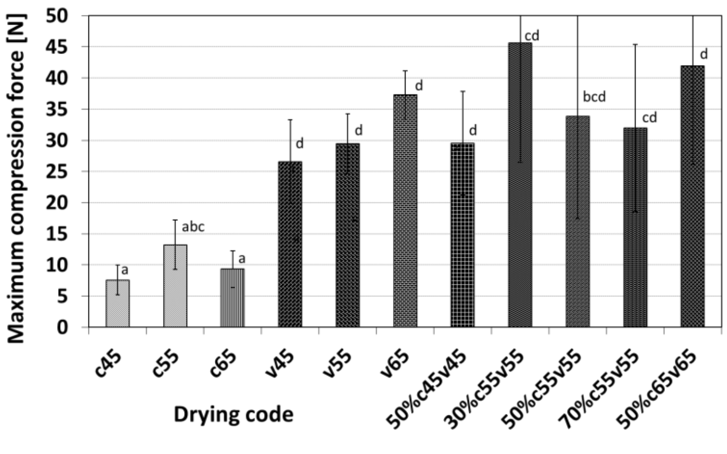

Fig. 6. Influence of drying temperature on maximum compression forces of convective, vacuum and convective-vacuum dried strawberries at temperatures of 45, 55 and 65°C

Convective dried strawberries were characterised by the smallest values of compression force, as proved by their soft texture which easily underwent compression. Statistical analysis showed that the maximum compression force for strawberries obtained by vacuum and convective-vacuum drying methods at the corresponding temperatures did not differ from each other (Fig. 6). Similar results were obtained by Marzec and Pasik (2008) who studied the effect of drying method on mechanical properties of dried carrot. Similarly, convection dried carrots were characterised by the lowest compression force compared with products obtained by different drying methods (Stępień 2009 B).

Strawberries dried by the vacuum method had higher compression force values (Fig. 6) and their structure was harder and crisper. During vacuum drying, lower pressure and temperature ranges were applied to minimise the impact of these factors on the delicate structure of the strawberries. Analogous to previous results, in the case of convective-vacuum drying compression forces were higher and increased with increasing temperature. Jakubczyk and Ksionek (2006) demonstrated that the recorded compression force of freeze-dried strawberries increased with lowering of the water content. Sitkiewicz *et al.* (2011) found that the maximum compression force for vacuum dried strawberries at a temperature of 65°C was about 5 times larger, at 30.8 N, while the maximum force for strawberries dried at 45°C was only 6.2 N. Results published by Sitkiewicz *et al.* (2013) indicated that the use of convective-vacuum drying allowed them to obtain a lower shrinkage of strawberries than the use of convection drying, and favourable mechanical properties for consumers. Sitkiewicz *et al.* (2011) demonstrated that for strawberries dried at 70°C the value of maximum force and the value of compression work are significantly higher than those parameters for strawberries dried at 50°C. Probably this is due to axial shrinkage obtained during the drying of strawberries, because a lower temperature vacuum drying causes the sagging of structure and a large axial shrinkage since the duration lengthens drying. Bondaruk *et al.* (2006) showed that potatoes dried by convective method at 70°C were characterised by greater resistance to compression and larger deformation energy than convective dried obtained at 50°C. There were no statistically significant differences between compression force of convective dried samples at 50°C and the samples dried in vacuum-microwave method.

Based on the Brown-Forsythe test of equality of means at a significance level of 0.05, we found that the temperature and drying method have a statistically significant impact on the value of the maximum compression force and it can be classified in one homogeneous group by the Games-Howell test. It was demonstrated that the maximum compression force obtained for vacuum and convective-vacuum dried strawberries at the same temperature ranges are statistically not different. Statistical analysis indicated that the convective stage used in the combined drying method did not significantly affect the maximum compression forces compared to forces registered for vacuum dried strawberries.

CONCLUSIONS

1. Convective drying causes the largest drying shrinkage and the lowest shrinkage was obtained for vacuum dried strawberries. The use of combined drying leads to a small amount of axial shrinkage (in the range of 20-40%) which is close to the shrinkage resulting from the vacuum drying process. Drying temperature has a significant effect on shrinkage. The use of higher temperatures in the considered range (maximum of 20°C) allows one to obtain a product with less shrinkage in vacuum and combined drying, which may be due to a shorter drying time at higher temperatures.

2. In the case of vacuum, convective and convective-vacuum drying, the fruits with the highest final water content were characterised by the lowest value of compression force. In convective-vacuum drying the increase of duration of the convective stage caused a decrease of compression force which was closely related to the increase of the water content.

3. Temperature and drying method have a statistically significant effect on mechanical properties of dried strawberries: on the course of compression curves and the maximum compression force.

4. From the compression of the curves and the values of the maximum compression force it can be concluded that the vacuum and the convective-vacuum dried strawberries are crisper and harder than strawberries dried by the convective method and are characterised by the lowest values of compression force.

5. The higher temperature of vacuum and combined drying led to a higher maximum compression force, which indicates greater resistance of the strawberry structure to compression.

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SKURCZ I WŁAŚCIWOŚCI MECHANICZNE ROZMROŻONYCH TRUSKAWEK SUSZONYCH METODĄ KONWEKCYJNĄ, PRÓŻNIOWĄ I KONWEKCYJNO-PRÓŻNIOWĄ

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Streszczenie. Właściwości mechaniczne są istotnym wskaźnikiem jakości żywności. Są uważane za jeden z najważniejszych kryteriów dotyczących akceptacji surowca przez konsumentów. Na teksturę owoców i warzyw ma wpływ proces suszenia – ściśle związany ze składem i strukturą ścian komórkowych – oraz jego parametry. Materiał do badań stanowiły truskawki odmiany Senga Sengana. Osiowy skurcz w płaszczyźnie pionowej oznaczano metodą liniową dla 4 truskawek przed suszeniem i dla tych samych truskawek po suszeniu, z wykorzystaniem suwmiarki elektronicznej. Właściwości mechaniczne suszonych truskawek analizowano metodą ściskania (krzywych ściskania i maksymalną siłą ściskająca).Test przeprowadzono na analizatorze tekstury TA-TX2 2i (Stable Micro Systems). W artykule przedstawiono badania, których zakres pracy obejmował wysuszenie truskawek trzema metodami konwekcyjnie, próżniowo, konwekcyjnie-próżniowo w różnych wariantach temperatur. Stwierdzono, że największy skurcz suszarniczy występuje w suszach konwekcyjnych, a najmniejszy w próżniowych. W przypadku suszenia próżniowego oraz konwekcyjnego wzrost temperatury suszenia spowodował uzyskanie mniejszego skurczu. Z krzywych ściskania oraz wartości maksymalnej siły ściskania wynika, że truskawki suszone metodą konwekcyjna oraz konwekcyjno-próżniową są bardziej chrupkie i twarde niż truskawki suszone konwekcyjnie, które charakteryzują się najniższymi wartościami siły ściskania.

Słowa kluczowe: truskawki, metody suszenia, temperatura suszenia, skurcz, krzywe ściskania, maksymalna siła ściskania