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DRYING KINETICS, WATER ACTIVITY, SHRINKAGE AND TEXTURE OF WALNUT KERNELS

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A b s t r a c t. Walnut kernels were dehydrated using two drying methods: convective and vacuum-microwave. In the convective method air velocity was 2 m s^{-1} and temperature 55°C. Vacuum-microwave dehydration was performed under pressure changing from 4 to 6 kPa at microwave power of 480W. The decrease in moisture content of walnut kernels dehydrated in convection was described by a two term exponential function, while in vacuum-microwave method by linear function in the first drying period and by an exponential function in the second period. The relationship between the moisture content and water activity for walnut kernels was described using an exponential equation. The study revealed that shrinkage was changing until the moisture content of walnut kernels reached 0.3 kg kg^{-1} db. It was found that decreasing moisture content of walnut kernels till 0.46 kg kg^{-1} db resulted in considerable increase in the breaking force and breaking extension estimated at bending strength test. Further lowering of moisture content caused a decrease in breaking force while the value of breaking extension remained constant. The significant decrease in breaking extension occurred when exceeding 0.14 kg kg^{-1} db.

K e y w o r d s: walnuts, drying kinetics, water activity, shrinkage, texture

INTRODUCTION

Walnuts (*Juglans regia* L.) are highly nutritious food due to their high oil content composed of unsaturated fatty acids, such as linoleic acid (59%), α-linolenic acid (13%) and oleic acid (18%) (Torres *at al.* 2005). They are rich in valuable minerals like phosphorus, potassium, sodium, magnesium and zinc (Lavedrine *et al.* 2000). The health benefits of walnuts include lowering of cholesterol, reducing inflammation, and improving arterial function (Nash and Westpfal 2005, Patel 2005). Regular consumption of walnuts has been reported to decrease the risk of heart disease (Lavedrine *et al.* 1999, Cortes *et al.* 2006).

Walnut kernels can be eaten as freshly picked fruits or after dehydration which enables longer storage at room conditions thanks to lowering of moisture content and water activity. Appropriate moisture content and compression load position in nuts facilitates cracking and separation of the kernel from the broken shell (Koyuncu *et al.* 2004, Asoegwu 1995). Nuts, usually with high moisture content before cracking, are subjected to a drying process. Usually nuts are subjected to convective dehydration (Kashaninejad *et al.* 2007), however microwave (Silva *et al.* 2006) or vacuum-microwave drying method (Delwiche *et al.* 1986) may be applied as well.

No attempts have been made so far to dry extracted walnut kernels and to estimate shrinkage as well as the relationship between the moisture content and water activity which is very important to the quality and stability of food (Maltini *et al.* 2003). The texture of walnut fruit is usually evaluated in sensory tests (Sinesio and Moneta 1996) and the instrumental method is limited to a narrow range of walnut moisture content values (Kita and Figiel 2007).

Therefore, the aim of the presented studies was to determine the drying kinetics of extracted walnut kernels dehydrated by convection and vacuum-microwaves. The aim was also to estimate the effect of water content on water activity, shrinkage, and bending strength of walnut kernels.

MATERIALS AND METHODS

Fresh walnuts of Jacek cultivar were used in the study. Extracted kernels with average moisture content of 0.52 kg kg^{-1} db were vacuum-packed and stored in a refrigerator at 5°C. Just before dehydration, samples were taken out from the refrigerator to obtain ambient temperature.

200 g of walnut kernels were subjected to convective dehydration using drying equipment designed and made at the Agricultural Engineering Institute of Wroclaw. The air velocity and temperature were 2 m s^{-1} and 55°C. Vacuum-microwave drying process of walnuts samples was performed in a VM 200 dryer (Plazmatronika, Wroclaw) that had two magnetrons of 1200W combined power and a revolving drum. The pressure in the drum was from 4 to 6 kPa. The microwave power was set at 480 W, a value that would provide a power density of 4.8 W g^{-1} when initial sample weight was 100 g. The drying kinetics was determined on the basis of mass losses of samples with previously estimated moisture content. Walnut samples were dehydrated using both methods to a similar moisture content (*Mc)* amounting to 0.045 g water g^{-1} dry matter. However, in the convective method, with successive portions of fresh material much longer drying times were applied to obtain several samples differing in

moisture content, whereas in the vacuum-microwave method only one control sample was obtained for the additional tests.

Shrinkage (*S*) represented by relative volume of the dried material was determined by calculating the ratio of kernels volume after drying (*V*) to kernels volume before drying (V_0). The volume of fresh and dried kernels was determined using the liquid displacement method. This method consisted in using a graduated cylinder filled with toluene (C_7H_8). Toluene was used because it is absorbed by biological material at low amount.

Water activity of walnut kernels (a_w) was measured at 25°C with apparatus made by Cobrabit (Poznań).

Bending strength of walnuts was determined with an Instron 5566 strength testing machine fitted with a strain gauge of the range up to 1 kN. Single walnut halves were bent in a three point support system at the speed of 5 mm min^{-1} (Kita and Figiel 2006). The test lasted until the examined sample was destroyed and this way enabled determination of maximum bending force (Fb_{max}) and the maximum bending extension (Lb_{max}). Each measurement was conducted on 15 nut kernels.

The results obtained in the bending test were evaluated by statistical analysis with the use of the Statistica v. 7.1. Homogeneous groups were determined with the multiplicative comparison test of Duncan (at significance level $\alpha = 0.05$). In order to find out if the differences in the mean values estimated were statistically significant, one-way analysis of variance was applied.

RESULTS AND DISCUSSION

Based on the measurement points obtained from drying experiments (Fig. 1) it was found that the decrease in moisture content (*Mc)* of walnut kernels during drying by the convective method can be described by a two term exponential equation (Henderson 1974):

$$Mc = 0.1213 \cdot e^{-\frac{t}{4}} + 0.3757 \cdot e^{-\frac{t}{65.52}} + 0.021 \qquad (1)$$

On the other hand the process of walnut kernels drying with the vacuum-microwave method, can be divided into two periods separated by the critical point K (Pabis and Jaros 2002). The decrease in (*Mc)* in the first drying period, between starting point and K, was described by a linear function (2) and in the second period, between K and final point – by an exponential function (3)

$$Mc = 0.518 - 0.0568 \cdot t \qquad (2)$$

$$Mc = 1.123 \cdot e^{-\frac{t}{3.39}} \qquad (3)$$

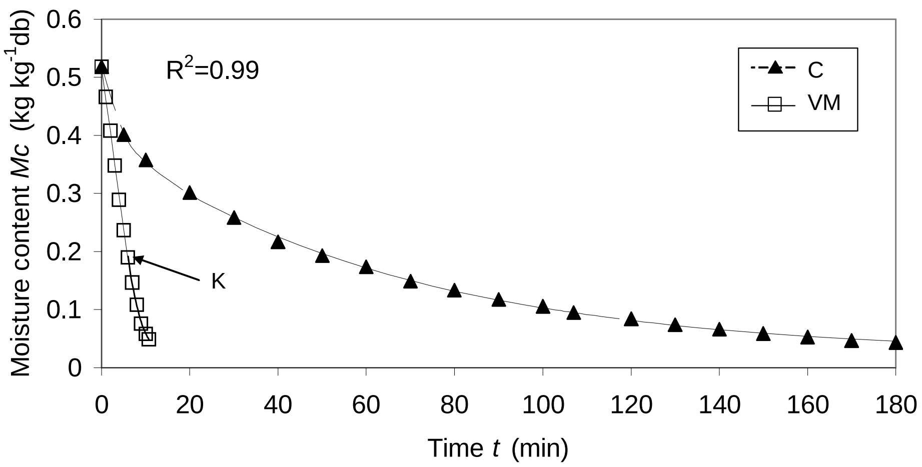

Fig. 1. Drying kinetics of walnut kernels for convective (C) and vacuum–microwave (VM) method, R^2 – coefficient of determination

A decrease in moisture content from 0.52 to 0.045 kg kg^{-1} db lasted about 180 minutes with the conventional method and only 10 minutes with the vacuum-microwave method. Numerous studies on different biological materials prove that drying with the vacuum-microwave method is much faster compared to the convective method (Durance and Wang 2002, Lin *et al*. 1998, Sunjka *et al.* 2004). In the vacuum-microwave method microwaves penetrate to the interior of the food causing water to boil within the food at low temperature. This creates a large vapour pressure in the centre of the product, allowing rapid transport of moisture out of the product (Sham *et al.* 2001).

Absolute values of derivatives of the functions describing walnut kernels drying allowed determination of the drying rate, which is represented by the plots in Figure 2.

Decreasing moisture content till about 0.3 kg kg^{-1} db was accompanied by changing shrinkage (*S)* of the dried material. On exceeding this value no further change in the volume of the walnut kernels was observed (Fig. 3). The relative volume of the sample dried with the vacuum-microwave method differed only slightly from the samples dehydrated in convection. This indicates that walnut kernels are not susceptible to puffing under vacuum-microwaves unlike other biological materials (Figiel 2006, Sham *et al.* 2001). The change of shrinkage *S* of walnut kernels was described with a power function:

$$S = 18.56 \cdot Mc^{6.25} + 0.686 \tag{4}$$

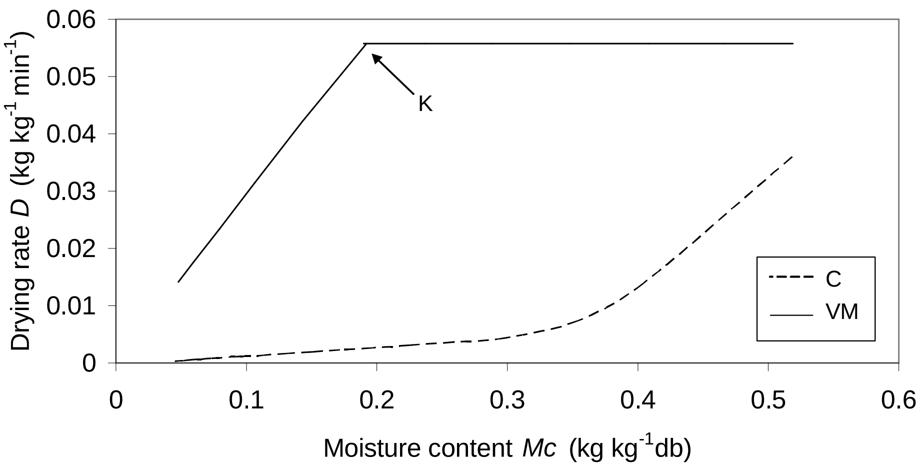

Fig. 2. Drying rate during dehydration of walnut kernels using convective (C) and vacuum–microwave (VM) method

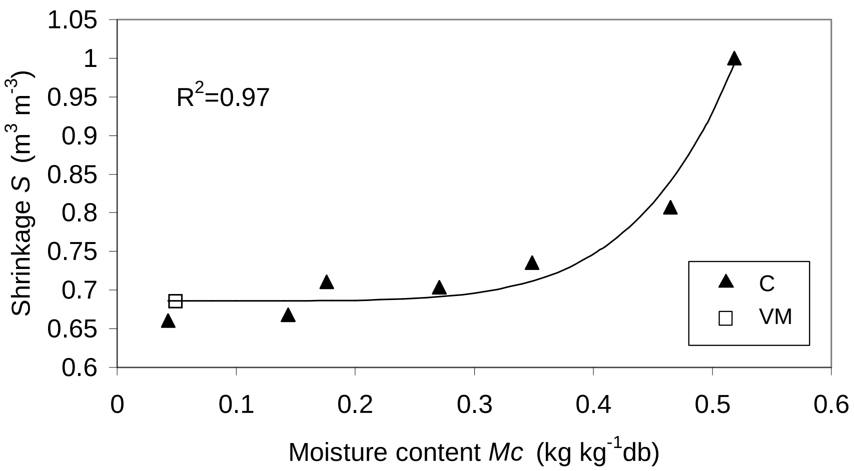

Fig. 3. Shrinkage of walnut kernels during dehydration using convective (C) and vacuum–microwave (VM) method, R^2 – coefficient of determination

The relationship between the moisture content (*Mc)* and water activity (a_w) for walnut kernels is shown in Figure 4. Two additional points with (*Mc)* below 0.045 kg kg^{-1} db represent the extra dehydrated samples. The extra dehydration was necessary to increase the range of walnut kernels water activity towards lower values and in this way to improve mathematical modelling. An exponential equation (5) was proposed to describe the effect of moisture content on water activity:

$$a_w = 0.925 \cdot (1 - e^{-\frac{Mc}{0.057}}) \qquad (5)$$

High water activities were associated with relatively low moisture contents of walnut kernels. Similar relationship was confirmed by studies made on other nut fruits like pistachio (Maskan and Gogus 1997, Yazdani *et al.* 2006) or macadamia (Dominguez *et al.* 2007).

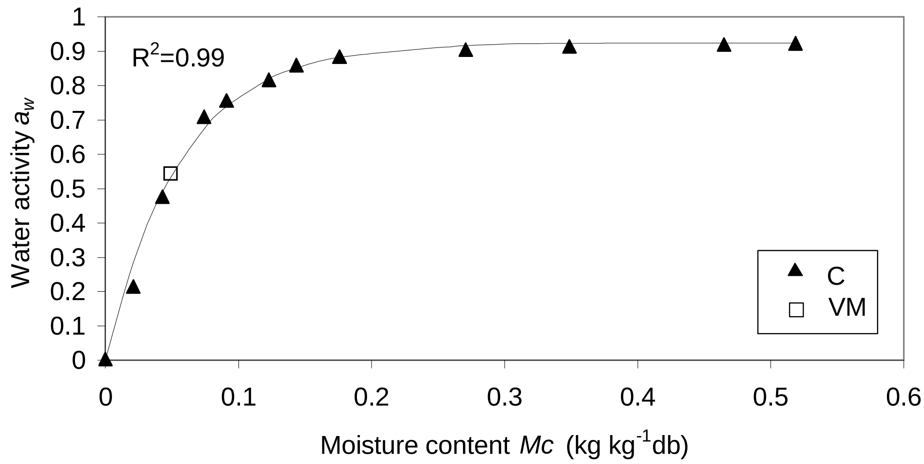

Fig. 4. Relationship between the moisture content and water activity of walnut kernels dried by convective (C) and vacuum–microwave (VM) method, R^2 – coefficient of determination

Based on the results of bending strength tests on walnut kernels (Fig. 5 and 6), it was found that lowering of moisture content to 0.46 kg kg^{-1} db caused considerable increase in the breaking force *(*Fb_{max}*)* and breaking extension *(*Lb_{max}*)*. Further lowering of moisture content below 0.46 kg kg^{-1} db caused a decrease in (Fb_{max}) according to exponential function (6) and change of (Lb_{max}) described by equation (7).

$$Fb_{\max} = 42.6 \cdot Mc^{1.41} + 6.89 \qquad (6)$$

$$Lb_{\max} = 5.67 - \frac{0.008}{Mc^2} \qquad (7)$$

It is worth noting that (Lb_{max}) maintained a similar value of 5.5 mm in the range of (*Mc*) from 0.46 to 0.14 kg kg^{-1} db. The decrease in breaking strength when decreasing moisture content of roasted walnut kernels in the range from 0.007 to 0.03 kg kg^{-1} db was reported in previous studies (Kita and Figiel 2006). The results of this study suggest that when increasing moisture content of walnuts beyond 0.46 kg kg^{-1} db a change in the relationship between the bending strength and moisture content may be expected. This implication enhances the necessity of further studies on the texture of fresh walnut kernels with high moisture content.

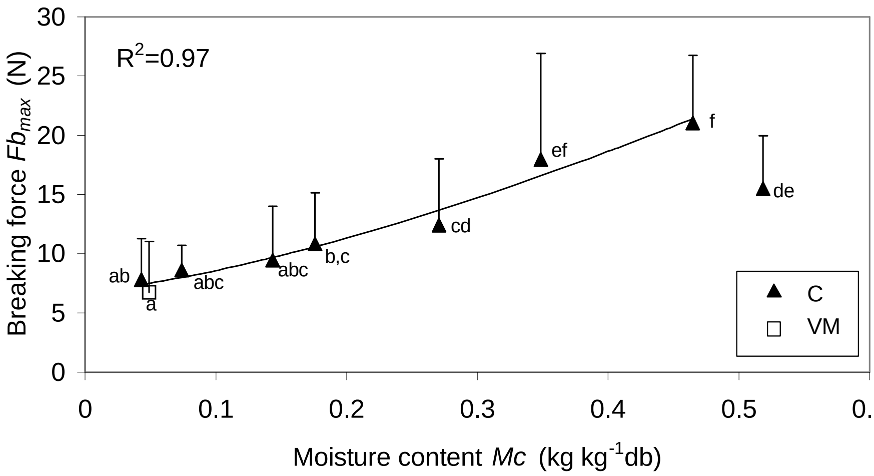

Fig. 5. Effect of moisture content on breaking force for walnut kernels dried by convective (C) and vacuum-microwave (VM) method, R^2 – coefficient of determination, similar letters (a, b, c, d, e, f) are indicative of no significant difference between the mean values

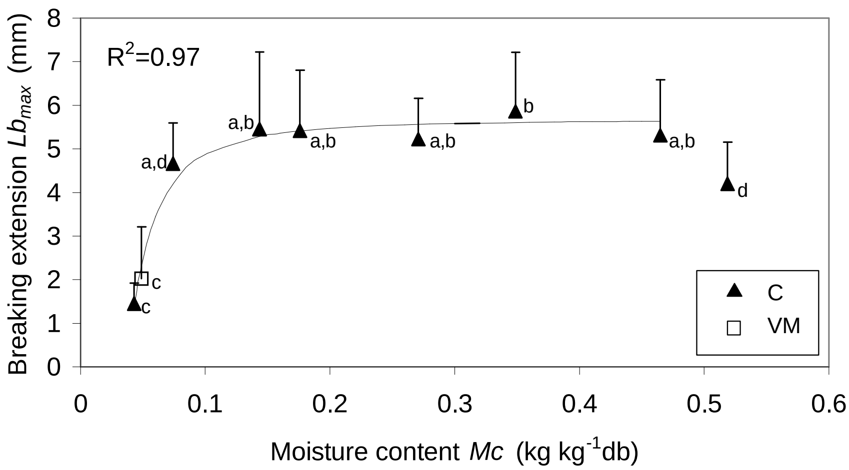

Fig. 6. Effect of moisture content on breaking extension for walnut kernels dried by convective (C) and vacuum-microwave (VM) method, R^2 – coefficient of determination, similar letters (a, b, c, d) are indicative of no significant difference between the mean values

CONCLUSIONS

1. The decrease in moisture content of walnut kernels dried in convection can be described by a two term exponential function, whereas in vacuum-microwave method by linear function in the first drying period and by an exponential function in the second period.
2. Shrinkage of walnut kernels changes while the moisture content decreases till about 0.3 kg kg^{-1} db. On exceeding this value no further change in the volume of walnut kernels is observed.
3. The relationship between the moisture content and water activity for walnut kernels can be described using an exponential equation.
4. Decreasing moisture content of walnut kernels till 0.46 kg kg^{-1} db results in a considerable increase in the breaking force and breaking extension. Further lowering of moisture content causes a decrease in breaking force while the value of breaking extension remains constant. The decrease in breaking extension occurs when exceeding 0.14 kg kg^{-1} db.

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KINETYKA SUSZENIA, AKTYWNOŚĆ WODY, SKURCZ ORAZ TEKSTURA ORZECHÓW WŁOSKICH

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S t r e s z c z e n i e. Orzechy włoskie wysuszono przy użyciu dwóch metod: konwekcyjnej i mikrofalowo – próżniowej. W metodzie konwekcyjnej prędkość powietrza wynosiła 2 $m \cdot s^{-1}$ a temperatura 55°C. Suszenie metodą mikrofalowo – próżniową przeprowadzono przy ciśnieniu zmieniającym się od 4 do 6 kPa przy mocy mikrofal 480W. Obniżenie wilgotności orzechów suszonych konwekcyjnie opisano przy użyciu funkcji złożonej z dwóch składników wykładniczych, a suszonych metodą mikrofalowo – próżniową przy użyciu funkcji liniowej w pierwszym okresie suszarniczym i funkcji wykładniczej w okresie drugim. Na podstawie wyników badań okazało się, że skurcz suszarniczy ulegał zmianie aż do osiągnięcia przez orzechy zawartości wody 0,3 kg wody·kg^{-1} suchej masy. Zależność między zawartością wody a aktywnością wody orzechów opisano przy użyciu funkcji wykładniczej. Stwierdzono, że obniżenie wilgotności orzechów do 0,46 kg wody·kg^{-1} suchej masy powodował znaczny wzrost siły niszczącej i odkształcenia niszczącego w teście wytrzymałości na zginanie. Dalsze zmniejszanie wilgotności powodowało zmniejszenie siły niszczącej, podczas gdy odkształcenie niszczące pozostawało bez zmian. Znaczne zmniejszenie odkształcenia niszczącego nastąpiło po przekroczeniu 0,14 kg wody·kg^{-1} suchej masy.

Słowa kluczowe: orzechy, kinetyka suszenia, aktywność wody, skurcz, tekstura