Acta Agrophysica, 2007, 9(1), 255-267

IMPACT OF THE DRYING METHOD ON THE PROCESS OF CARROT CUTTING

Bogdan Stępień

Agricultural Engineering Institute, Wroclaw University of Environmental and Life Sciences
ul. Chełmońskiego 37/41, 51-630 Wrocław
e-mail: stepien@imr.ar.wroc.pl

Abstract. The testing of the carrot drying process was performed using three methods: convection drying, freeze-drying and vacuum-microwave drying. The raw material, blanched and osmotically dehydrated, was fixed. The cutting process test was performed for raw material, dried material and hydrated material. The value of the total work input into the cutting of carrot and the value of the parameter called the compression degree was computed. A hypothesis about the possibility of using the compression degree as a criterion for the evaluation of dried carrot internal structure was confirmed. Among the suggested carrot fixing methods, the sublimation drying allows to obtain a product of the least resistance to cutting. Rehydration of the dried material obtained with the sublimation method produces numerous cracks of cell walls, which essentially reduces the cutting work value, at the same time increasing the compression degree value.

Keywords: blanching, osmotic dehydration, microstructure

INTRODUCTION

The seasonal nature of occurrence of some plants enforces the application of interventions allowing to store the food stuffs over a longer period of time. The fixing of agricultural raw materials aims at the reduction of the rate of vital processes, inhibition of the interference of micro-organisms, adjustment of physiological processes, and also at the inhibition and, if possible, elimination of factors that decay the food stuffs. The oldest methods of fixing food stuffs consist in drying, smoking, cooling and freezing operations. Irrespectively of the fixing technology applied, the product quality is deteriorated in relation to the raw material quality (Horubała 1975).

The drying of vegetables and mushrooms is a domain of the agricultural dehydration industry, much less recognized than drying of cereals or green fodder. We are still missing the knowledge allowing to optimise the drying process in the aspect of energy consumption and product quality. Advanced study and laboratory research is conducted, related to the drying conditions and the methods of storing raw material for the fixing processes (Kramkowski 1998, Szarycz 2001, Witrowa-Rajchert 1999).

Preliminary treatment before the convection drying, such as washing, disintegration or blanching, result in a rise of power supply expenditure while producing alimentary dried materials, however, they considerably improve the product quality. The blanching time and temperature as well as the blanching agent type have the strongest impact on the rate of thermal inactivation of enzymes. The blanching temperature and the intervention duration are chosen empirically depending on the type of enzymes appearing in the raw material and on the short time of running the process (Kaleta 1999, Klimczak *et al.* 1994a, Klimczak *et al.* 1994b).

Osmotic dehydration is a treatment frequently used before the drying in order to improve dried material quality. The impact of the osmotic dehydration of vegetables on the reconstitution properties of dried materials has been broadly investigated (Witrowa-Rajchert 1999). Sowti Khiabania and others (2002) demonstrated that the rise in the solution concentration from 50% to 60% or the addition of sodium chloride results in a significant rise in the dehydration degree of peaches. Sensory analysis showed an improvement of the peach dried material colour and taste, obtained from osmotically dehydrated fruits before the convection drying, in relation to the dried material from a raw material that had not been subjected to a preliminary treatment. The impact of osmotic dehydration on the mechanical properties of fruits was investigated by Sanjinez-Argandona and others (2002). They compared the properties of fresh, osmotically dehydrated, and convection dried and osmotically dehydrated fruits before the drying process. They determined the basic mechanical properties: stress, true strain, destruction work and relaxation time. The final product obtained from fruits subjected to osmotic dehydration before the drying process was characterized by the most advantageous mechanical features.

Convection drying is a method of fixing food stuffs on an industrial scale. Simultaneously, the method is considered to be the most destructive. There exist many modern drying methods allowing to get a product of a suitably high quality, their disadvantage being, however, high cost of making dry products. For those reasons the drying techniques that provide some hopes for their mass use make an object of thorough laboratory examinations. One of such methods is the microwave drying or vacuum-microwave drying (Szarycz 2001). A series of reference reports describe the impact of microwaves on the drying kinetics and product quality. Wang and Xi (2005) investigated the microwave drying kinetics of carrot slices of a thickness ranging from 1.5 to 9.0 mm. They determined the dependence of hydration degree and the size of power supply expenditure in the function of moisture contents, at various levels of microwave power. They found that with reduction in the carrot slice thickness the hydration degree rises and the energy consumption during the drying process drops.

For the fixing of biological materials the dehydration in frozen state, called freeze-drying, is used more and more frequently. This is a method that has well recognized theoretical bases (Kramkowski 1998). It is considered to be the least destructive drying method. However, the product manufacturing cost is too high for the method to find application on an industrial scale already now. Attempts to perform combined drying are undertaken, consisting in combining various dehydration methods. Litvin and others (1998) dried carrot of humidity contents up to 40% by sublimation, next, over 50 seconds, they acted on the carrot samples with microwaves in order to reach the final moisture contents, amounting to 5%, in a vacuum drier. The colour preservation capability, the drying shrinkage and the hydration degree of the product obtained with the combined drying method were the same as for the freeze-drying. Dyestuff losses were lower with the vacuum drying than with the drying using the combined method.

While evaluating the product quality, knowledge of the impact of individual drying methods on features constituting an evaluation criterion is essential. Prakash and others (2004) investigated the impact of three drying methods: convection drying, drying in a spouted bed and microwave drying on selected features of the carrot being blanched. They found that raw material dried in a spouted bed showed better preservation capability of colour, better rehydration properties and more advantageous retention of β-carotene than a product obtained using the two other methods.

The aim of the paper was an analysis of the cutting process of dried material and that of hydrated carrot to be dried by convection, sublimation and vacuum microwave, using blanching and osmotic dehydration as pretreatment operations.

MATERIALS AND METHODS

A popular root plant, carrot of the Cesaro variety, was subjected to testing of resistance to cutting. Samples were prepared in the form of cylinders, 5 mm high and 20 mm in diameter. The raw material, blanched and osmotically dehydrated, was dried. The blanching operation was performed in water of 95°C ± 2°C temperature for 3 minutes. During the blanching operation there occurred dry mass losses amounting to 11%. A 5% solution of NaCl of 20°C temperature was used for the osmotic dehydration. The dehydration duration was 24 hours. A drop of moisture contents from 88% down to 79% was obtained. The convection drying was performed on a laboratory drier at cooling agent temperature of 50°C and air flow velocity equal to 1.5 m/s. The system had six individually controlled stand-alone units with heaters of 2 kW maximum power. A drier type OE-950 was used for the freeze-drying. The samples were frozen at –20°C with a rate of 1°C min^{-1}. The following drying parameters were applied: heat plate temperature (20°C), pressure in the drying chamber (100 Pa), heat delivery by the contact method. The microwave drying was performed in a microwave-vacuum drier with an amplitude control of magnetrons. The power of the magnetrons was set at the level of 40% of their maximum power, i.e. 480 W. The pressure in the drying chamber was kept within the range of 4-10 kPa.

Rehydration was made in distilled water of 20°C temperature. The rehydration time was chosen empirically in order to obtain moisture contents close to those of the raw material.

The carrot cutting tests were performed on a machine type Instron 5566 with replaceable cutting heads of a class 0.5. For the testing an attachment of our own design was used, with a cutter of blade and opening angles amounting to 60° each. The cutter speed was 10 mm min^{-1}.

The value of the cutting work was calculated using the trapezium method.

The moisture contents of the dried material as well as those of the hydrated material were determined by drying the samples in the drier type KC 100/200 at the temperature of 105°C for 48 hours.

The shrinkage accompanying the drying process of the plant tissue essentially influenced the values of obtained cutting work. In order to use the resistance to cutting as an evaluation criterion and to compare the various drying methods, the value of the total work was converted per square centimetre of the surface being cut. Samples were cut along the axis of symmetry, thus the product of the height and the diameter of the slice constituted the area of the surface being cut. The sample height and diameter were measured using a digital slide caliper with an accuracy of $\pm$0.01mm.

In order to clarify the reasons for the occurrence of differences in the resistance to cutting of the carrot dried using the various methods, microscope photographs of the internal structure were taken. The deformation of cells with a particular stress put on changes visible on cell walls, whose basic function is to play the role of the plant skeleton, was observed. To this aim the scanning microscope type ZEISS 435 VP was used.

RESULTS AND DISCUSSION

Dried materials obtained using the three methods differed significantly in their moisture contents. For the convection drying the moisture contents of dried materials was 8% ± 0.5%, for the freeze-drying 4.5% ± 0.5%, and for the vacuum-microwave drying 3.5% ± 0.5%.

The highest linear drying shrinkage was noticed for samples obtained during the convection drying process. The cylinder diameter and the cylinder height were getting lower by ca. 40% in relation to initial dimensions. The shrinkage observed for the carrot subjected to freeze-drying did not exceed 5%, and it amounted to ca. 28% of vacuum-microwave drying.

A typical course of the carrot cutting process is presented in Figure 1. The nature of the course did not change irrespective of the drying method, the preliminary treatment, or the dried material hydration. Three characteristic points corresponding to specific stages of the cutting process were observed. At the first stage, the moving blade of the cutting attachment deforms the sample without penetrating the material. This stage ends at the point A, being a compression end and a beginning of the cutting, understood as the plunging of the blade in the material, this being accompanied by penetration. This is linked to an instantaneous drop in the cutting force. The maximum value of the cutting force (point B) corresponds to that cutting moment when the top corner of the triangular blade starts sinking in the material. The point C shows the value of the maximum force appearing at the post-cutting stage.

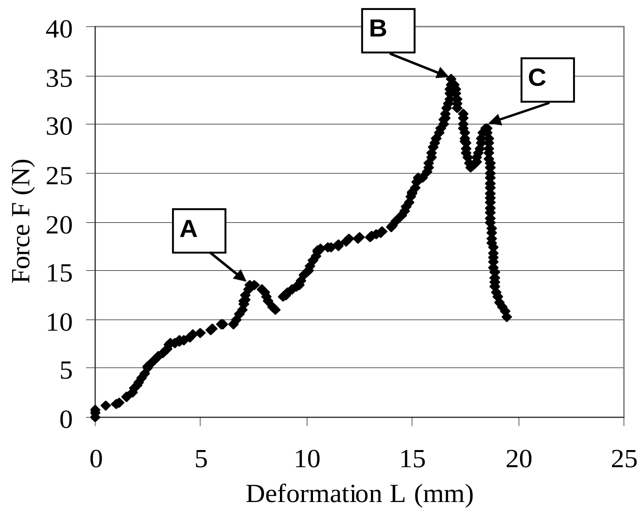

Fig. 1. Example of the course of the carrot cutting process

A hypothesis was formulated that the first stage of the cutting process, related to the stage of material compression by the cutter blade, can be a measure of the deformation degree of the internal structure of plant materials dried using various methods. The area under the curve reflects the value of the total work input into the cutting of the sample. The area under the portion of the curve that ends at point A (Fig. 1) corresponds to the value of work input at the stage of material compression by the cutter blade. The values of both these magnitudes are closely related to the dimensions of the sample, therefore the impact of the drying method on the value of the total work and that of the parameter being the ratio of the work input at the compression stage (Ps) to that of the total work (Pc), hereinafter called compression degree (Ss), was subjected to an analysis.

The impact of the drying method on the resistance to cutting of the carrot, using various preliminary treatments, is depicted in Figures 2-3.

The cutting of dried material requires higher power expenditure than that of hydrated material. Only for the carrot blanched before the freeze-drying and the vacuum-microwave drying no significant differences in the value of the work for cutting dried and hydrated material were found. As a result of the freeze-drying, the resistance to cutting of the dried material is close to that for the raw material. The highest resistance to cutting is characteristic of the osmotically dehydrated carrot before the vacuum-microwave drying and of the dried material from the raw material blanched before the convection drying. Those dried materials have a resistance to cutting circa eight-fold higher than that of the raw material. An almost twice lower resistance to cutting in relation to that of the raw material is characteristic of dried material obtained from carrot blanched before the freeze-drying.

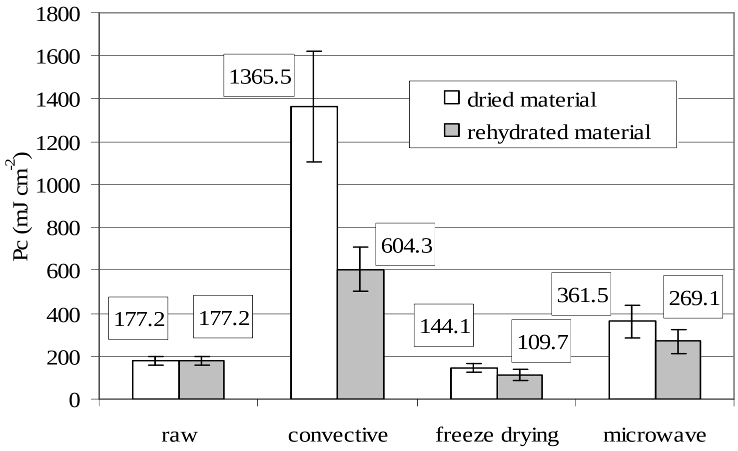

Fig. 2. Values of the total cutting work for carrot blanched before drying

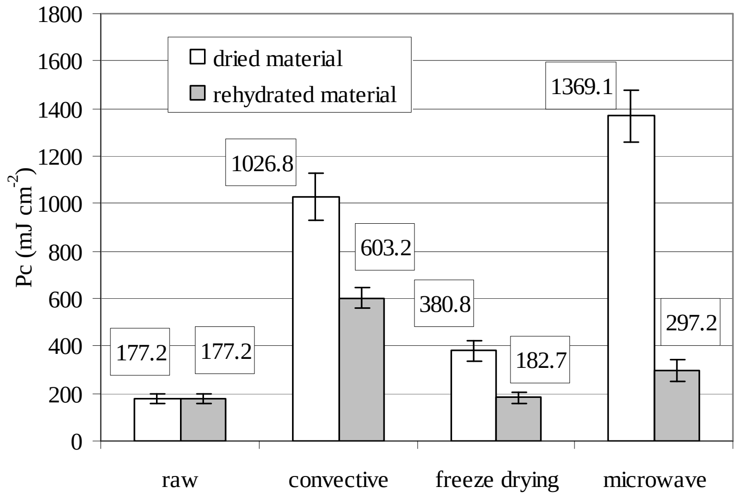

Fig. 3. Values of the total cutting work for carrot dehydrated osmotically before drying

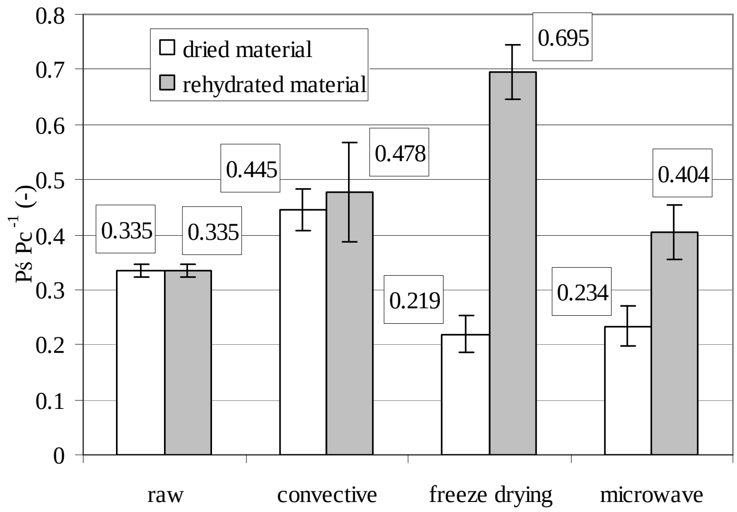

Fig. 4. Values of the compression degree of carrot cut and blanched before drying

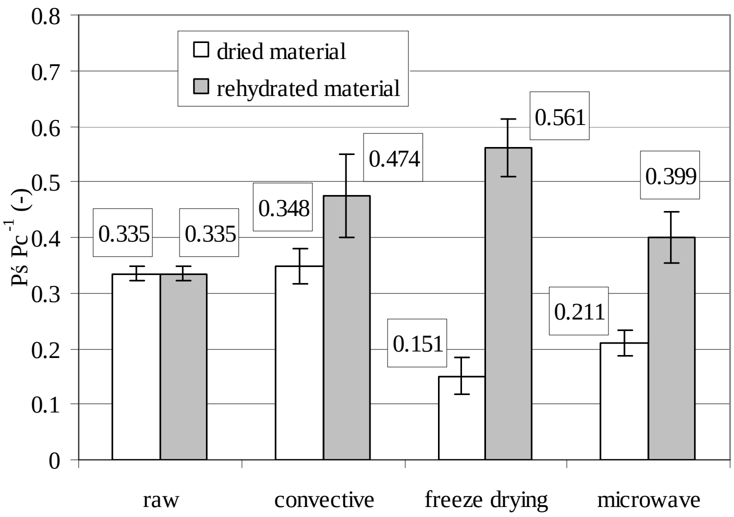

Fig. 5. Values of the compression degree of carrot cut and dehydrated osmotically before drying

Photo 1 presents a microscope image of a raw carrot with visible thick, hydrated walls that form cells of a regular shape. Photos 2 and 4 show examples of microscope photographs of dried materials as obtained with various dehydration methods. The cellular walls of the dried material obtained with the sublimation method (Photo 2) are thin, fuzzy, with visible losses. They create, however, cells of a size and a shape close to the raw material. Such changes produced a significant reduction of the resistance to cutting of the dried material. Microscope photographs presented in Photo 4 show a deformation of the internal structure of the carrot caused by the convection drying. Cellular walls, much changed in relation to the raw material, producing tightly packed groups of cells, are visible. The overcoming by the cutter of such a structure required high power expenditure.

The resistance to cutting of the blanched or osmotically dehydrated carrot before the freeze-drying is close to that of the raw material, and is, at the same time, the lowest one for the drying methods examined. The microscope image shown in Photo 3 illustrates the cause for the reduction in the resistance to cutting of the hydrated material after freeze-drying. The rehydration resulted in multi-spot breaks of cellular walls producing the removal of boundaries between the adjacent cells. The hydration of the dried material as obtained with the two other methods did not produce such essential changes in the cell skeleton, which is shown, as an example, for convective dried carrot in Photo 5.

Figures 4-5 show the values of the compression degree during the cutting process of the carrot for the raw material, the carrot dried with the three methods, and while using various preliminary treatments. Higher values of the compression degree appear when cutting hydrated carrot than when cutting the dried material. The highest values of the compression degree were observed for the hydrated carrot after freeze-drying. This is linked to numerous cracks and losses in cellular walls due to the hydration process. High viscoelastic deformations within the area of cellular walls produce an extension of the first cutting stage. Added to this is the capability of free water flow between adjacent cells without the interference of hydrostatic pressure on the cellular walls. Lack of turgor in cells is an additional factor that reduces the stiffness of the structure being cut. The lowest values of the dried material compression degree also appear for the product obtained with the sublimation method. Dry, thin and very delicate cellular walls are brittle and thus poorly susceptible to deformations. It was found that in the case of the appearance of a high difference between the values of the compression degree during the cutting of dried material and hydrated material essential changes in the structure of the cellular walls constituting the cell skeleton and decisive for the material stiffness should be expected.

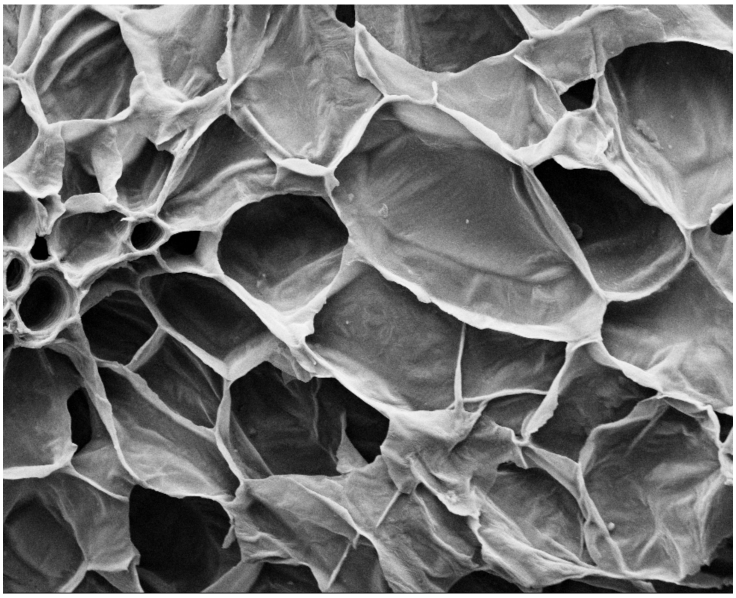

Photo. 1. Photograph of the microstructure of fresh carrot material (magnification 700x)

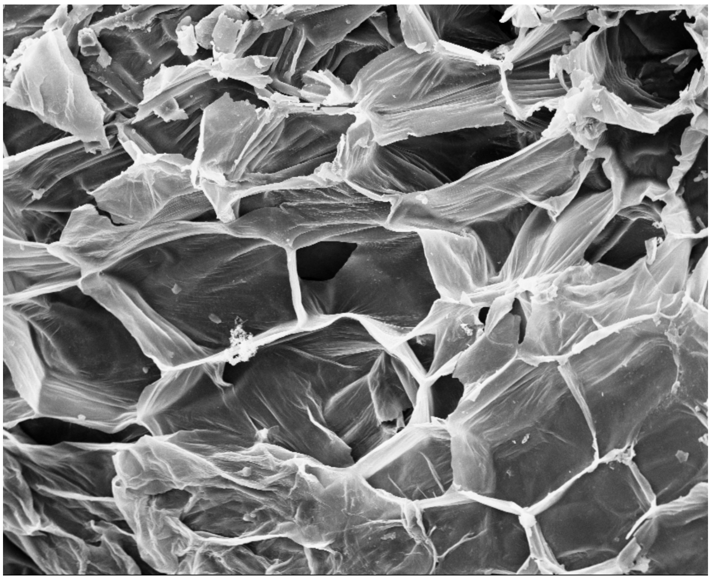

Photo. 2. Photograph of the microstructure of dried carrot material, blanched and sublimation dried (magnification 700x)

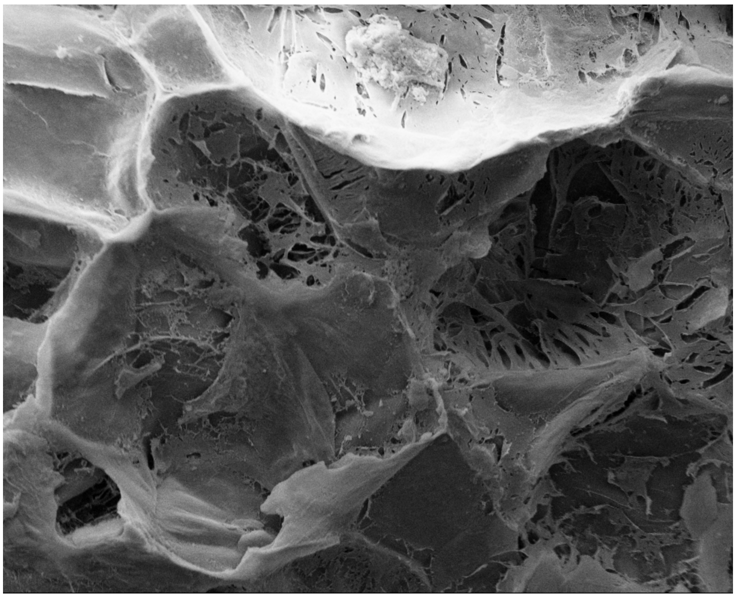

Photo. 3. Photograph of hydrated carrot material, blanched and sublimation dried (magnification 700x)

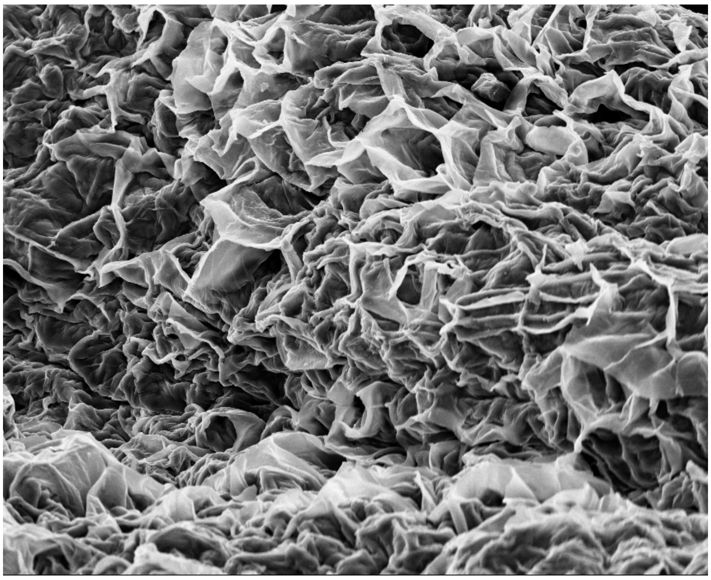

Photo. 4. Photograph of dried carrot material, blanched and sublimation dried (magnification 700x)

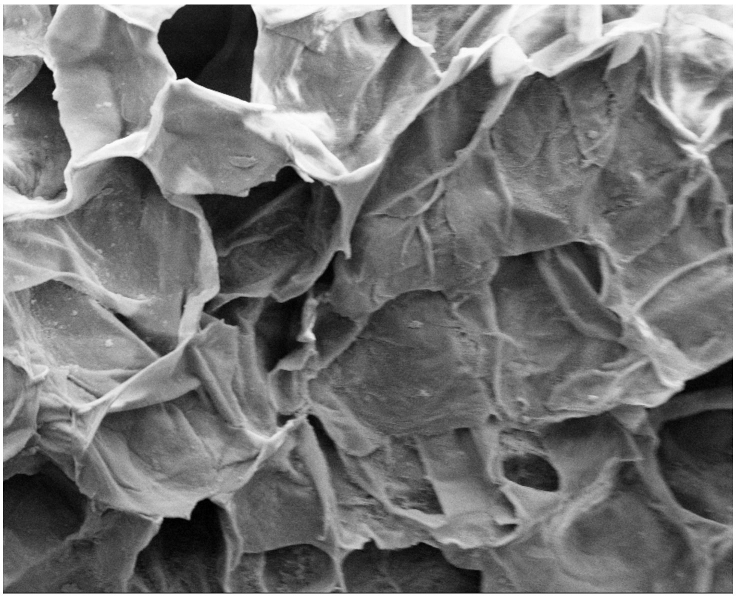

Photo. 5. Photograph of hydrated carrot material, blanched and sublimation dried (magnification 700x)

CONCLUSIONS

1. The compression degree, understood as the ratio of the compression work value during the carrot cutting to the total work value, can be a criterion for the evaluation of damage to the internal structure during the drying process.
2. The freeze-drying allows to obtain a dried material or a hydrated material for which lower values of cutting work appear than for products obtained by convection drying and vacuum-microwave drying.
3. The performance of preliminary treatment before the drying process substantially changes the resistance to cutting of the obtained product.
4. The hydration of dried material obtained with the sublimation method produces a considerably higher number of cell wall cracks of the carrot than it happens with the other drying methods, which essentially reduces the cutting strength and, at the same time, produces a rise in the compression degree value.

REFERENCES

Horubała A., 1975. Food Stuff Storage Principles (in Polish). PWN Warszawa.

Kaleta A., 1999. Preliminary Treatment Methods Used in the Convection Drying Process for Vegetables and Mushrooms (in Polish). Problemy Inżynierii Rolniczej Vol. 3/99, pp. 43-54.

Klimczak J., Irzyniec Z., 1994a. Blanching of Vegetables. Criteria for the Selection of Process Requirements and Running Methods. Part I (in Polish). Przemysł Fermentacyjny i Owocowo-Warzywny, Vol. 9/94, pp. 25-26.

Klimczak J., Irzyniec Z., 1994b: Blanching of Vegetables. Criteria for the Selection of Process Requirements and Running Methods. Part II (in Polish). Przemysł Fermentacyjny i Owocowo-Warzywny, Vol. 11/94, pp. 19-20.

Kramkowski R., 1998. Analysis of Freeze-drying of Selected Food Stuffs (in Polish). Zeszyty Naukowe Akademii Rolniczej we Wrocławiu, Rozprawy CLIII, 333.

Litvin S., Mannheim C.H., Miltz J., 1998. Dehydration of Carrots by a Combination of Freeze Drying, Microwave Heating and Air Vacuum Drying. Journal of Food Engineering 36, pp. 103-111.

Prakash S., Jha S.K., Datta N., 2004. Performance Evaluation of Blanched Carrots Dried by Three Different Driers. Journal of Food Engineering 62, pp. 305-313.

Sanjinez-Avgandona E.J., Hubinger M.D., Menegalli F.C., 2002. Effect of Osmotic Dehydration on Colour and Mechanical Properties of Dried Guavas. IDS 2002, Vol. B, pp. 968-977.

Sowti Khiabani M., Emam-Djomeh Z., Sahari M.A., 2002. Improving the Quality of Sun-dried Peaches by Osmotic Dehydration Pre-treatment. IDS 2002, Vol. B, pp. 952-959.

Szarycz M., 2001. Mathematical Modelling of Microwave-convection Drying of Agricultural Raw Material on the Example of Apples (in Polish). Zeszyty Naukowe Akademii Rolniczej we Wrocławiu, Rozprawy CLXXXIII, 420.

Wang J., Xi Y.S., 2005. Drying Characteristics and Drying Quality of Carrot Using a Two-stage Microwave Process. Journal of Food Engineering 68, pp. 505-511.

Witrowa-Rajchert D., 1999. Rehydration as an Index of Changes Occurring in Plant Tissues During Drying (in Polish). Fundacja "Rozwój SGGW", Warszawa.

WPŁYW METODY SUSZENIA NA PRZEBIEG PROCESU PRZECINANIA MARCHWI

Bogdan Stępień

Instytut Inżynierii Rolniczej, Uniwersytet Przyrodniczy we Wrocławiu
ul. Chełmońskiego 37/41, 51-630 Wrocław
e-mail: stepien@imr.ar.wroc.pl

Streszczenie. Wykonano badania suszenia marchwi przy użyciu trzech metod: konwekcyjnie, sublimacyjnie i mikrofalowo pod obniżonym ciśnieniem. Utrwalono surowiec blanszowany i odwodniony osmotycznie. Testy przecinania wykonano dla surowca, suszu oraz dla materiału uwodnionego. Obliczono wartości pracy całkowitej włożonej w przecinanie marchwi oraz wartości parametru nazwanego stopniem ściskania. Potwierdzono hipotezę o możliwości wykorzystania stopnia ściskania jako kryterium do oceny deformacji struktury wewnętrznej suszonej marchwi. Spośród zaproponowanych metod utrwalania marchwi, suszenie sublimacyjne pozwala uzyskać produkt o najniższej wytrzymałości na przecinanie. Rehydracja suszu uzyskanego metodą sublimacyjną powoduje liczne pęknięcia ścian komórkowych co istotnie obniża wartość pracy przecinania, zwiększając jednocześnie wartość stopnia ściskania.

Słowa kluczowe: blanszowanie, odwadnianie osmotyczne, mikrostruktura