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APPLICATION OF THE STATISTICAL MODEL FOR EVALUATION OF THE INFLUENCE OF DRYING METHODS ON THE MECHANICAL PROPERTIES OF CARROT

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Summary

A main goal of this paper was examination of the influence of three drying methods: convection, freeze-drying and vacuum-microwave on the mechanical properties changes of dried vegetables occurring during storage. In testing two kinds of pretreatment: blanching and osmotically dehydration were used. The tests of strength were performed for raw material, dried material and rehydrated material. The value of the total work inputted into the cutting of carrot and the value of the compression work was computed. Stress compression tests and cutting tests were curried out for samples just after drying and for samples stored 6, 12 and 18 months. For data obtained from these experiments ANOVA methods for complete multifactor designs was applied. In order to performing a proper statistical inference of the data analysis requested using the transformation for stabilization group variances.

Key words and phrases: ANOVA, factor design, stabilization of variances, test of multiple comparisons

Subject classification AMS: 62F03, 62F10, 62J02

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1. Introduction

The seasonal nature of occurrence of some plants enforces the application of interventions allowing to store the food stuff over a longer period of time. The oldest methods of fixing the food stuff 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 (see Horubała 1975). The knowledge allowing to optimize the drying process in the aspect of energy consumption and product quality is still discovered. Advanced study and laboratory research is conducted, related to the drying conditions and the methods of storing the raw material for the fixing process (Kramkowski, 1998; Wang and Xi, 2005).

The blanching time and temperature as well as the blanching agent type have the largest 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 the short time of running the process (see Kaleta, 1999; Klimczak et al. 1994a, 1994b).

The osmotic dehydration is a treatment frequently used before the drying in order to improve dried material quality. The influence of the osmotic dehydration of vegetables on the reconstitution properties of dried materials was broadly investigated (Witrowa-Rajchert, 1999).

The convection drying is a method to fix the food stuff on an industrial scale. Simultaneously, the method is considered to be the most destructive one. There exist many modern drying methods allowing to get a product of a properly high quality, their disadvantage being, however, a 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 (see Szarycz, 2001). A series of reference reports describe the influence of microwaves on the drying kinetics and the product quality. Wang and Xi (2005) found that with the 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.

While evaluating the product quality, the knowledge of the influence of individual drying methods on features constituting an evaluation criterion is essential. Prakash and others (2004) investigated the influence 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 a raw material dried in a spouted bed showed a better preservation capability of the colour, better rehydration properties and a more advantageous retention of β-carotene than a product obtained while using the two other methods.

The aim of the paper was an analysis of the cutting process as well as of the compression work of the dried material and that of the rehydrated material of carrot to be dried by convection, freeze-drying and vacuum-microwave, using blanching and osmotic dehydration as pretreatments. To determinate the influence of the drying methods on mechanical properties of examined samples of carrot was applied a statistical model for factor designs.

2. Material and methods

A popular root plant carrot of the *Cesaro* variety was subjected to the testing of resistance to cutting and compression. Samples were prepared in form of 5 mm high cylinders of a 20 mm diameter. The raw material blanched and osmotically dehydrated was dried. The blanching operation was performed in water of a 95°C $\pm$ 2°C temperature for 3 minutes. A 5% solution of NaCl of a 20°C temperature was used for the osmotic dehydration. The dehydration duration was 24 hours. The convection drying was performed on a laboratory drier at the cooling agent temperature amounting to 50°C and the air flow velocity equal to 1.5 m/s. 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 a 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 a range of 4-10 kPa. The rehydration was made in distilled water of a 20°C temperature. The rehydration time was chosen empirically in order to obtain moisture contents close to those of the raw material. Stress compression tests and cutting tests were performed on a machine type Instron 5566.

The values of the cutting work and the values of the compression work were calculated using the trapezium method. The values of both kinds of work were calculated for samples just after drying and for samples stored 6, 12 and 18 months in 5 to10 replications.

To clarify the reasons for the occurrence of differences in the resistance to compression and cutting of the vegetable dried using various methods, microscopic 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.

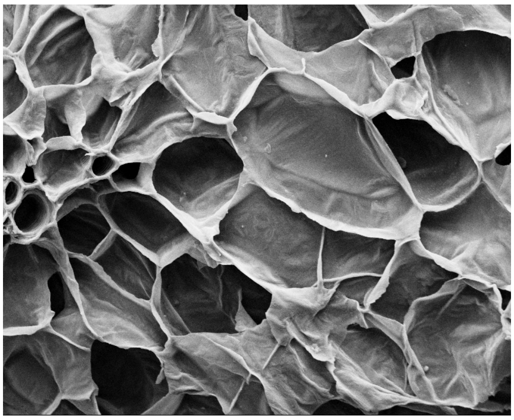
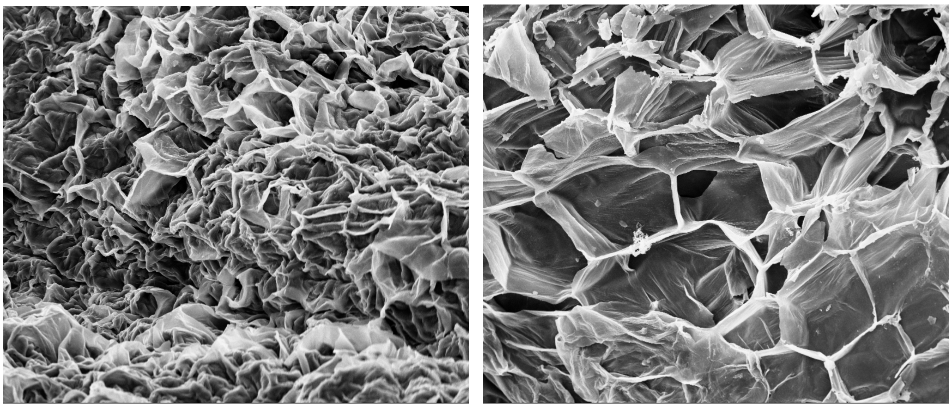


Fig. 1. Photograph of the microstructure of a fresh carrot (magnification 700x)



a b

Fig. 2. Photographs of the microstructure of the carrot dried material, sublimation drying (a) and convection drying (b), blanched material (magnification 700x)

Figure 1 presents a microscopic picture of a raw carrot with visible thick, hydrated walls that form cells of a regular shape. For example Figure 2 (a, b) shows microscopic photographs of dried materials as obtained with various dehydration methods. The cellular walls of the dried material obtained with the sublimation method (Fig. 2a) 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. Microscopic photographs as presented in Figure 2b 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 supply expenditures.

The rehydration of the dried material obtained with the sublimation method produces numerous cracks of cell walls, which essentially reduces the cutting work value. The microscopic picture as given in Figure 3 shows the cause for the reduction in the resistance to cutting of the hydrated material after the freeze-drying. The rehydration resulted in multispot breaks of cellular walls producing the removal of boundaries between the adjacent cells.

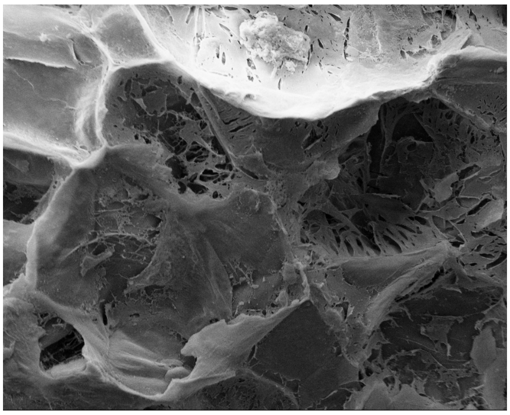


Fig. 3. Photograph of the microstructure of the hydrated carrot dried, sublimation drying, blanched material (magnification 700x)

More details connected with changes of microstructure of dried materials using different drying methods and hydrated materials and theirs influence on the mechanical properties changes can be found in the paper of Stępień (2007).

3. Anova model for full three-factor design

A main aim of researches and of statistical analyses for obtained experimental data was the evaluation of the influence of drying method, type of pretreatment and storage time on the mechanical properties of carrot. This experiment was performed accordance with a full three-factor design, in which drying method as factor A arises at three levels: convection (SK), freeze-drying (SS) and vacuum-microwave (SMP), type of pretreatment as factor B appears at three levels too: lack of pretreatment (BO) as control level, blanching (BL) and osmotically dehydration (OS), and third factor C represents different periods of storage time: first level - beginning of storage process (0 months), and next, 6 months, 12 months and 18 months. The values of mechanical traits of dried vegetables were determined by the values of the total work inputted into the cutting (Pp) of samples of vegetables (carrot, parsley, celery) and the values of the compression work (Pc). For each of elementary combination of levels of factors A, B and C (36 different quality groups) were performed tests of strength Pp and Pc in 10 replications (for rehydrated material and raw material as a control group) and in 5 replications for dried material.

We want to verify the hypotheses H_i for ANOVA model for effects of different drying methods, types of pretreatment and for effects of storage time, corresponding to factors A, B, and C, respectively (in a formal form given by 3.5). Moreover, we verify the hypotheses connected with the first and the second order interactions, i.e. AB, AC, BC and ABC between examined factors, corresponding to the hypotheses $H_4 - H_7$ (see 3.5) .

To conduct the statistical inference properly we apply method of variance analysis for full three-factor design with all interactions. Assuming that effects of factors: drying method (α_i), type of pretreatment (β_j) and storage time (γ_k) of vegetables are fixed and theirs influence together with interactions (first and second order) on the mean value of dependent variable Y (compression strength Pc and strength of cutting Pp) are additive we have a following model:

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} + \varepsilon_{ijkl} \qquad (3.1)$$

where

Y_{ijkl} are observations of dependent (response) variable Y ,

μ is a main effect of response variable Y ,

α_i represents effect of *i*-th level of factor A - drying method (SK, SS, SMP), i=1,2,3,

β_j represents effect of *j*-th level of factor B - type of pretreatment (BO, BL, OS), j=1,2,3,

γ_k represents effect of *k*-th level of factor C - storage time (0 months, 6 months, 12 months and 18 months), k=1, 2, 3, 4,

$(\alpha\beta)_{ij}$, $(\alpha\gamma)_{ik}$, $(\beta\gamma)_{jk}$ signify effects of the first order interactions AB, AC and BC, respectively,

$(\alpha\beta\gamma)_{ijk}$ signify effects of second order interactions ABC (i.e. for 36 different factor groups),

ε_{ijkl} determines a random effect of uncorrelated measurement errors and other uncontrolling factors which can disturb the values of response variable. We may assume that random errors are normally distributed with an expectation 0 and unknown common variance σ^2.

In a matrix notation the model (3.1) has a following form

$$\boldsymbol{Y}_n = \mathbf{1}_n\mu + (\boldsymbol{I}_a \otimes \mathbf{1}_{bcr})\alpha + (\mathbf{1}_a \otimes \boldsymbol{I}_b \otimes \mathbf{1}_{cr})\beta + (\mathbf{1}_{ab} \otimes \boldsymbol{I}_c \otimes \mathbf{1}_r)\gamma + (\boldsymbol{I}_{ab} \otimes \mathbf{1}_{cr})(\alpha\beta) + (\boldsymbol{I}_{ac} \otimes \mathbf{1}_{br})(\alpha\gamma) + (\mathbf{1}_a \otimes \boldsymbol{I}_{bc} \otimes \mathbf{1}_r)(\beta\gamma) + (\boldsymbol{I}_a \otimes \boldsymbol{I}_b \otimes \boldsymbol{I}_c \otimes \mathbf{1}_r)(\alpha\beta\gamma) + \boldsymbol{I}_n\varepsilon \quad (3.2)$$

where $\mathbf{1}_s$ is the s-dimensional vector of ones, $\boldsymbol{I}_t$ – identity matrix of size t and a symbol "⊗" stands for Kronecker product of matrices. According to the lexicographical order of factors A, B , C (i.e. $A_iB_jC_k$, i=1,…,a; j=1,…,b; k=1,…,c) the model (3.1) can be presented as

$$\boldsymbol{Y}_n = \boldsymbol{X}\tau + \boldsymbol{I}_n\varepsilon \,,$$

where a design matrix $\boldsymbol{X}$ has a following form

$$\boldsymbol{X} = \mathbf{1}_r \otimes \left[\mathbf{1}_{abc} \vdots \boldsymbol{I}_a \otimes \mathbf{1}_{bc} \vdots \mathbf{1}_a \otimes \boldsymbol{I}_b \otimes \mathbf{1}_c \vdots \mathbf{1}_{ab} \otimes \boldsymbol{I}_c \vdots \boldsymbol{I}_{ab} \otimes \mathbf{1}_c \vdots \boldsymbol{I}_a \otimes \mathbf{1}_b \otimes \boldsymbol{I}_c \vdots \mathbf{1}_a \otimes \boldsymbol{I}_{bc} \vdots \boldsymbol{I}_{abc}\right] \quad (3.3)$$

and fixed effects vector τ is defined as

$$\tau = \left[\mu, \alpha_1,...\alpha_a, \beta_1,...,\beta_b, \gamma_1,...,\gamma_c, (\alpha\beta)_{11},...,(\alpha\beta)_{ab}, (\alpha\gamma)_{11},...,(\alpha\gamma)_{ac}, (\beta\gamma)_{11},...,(\beta\gamma)_{bc}, (\alpha\beta\gamma)_{111},..., ,...,(\alpha\beta\gamma)_{abc}\right],$$

where vector $\mathbf{1}_r$ corresponds to r replications of three-factor design in the experiment.

Under above assumptions the analyzed traits are independent random variables on normal distributions with unknown expected values μ_{ijk} for each (ijk)-th groups as follows

$$\mu_{ijk} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_{ij} + (\alpha\gamma)_{ik} + (\beta\gamma)_{jk} + (\alpha\beta\gamma)_{ijk} \qquad (3.4)$$

$$(i=1,\ 2,\ 3;\ j=1,2,3;\ k=1,2,3,4)$$

and with unknown but the same variance σ^2. The statistical problem amounts to testing the following hypotheses H_i :

$$\begin{aligned}
&H_1 : \alpha_1 = \alpha_2 = \alpha_3 = 0;\ \ H_2 : \beta_1 = \beta_2 = \beta_3 = 0;\ \ H_3 : \gamma_1 = \gamma_2 = \gamma_3 = \gamma_4 = 0 \\
&H_4 : (\alpha\beta)_{11} = (\alpha\beta)_{12} = \ ...\ = (\alpha\beta)_{33} = 0 \\
&H_5 : (\alpha\gamma)_{11} = (\alpha\gamma)_{12} = \ ...\ = (\alpha\gamma)_{34} = 0 \\
&H_6 : (\beta\gamma)_{11} = (\beta\gamma)_{12} = \ ...\ = (\beta\gamma)_{34} = 0 \\
&H_7 : (\alpha\beta\gamma)_{111} = (\alpha\beta\gamma)_{112} = \ ...\ = (\alpha\beta\gamma)_{334} = 0\ .
\end{aligned} \qquad (3.5)$$

Each of the hypotheses H_i (i=1,2,…7) can be verified under the established assumptions of the model, using adequate test statistics, which under true hypotheses H_i , ones have the Snedecor's F- distribution with appropriate degrees of freedom (e.g. Rao 1982).

To obtain a correct and reliable results of statistical analyses the assumptions about the model (3.2) have to be verified by using a test for the normality of model residuals and by using a test of variance homogeneity (see Scheffé, 1959).

4. Statistical analysis of experimental data

In this section, by reason of extensive empirical material, we present only chosen results of statistical data analysis for rehydrated material of carrot (as example of source data in Tab. 1, the results in Figures 5 and 7) and for dried material of carrot (the results in Figures 6 and 8).

Table 1. The values of the total work inputted into the cutting of rehydrated carrot in [mJ/g] by using 3 drying methods and 3 types of pretreatment (BO – lack of pretreatment, BL – blanching, OS – osmotically dehydration

Storage time in months	**convection**			**freeze-drying**			**vacuum-microwave**		
	BO	**BL**	**OS**	**BO**	**BL**	**OS**	**BO**	**BL**	**OS**
0	208.0	415.4	540.0	212.3	133.4	206.9	361.7	295.1	380.6
	214.0	456.7	534.8	207.7	130.0	166.4	391.0	306.5	379.8
	208.4	417.8	548.7	216.9	148.5	170.1	400.3	256.7	345.2
	211.1	450.6	491.8	222.6	154.8	209.9	370.8	302.7	375.8
	187.1	448.0	506.4	196.1	159.4	179.1	374.6	270.3	393.7
	185.8	435.1	485.1	202.9	162.1	162.1	401.6	262.2	332.9
	190.7	442.9	489.6	217.5	137.8	185.4	372.8	259.5	338.7
	212.1	438.1	492.1	198.6	153.7	203.6	367.7	271.2	358.6
	193.2	429.8	502.1	209.5	147.2	185.4	384.6	267.3	361.5
	207.0	437.6	493.1	211.5	138.4	189.1	376.8	276.8	371.1
6	181.9	336.8	396.5	159.4	143.9	233.9	321.7	439.8	356.7
	171.4	342.5	389.5	198.6	177.7	265.6	279.0	389.3	388.1
	214.3	344.4	386.3	175.1	149.8	234.1	307.4	385.8	372.5
	182.0	349.0	405.3	193.1	147.0	264.4	311.2	402.2	343.6
	207.0	338.5	396.8	179.1	180.7	233.8	306.0	419.9	374.1
	194.5	375.7	392.2	194.8	158.3	243.4	313.9	398.3	352.4
	209.2	395.4	367.8	172.2	149.2	238.2	292.2	412.3	364.1
	188.8	365.3	411.3	164.9	157.7	241.8	291.4	407.6	371.1
	196.6	389.5	394.2	159.4	147.5	251.3	300.1	395.1	368.9
	211.3	391.2	385.3	151.7	150.9	256.2	289.2	397.4	375.9
12	268.2	461.6	425.6	173.1	173.6	221.2	278.6	288.4	265.2
	232.6	485.4	389.2	217.5	186.4	184.6	335.9	258.5	285.9
	224.9	508.9	416.5	184.3	177.9	217.2	305.4	270.9	244.6
	258.3	465.9	420.0	206.9	201.9	215.1	343.5	285.1	275.1
	221.2	516.6	383.2	194.5	219.9	202.5	279.9	277.8	289.3
	249.9	451.8	397.4	186.3	179.8	189.5	280.9	269.0	236.9
	258.9	464.3	454.7	219.5	218.7	178.3	311.2	257.2	249.6
	262.4	504.3	418.7	185.1	197.8	209.7	298.7	290.9	290.3
	236.1	476.1	448.2	191.2	207.0	208.0	309.2	278.4	278.1
	249.1	465.1	395.0	198.1	185.7	195.4	311.6	291.5	281.3
18	251.7	510.8	462.2	197.0	128.3	246.9	316.4	253.5	408.4
	227.4	462.8	503.2	208.4	156.0	235.8	324.0	204.7	349.7
	284.7	500.5	487.8	187.1	135.9	208.2	337.4	259.8	385.3
	281.2	461.7	519.5	216.3	141.1	235.3	328.4	213.4	353.6
	272.3	456.5	458.7	193.2	156.4	229.9	308.9	232.0	407.2
	266.1	460.5	467.5	180.3	146.6	191.4	294.8	207.7	378.3
	270.6	463.0	509.3	221.5	148.1	210.9	309.4	224.6	397.9
	277.2	510.3	515.9	187.7	144.6	222.9	318.4	243.5	373.2
	305.9	459.7	476.2	196.8	140.7	206.0	311.9	239.7	385.2
	275.9	495.1	487.6	209.8	152.1	223.6	299.7	239.8	376.4

Because of a large discrepancy between variances in groups (see Figure 4) it was necessary to use the transformation for stabilization group variances according to the following theorem:

Theorem (Curtiss, 1943)**.** If φ expresses a relation between means μ_i and variances σ_i^2 for the variable Y in distinguished groups, then a transformation of Y which stabilizes the variances in the groups is given by the following formula

$$Z = \int \frac{c}{\sqrt{\varphi(y)}} dy \quad , \tag{4.1}$$

where a constant c is an approximated variance of a new variable Z.

Corollary. For the relationship φ between expectation values μ and standard deviations σ as $\log(\sigma) = a\log(\mu) + b$, we obtain $\sigma^2 = \varphi(\mu) = e^{2b}\mu^{2a}$ and after integration $Z = c\,e^{-b} / (1-a)\mu^{1-a}$, i.e. finally, the transformation as: $Y \to Y^{1-a}$ (see e.g. Bickel and Doksum, 1977).

To verify a hypothesis $H_\sigma : \sigma_1^2 = ... = \sigma_{36}^2$ for above experimental data Levene's test (Levene 1960) was applied (see Table 2).

Table 2. The values of Levene's test (F statistic) for data set of rehydrated carrot with p-value, where Pp* (strength of cutting) corresponds to the variable after transformation

variable	SS effect	df effect	MS effect	SS error	df error	MS error	F	p
Pp	5056.79	35	144.48	25025.06	324	77.24	1.87	0.00282
Pp*	15.93	35	0.455	121.85	324	0.376	1.21	0.19973

The results in Table 2 (p=0.19973) and Figure 4 (lack of statistical dependence between the averages and the standard deviations in factors groups – right panel) prove effectiveness and validity of used transformation. An additional effect of using power transformation which stabilized the group variances in considered ANOVA models was a normalization of residuals from model (p-values for Kolmogorov-Lilliefors' test and for Shapiro-Wilk's test were close value 0.11). From results of analysis of variance for complete factor designs implies that we reject all hypotheses H_i given by (3.5) at significance level $p < 10^{-6}$. Most interesting and most reach for experimenter is alternative hypothesis to hypothesis H_7, which states that effects of interaction for all factors A, B, C are statistically significant as shown in Figure 5.

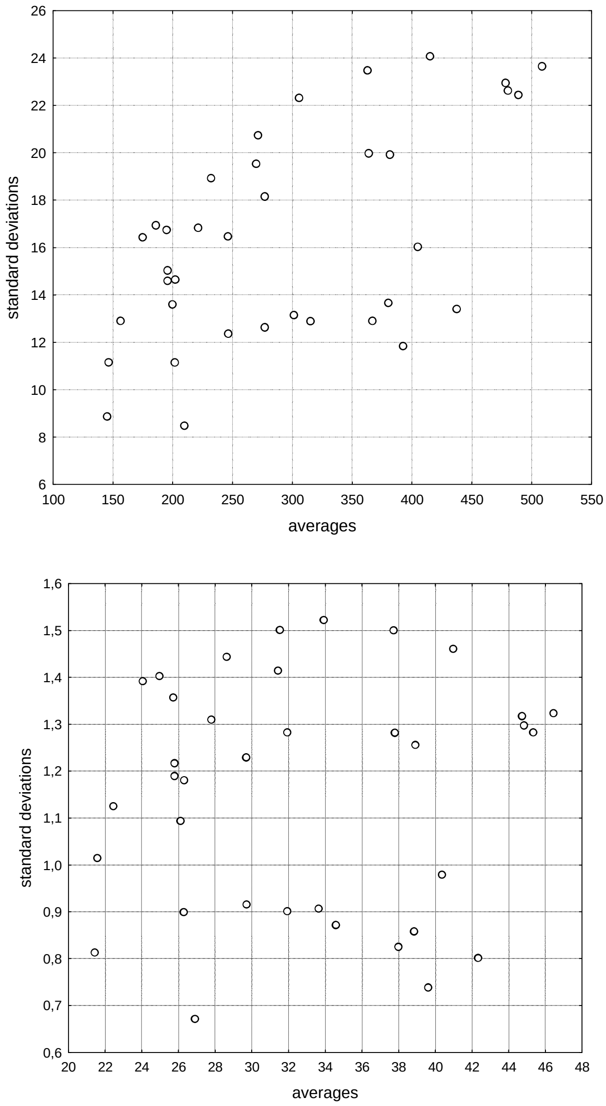


Fig. 4. Graphs of the dependence between the averages and the standard deviations in factor groups for original data (variable Pp, left panel) and after transformation $Pp^*=Pp^{1-a}$ (a = 0.384, right panel)

Table 3. Results of the HSD Tukey's test . The homogonous groups are distinguished in the columns 1-16 as shaded areas (limit difference = 2.41 at the sig. level =0.05) according to increasing mean effects of response variable Pp*, where factor A means drying methods, B - type of pretreatment and C - storage time for rehydrated carrot

No.	A	B	C	Pp* mean effect	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
20	SS	BL	18	21.44	****															
17	SS	BL	0	21.57	****															
18	SS	BL	6	22.45	****	****														
14	SS	BO	6	24.05		****	****													
21	SS	OS	0	24.97			****	****												
19	SS	BL	12	25.71			****	****												
15	SS	BO	12	25.78			****	****	****											
2	SK	BO	6	25.78			****	****	****											
16	SS	BO	18	26.12				****	****											
1	SK	BO	0	26.28				****	****											
23	SS	OS	12	26.31				****	****											
13	SS	BO	0	26.91				****	****	****										
24	SS	OS	18	27.80					****	****	****									
32	SMP	BL	18	28.62						****	****									
3	SK	BO	12	29.70							****	****								
22	SS	OS	6	29.72							****	****								
35	SMP	OS	12	31.41								****	****							

cd. tabeli 3

4	SK	BO	18	31.53								****	****							
29	SMP	BL	0	31.93									****	****						
31	SMP	BL	12	31.93									****	****						
26	SMP	BO	6	33.64										****	****					
27	SMP	BO	12	33.92										****	****					
28	SMP	BO	18	34.58											****					
6	SK	BL	6	37.72												****				
33	SMP	OS	0	37.79												****				
34	SMP	OS	6	37.98												****				
25	SMP	BO	0	38.83												****	****			
36	SMP	OS	18	38.91												****	****			
10	SK	OS	6	39.61												****	****	****		
30	SMP	BL	6	40.36													****	****	****	
11	SK	OS	12	40.97														****	****	
5	SK	BL	0	42.33															****	
8	SK	BL	18	44.72																****
7	SK	BL	12	44.83																****
12	SK	OS	18	45.33																****
9	SK	OS	0	46.44																****

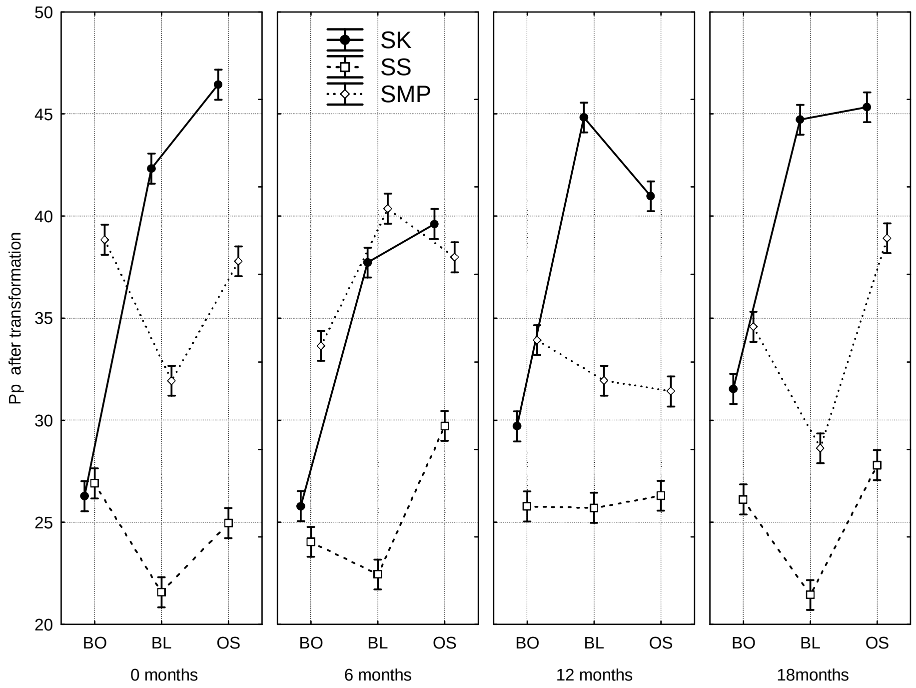


Fig. 5. 95% - confidence intervals for mean effects $(\alpha\beta\gamma)_{ijk}$ in factor groups for variable $Pp^{*}=Pp^{1-a}$ (a=0.384) for rehydrated material of carrot

For more detailed differences among 36 factor groups we use Tukey's table of homogonous groups. The Tukey's test of multiple comparisons (HSD test as measure of studentised range) makes possible to separate groups of similar effects, so called, homogonous groups at fixed significance level, as shown in Table 3.

Because of a large amount of empirical and statistical results we present only some selected ones for rehydrated and dried material for carrot (for example) connected with second order interactions for variables Pp and Pc which characterize the mechanical properties of dried vegetables (Figures 6-8).

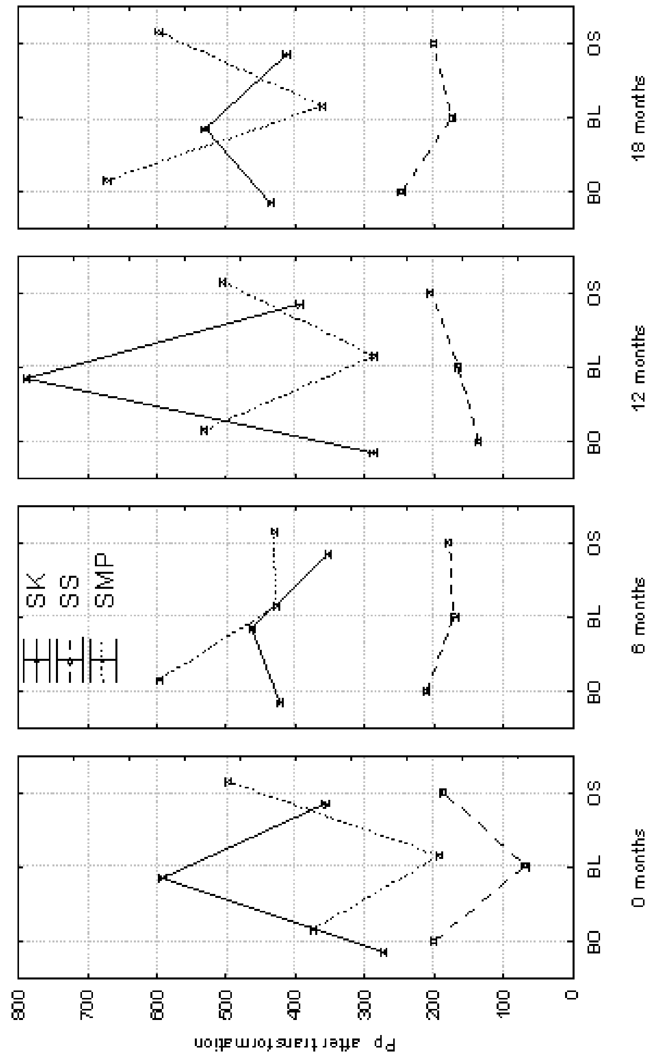


Fig. 6. 95% - confidence intervals for mean effects $(\alpha\beta\gamma)_{ijk}$ in factor groups for variable $Pp^{*}=Pp^{1-a}$ (a=0.1332) for dried material of carrot

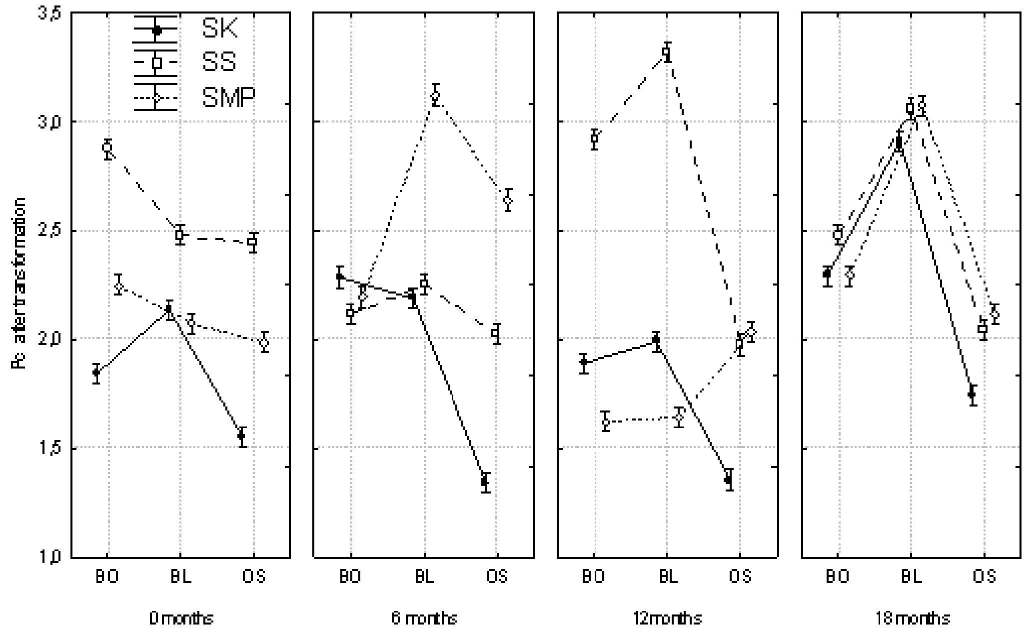


Fig. 7. 95% - confidence intervals for mean effects $(\alpha\beta\gamma)_{ijk}$ in factor groups for variable $Pc^*=Pc^{1-a}$ (a=0.6477) for rehydrated material of carrot

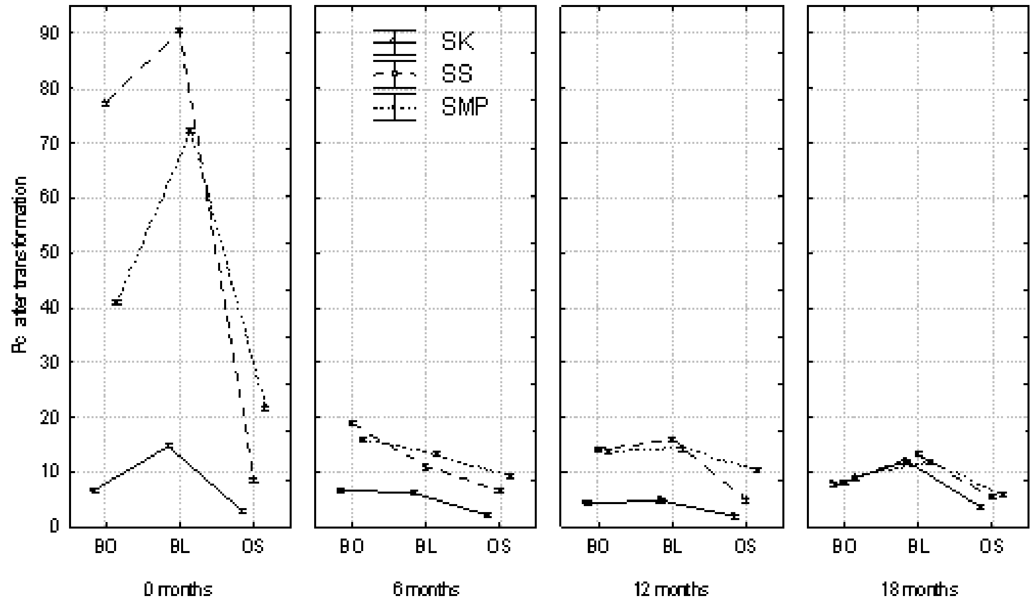


Fig. 8. 95% - confidence intervals for mean effects $(\alpha\beta\gamma)_{ijk}$ in factor groups for variable $Pc^{*}=Pc^{1-a}$ (a=0.1842) for dried material of carrot

5. Conclusions

1. The performance of preliminary treatment before the drying process substantially changes the resistance to cutting of obtained product and its compression.
2. The hydration of the dried material obtained with the freeze-drying method (SS) products a considerably higher number of cell wall cracks of the carrot than it happens with other drying methods, which essentially reduces the strength to cutting and, at the same time, produces a rise of values of the compression work (e.g. compare suitable broken lines in Figure 5 and in Figure 7 - excluding the cases for 12 months (line SS lies between lines SK and SMP) and for 18 months, where differences are not significant and lines very similar).
3. The convection (SK) drying does not affect essentially the mechanical properties of different materials of carrot, excluding the case of the blanching (BL) for a storage time of 12 months and at lower level for 0 months (see Fig. 6) and the case of all types of pretreatment (broken line BO-BL-OS) for 18 months for the compression Pc* in comparison with drying methods SS and SMP (see Figure 7).
4. For rehydrated material, the vacuum-microwave drying (SMP) produces considerably higher values of the strength of cutting Pp* than for method SS always and lower values than for drying method SK (excluding case for 6 months, and case 0 months for BO); after 18 months storage we have similar situation as at beginning of process (see Figure 5). We have dissimilar situation for effects Pc* with respect to a storage time and type of pretreatment: increase of values Pc* for 6 months, decrease for 12 months and again increase for 18 months, jointly with character of changes of method SMP (see Figure 7). However for dried material the storage time essentially decreases a resistance to compression for drying methods SS and SMP (Figure 8.)
5. The blanching of carrot before the drying process substantially raises whereas the osmotic dehydration reduces the elasticity and viscosity of a product obtained with the vacuum-microwave method.

Note. The package STATISTICA 8.0 and own procedures were used for numerical calculations.

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ZASTOSOWANIE MODELU STATYSTYCZNEGO DLA UKŁADÓW CZYNNIKOWYCH DO OCENY WPŁYWU METOD SUSZENIA NA ZMIANY CECH MECHANICZNYCH MARCHWI

Streszczenie

Głównym celem pracy było zbadanie wpływu trzech metod suszenia: konwekcyjnego sublimacyjnego i mikrofalowo-próżniowgo na zmiany cech mechanicznych marchwi, zachodzących w trakcie przechowywania suszu. W badaniach zastosowano dwa rodzaje obróbki wstępnej materiałów: blanszowanie i odwodnienie osmotyczne. Testy wytrzymałościowe wykonano dla surowca, suszu oraz dla materiału uwodnionego. Obliczono wartości pracy całkowitej włożonej w przecinanie marchwi oraz wartości pracy ściskania. Testy przecinania i ściskania zostały wykonane dla próbek materiału bezpośrednio po suszeniu i dla próbek przechowywanych, odpowiednio 6, 12 i 18 miesięcy. Dla danych uzyskanych z tych eksperymentów zastosowano metody analizy wariancji dla układów wieloczynnikowych. Dla przeprowadzenia poprawnego wnioskowania statystycznego koniecznym było użycie w analizie danych przekształceń stabilizujących wariancje grupowe.

Słowa kluczowe: ANOVA, układ czynnikowy, stabilizacja wariancji, test porównań wielokrotnych

Klasyfikacja AMS: 62F03, 62F10, 62J02