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EFFECT OF PERFORATING MAIZE SHELL ON CONVECTIVE DRYING SPEED

DJELOVANJE PERFORACIJE KUKURUZNE LJUSKE NA KONVEKTIVNU BRZINU SUŠENJA

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ABSTRACT

The research was carried out during three years under laboratory conditions. The procedure of drying was performed on a laboratory – scale dryer. The perforation of maize shell was carried out by means of a "hedgehog" – a laboratory-scale device. Both perforated and unperforated maize kernels were dried under the same conditions at the temperatures of 130, 110 and 90ºC, and air velocity from 1,75m/s to 2,2m/s. All the values obtained were statistically analyzed and compared by using polynomial and exponential equations. When the process of drying of both perforated and unperforated maize kernels was completed, basic nutritive values and dynamic properties were analysed, particularly the level of breakage.

It was observed that the perforation procedure had the highest effect during drying at the temperature of 110 ºC, regardless of the depth of the hole.

Perforations had no effect on raw protein, raw fibre, raw ash and raw fat content, which proves that such a procedure does not reduce maize nutritive value, and caused some additional reduction in kernel resistance.

Key words: drying, perforation, maize kernel, breakage, nutritive value

INTRODUCTION

It is well known that during harvest time, the moisture of maize kernel is higher than the equilibrium at which it can be kept. Thus drying comes as a final stage of kernel maturation which could not be completed naturally. To enable the longest possible storage duration of kernel, the drying process should be included in kernel preservation, ensuring an appropriate conditions. The objective of drying is to take away excess water from the kernel until it reaches its equilibrium value.

In the overall production of field crops in Croatia, corn and wheat are the most common ones.

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According to the data provided by *Pucarić et al.* (*1993*), on all the arable land in Croatia maize is grown on 76.3% of sown fields for the production of dry kernel, 17.3% for the production of wet kernel suitable for silage, and 6.4% for the production of the whole plant. In terms of costs, the process of drying is 30% more expensive than the entire agricultural engineering during maize production.

Both the velocity and quality of kernel drying depend on the procedure of drying. Increased air temperatures reduce the level of moisture in the kernel, thus the increased difference in partial pressures between the kernel and the air improve drying (*Krička, 1993; Krička and Pliestić 1995; Katić, 1997*). Drying efficiency depends on the air with its heating intensity, velocity of movement and relative humidity, as well as on the structure of the dryer. The evaporation of excess water up to the hygroscopic equilibrium (14% for maize) varies in different hybrids. Maize shell puts up the biggest resistance to water movement (*Dubravec, 1997*). Following *Purdy and Crane*, *Katić* (*1985*) came to the conclusion that the speed of drying is highly negatively correlated ($r = -0.83$) with the thickness of the shell. *Vlahović* (*1987*) reached the conclusion that, owing to the structure of the shell, as much as 90% of water must travel all the way along the kernel length to reach the embryo in which it evaporates.

Since increased kernel heating during drying enables higher drying capacity with the same amount of air, efforts are made every day to achieve higher temperatures of drying air. Too much heating reduces kernel quality because it becomes brittle and breaks at a slightly increased burdening. In addition to this, kernel is dynamically burdened with long transportation to finishing and storage centres, inappropriate application and choice of means of transport, and some technological problems as well. Thus it is rendered more susceptible to breakage (*Page, 1949; Martins, 1988*).

With regard to all the information mentioned above, new machines have appeared on the European market (Austria, Hungary) that can mechanically, by means of tiny needles, perforate the kernel's surface and thus simplify and accelerate its drying.

MATERIALS AND METHODS

Problems and objectives of the study

Nowadays, the kernel is most often preserved by means of drying, silage, chemical treatment and cooling, drying being the most common of all. Artificially dried maize can be afterwards used for all kinds of purposes, whereas the maize exposed to silage or chemical treatment can only be used to feed certain kinds of animals.

In addition, the kernel which has been exposed to drying has a market value at any later stage of storage and can endure a longer period of transportation. Therefore the suitable technical solutions related to this particular technology of conservation have been widely applied.

The existing dryers are of different types and shapes and in most of them convective drying is applied in the course of which the heated air is conducted through the kernel layer whose depth is 15 – 30 cm (*Krička and Pliestić, 1995*).

It is essential to point out that dryers are big energy consumers and that a great deal of scientific effort made in this field is being aimed at reducing the energy needed for drying.

It is well known that the process of drying capillary – porous plants such as maize kernel is a complex process of heat and mass exchange between the kernel and the air (*Li and Morey, 1984*).

A general analytical expression that would describe this phenomenon has not yet been formulated since great difficulties are encountered if one tries to solve partial non-linear differential equations of the second order that express the relations between the moisture and the temperature in the material.

The biggest amount of water evaporates from the kernel through the surface surrounding the embryo, as well as at the point of direct contact of the kernel with the maize cob. It has also been observed that damaged kernels dry faster than the whole ones (*Vlahović et al., 1986*). In other words, it is impossible to define unambiguously the initial and borderline conditions, the geometrical shape and the physical properties of the kernel (*Mohsenin, 1970*).

The European market has seen the emergence of the machines that mechanically, by using tiny needles, perforate the surface of the kernel, to facilitate its drying. It is assumed that a deliberately perforated corn shell should dry faster and more easily in the machine, although the storage technology has demanded quite the opposite so far, i.e. it has required a completely undamaged kernel for permanent storage. The research conducted by *Vlahović* (*1987*), *Krička* (*1993*) and *Kričkа and Pliestić* (*1994*) confirmed that a perforated kernel dried faster if its initial moisture exceeded 25%. Producers claim that in this way they can save from 10 to 12%, failing to mention at what kernel moistures. A possible solution to this problem of drying is an experiment that can be done in a laboratory or an industrial plant, although a laboratory device offers a more reliable monitoring of the process. The interactive influence of physical properties on the process is accomplished by doing a planned experiment in a laboratory dryer. That is why such an approach to solving the problem of drying the deep, immobile layer of maize kernel was accepted for the purpose of this study.

In this study a laboratory dryer was used in which a whole, hand-shelled kernel was being dried simultaneously with a previously perforated one. The experiment was set up in such a way to enable the simulation of the process that is carried out in industrial plants. Selecting the factors that affect the process of drying and choosing their appropriate levels are, therefore, very important. The factors are as follows:

- air temperature immediately prior to entering kernel layer;
- air speed after its passage through kernel layer;
- kernel layer height;
- initial moisture of kernel weight;
- final moisture of kernel weight.

The levels of the above listed influential factors were chosen within their borderline values achieved during drying in industrial plants.

The results of an experiment planned in such way are an interaction among the chosen factors that influence the process of drying.

In industrial plants, a dried kernel is transported to a silo cell. As silo cells are in most cases 30 m high, a kernel gathers high speed on its way down the cell. Therefore the second part of the research was directed towards determining the resistance of both unperforated and perforated pericarp of the kernel by applying dynamic burdening. A laboratory centrifugal drum operating on D'Alembert's principle was used throughout the investigation.

It is well known that a higher level of protein decomposition, i.e. their denaturation, can be caused if a so-called blocking occurs during drying. The last objective of this study was to determine the effect of perforating corn shell on the grounds of elementary chemical analysis. The raw protein, raw fat, raw fibre, raw ash contents and the influence of perforating kernels were determined by using Weende method.

Thus obtained data that simulate the process of drying in big dryers, transport and fall of the kernel down the silo cell, were first statistically analyzed and then used to formulate the equations for drying unperforated and perforated maize kernels and for their dynamic burdening as well. The differences that were observed between the speed of drying, the amount of breakage and elementary chemical analyses of unperforated and perforated maize shell were analyzed separately.

Methodology of research into drying speed of unperforated and perforated maize shell

A laboratory dryer was used for experimental drying of unperforated and perforated maize kernel in order to test the effect of perforating on the speed of drying maize shell. Because the depth of the shell was not measured, it was understood that the process of perforating reached other parts of the kernel, including the peripheral part of the endosperm. The experiment was set up in such a way that it succeeded in simulating the real process.

The research was carried out on the Bc 492, FAO group 400, dent maize during a 3-year period. The maize was grown in the Slavonia region in Croatia.

To avoid any potential injuries during drying, the maize was harvested in cobs and hand-shelled, which served as a starting point for the research. After the maize cobs had been shelled, a few samples were taken and their moisture measured by using two-phase dryer.

Drying was carried out inside a laboratory dryer, at the temperatures of 130, 110 and 90°C, and the outlet air velocity between 1.75 and 2.2 m/s. The sample was dried in the stationary layer and its weight, i.e. moisture loss, was measured every 5 min. The temperature and velocity of the air, plus the kernel temperature in the air flow were also measured. The kernel weight during drying was measured on a digital balance placed under the dryer.

After drying, kernel weight converted into the moisture following the next formula:

$$w_2 = 100 - \frac{M_1}{M_2} \cdot (100 - w_1)$$

w_1 – kernel moisture before drying (%)

w_2 – kernel moisture after drying (%)

M_1 – kernel weight before drying (gr.)

M_2 – kernel weight after drying (gr).

Ambient temperature and relative moisture were monitored throughout the period of measuring.

All the measuring was repeated 20 times for each temperature and each year. Thus obtained data were statistically analyzed and then used to formulate the equations (exponential and polynomial) of drying for the particular hybrid of unperforated and perforated maize.

The kernel pericarp was perforated by means of a specially designed "hedgehog" consisting of 589 needles. The maize sample to be perforated was placed under the "hedgehog" in the elementary layer. The frontal side of the kernel was perforated because the design of the "hedgehog" made it possible to avoid perforating the lateral side of the maize kernel. The perforation depth of the kernel and its increased surface for water evaporation were determined on the basis of moving needles, the kernel depth and the surface of the needle that entered the kernel. The number of punches per maize kernel was determined by visually controlling 50 samples.

Thus perforated kernel was dried inside a laboratory dryer under the same conditions as the unperforated one.

Methodology of research into maize kernel injuries by applying dynamic burdening

After the samples had been hand-shelled and dried at 130°C for the unperforated kernel, and hand-shelled, perforated and then dried at 130°C in the forced air flow, the resistance of maize kernel to dynamic burdening was tested. The samples were tested in a centrifugal drum at 1000 r.p.m. 250 maize kernels were set aside for each sample. The angular speed was $104.7 s^{-1}$, the absolute speed 16.7 m/s, the relative speed 4.1 m/s, while the transfer speed was 16.2 m/s.

The samples were counted and weighed, and then exposed to the centrifugal drum. When their exposure to the burdening inside the drum was over, both whole and broken kernels were collected and then once more counted and weighed. The ratio between the whole kernels and the broken ones was calculated, while the 250 kernel weight served as a basis to get the 1000 kernel weight.

Methodology of research into basic chemical analyses of maize kernel

The content of crude protein, fat, ash and fibre in maize kernel was estimated according to Weende method. After the samples had been dried at 130 ºC, or first perforated and then dried at 130 ºC, the analyses were done on the basis of a joint sample. Following the suggestions by *Ensminger and Olentine* (*1978*), the values obtained were then converted to the moisture of 14% and the dry matter.

RESULTS

Results of research into drying unperforated and perforated maize shell

The investigation was conducted on the Bc 492 maize hybrid, at air temperatures of 130, 110 and 90ºC. All the measuring for each temperature and each research year was repeated 20 times.

Immediately prior to perforating, the approximate size of the kernel was measured and it turned out it had the same values as those shown in Table 1.

Table 2 shows the polynomial and exponential equations for drying of unperforated and perforated maize kernel in the 3-year period.

Table 1. Approximate size of Bc 492 hybrid maize kernel and number of perforations during research
Tablica 1. Približna veličina zrna kukuruza hibrida Bc 492 i broj perforacija za vrijeme ispitivanja

Bc 492	Approximate size of hybrid - Približna veličina hibrida			Number of perforation Broj perforacija	Area of evaporation Područje isparivanja mm^2
	Linear measure Linearna mjera mm	Wide measure Širina mm	Altitude measure Visina mm		
Main value Glavna vrijednost	10,938	8,752	5,098	3,56	0,247
St. deviation St. odstupanje	0,723	1,012	0,431	1,327	-
Minimum - Minimum	9,6	6,9	4,1	2	-
Maximum - Maksimum	12,7	13,5	5,9	5	-

Table 2. Drying equations for unperforated and perforated maize kernel during research into Bc 492 hybrid
Tablica 2. Jednadžbe sušenja neperforiranog i perforiranog zrna kukuruza za vrijeme istraživanja hibrida Bc 492

Bc 492			t_0 °C	φ_0 %	v_2 m/s	w_1 %	Depth of perforation Dubina perforacije mm	Exponential equations Eksponencijalne jednadžbe	R^2
1st year 1. godina	130 °C	U	22,0	45,5	1,88	24,86	0,30	$w_1=23,953e^{-0,01\tau}$	0,9861
	130 °C	P	22,4	45,5	1,93	24,86		$w_1=23,85e^{-0,0112\tau}$	0,9875
	110 °C	U	21,5	62,2	2,20	25,05		$w_1=23,324e^{-0,0048\tau}$	0,9781
	110 °C	P	21,6	69,9	2,08	25,05		$w_1=24,066e^{-0,0078\tau}$	0,9885
	90 °C	U	22,0	65,6	2,10	24,87		$w_1=24,336e^{-0,0043\tau}$	0,9950
	90 °C	P	24,3	61,3	2,18	24,87		$w_1=23,426e^{-0,0053\tau}$	0,9827
2nd year 2. godina	130 °C	U	23,4	62,3	2,10	28,05	0,70	$w_1=27,589e^{-0,0123\tau}$	0,9869
	130 °C	P	25,6	54,5	2,03	28,05		$w_1=26,739e^{-0,0123\tau}$	0,9914
	110 °C	U	24,9	58,9	1,97	28,81		$w_1=26,564e^{-0,0059\tau}$	0,9688
	110 °C	P	24,9	56,4	2,00	28,81		$w_1=26,827e^{-0,0077\tau}$	0,9836
	90 °C	U	23,7	52,3	2,02	28,81		$w_1=26,61e^{-0,0046\tau}$	0,9826
	90 °C	P	23,2	54,2	1,94	28,81		$w_1=26,667e^{-0,0063\tau}$	0,9790
3th year 3. godina	130 °C	U	24,5	59,0	2,05	28,55	0,59	$w_1=27,017e^{-0,011\tau}$	0,9840
	130 °C	P	23,9	57,5	2,10	28,55		$w_1=27,311e^{-0,0126\tau}$	0,9945
	110 °C	U	20,0	58,9	1,98	28,79		$w_1=25,984e^{-0,0064\tau}$	0,9639
	110 °C	P	20,2	59,7	1,98	28,79		$w_1=25,861e^{-0,0092\tau}$	0,9516
	90 °C	U	23,1	55,1	2,06	28,81		$w_1=26,787e^{-0,0046\tau}$	0,9854
	90 °C	P	24,5	58,6	2,10	28,81		$w_1=27,343e^{-0,0063\tau}$	0,9849

U - Unperforated - Neperforirano P - Perforated - Perforirano

Results of research into mechanical-dynamic injuries of unperforated and perforated maize kernel

After drying, the same methodology was applied to investigate the mechanical-dynamic injuries of both unperforated and perforated maize kernel. Table 3 shows the results of kernel injuries.

Table 3. Percentage of breakage in unperforated and perforated Bc 492 maize kernel after drying at temperature of 130 °C

Tablica 3. Postotak loma na perforiranom i neperforiranom zrnu kukuruza Bc 492 nakon sušenja na temperaturi od 130 °C

Bc 492 maize Kukuruz Bc 492		w_1 %	w_2 %	Mass of 1000 kernels Masa 1000 zrna	Whole kernel Čitavo zrno %	Breakage Lom %
Natural dry Prirodno sušeno		24,86	13,72	321,2	69,24	30,76
1st year 1. godina	Unperforated Neperforirano	24,86	13,90	320,0	30,88	69,12
	Perforated Perforirano	24,86	13,91	321,6	20,15	79,85
2nd year 2. godina	Unperforated Neperforirano	28,05	13,78	305,2	16,78	83,22
	Perforated Perforirano	28,05	13,88	299,2	15,37	84,63
3th year 3. godina	Unperforated Neperforirano	28,55	13,89	328,4	31,06	68,94
	Perforated Perforirano	28,55	13,92	319,6	22,90	77,10

As the right insight was gained into the dynamic strength, Table 3 shows the breakage percentage in unperforated and perforated corn hybrid kernel during a 3-year period. As it has already been proved, the dynamic strength of a kernel is directly dependent on its moisture content (*Pliestić, 1989*). To compare the breakage results between unperforated and perforated kernel, it was essential to prove that the research was conducted on statistically approximately the same kernel moistures.

It also turned out that the research was done on the samples of the same moisture levels, which means that the dynamic strength of unperforated and perforated hybrid kernel can be compared.

Results of research into basic chemical analyses of maize kernel

The crude protein, fat, ash and fibre content was used for basic chemical analyses after being converted to the kernel moisture of 14%, that is to the dry matter (*Ensminger and Olentine, 1978*). Table 4 shows the values obtained for the moisture of 14% and the dry matter.

If the obtained values are compared, it can be noticed that there is no significant difference in basic chemical properties between unperforated and perforated kernel. It is, therefore, evident that the process of perforating does not affect the chemical composition of maize.

Table 4. Nutritive values of Bc 492 maize hybrid
Tablica 4. Hranidbene vrijednosti hibrida kukuruza Bc 492

Bc 492 maize Kukuruz Bc 492		Moisture - Vlaga %		Ash - Pepeo %		Fat - Masnoća %		Protein - Bjelančevina %		Fibre - Vlaknina %	
Natural dry Prirodno sušeno		14%	D.M. S.T.	14%	D.M. S.T.	14%	D.M. S.T.	14%	D.M. S.T.	14%	D.M. S.T.
		13,72	0	1,04	1,21	3,51	4,08	6,92	8,05	2,75	3,20
1996.	Unperforated Neperforirano	13,90	0	1,19	1,39	3,44	4,00	6,93	8,06	2,63	3,13
	Perforated Perforirano	13,91	0	1,29	1,49	4,55	5,29	7,12	8,28	2,77	3,22
1997.	Unperforated Neperforirano	13,78	0	1,03	1,20	5,36	6,23	6,88	8,00	2,85	3,31
	Perforated Perforirano	13,88	0	1,08	1,25	3,97	4,62	6,95	8,09	2,94	3,42
1998.	Unperforated Neperforirano	13,89	0	1,04	1,21	3,73	4,33	7,25	8,43	2,48	2,89
	Perforated Perforirano	13,92	0	0,93	1,09	3,74	4,34	7,72	8,97	2,75	3,19

DISCUSSION

The research and comparing of the effect of perforating on the speed of water evaporation during the 3-year period was carried out on the Bc 492 dent maize, bred in the Slavonia region. Due to the increased starch content, this hybrid was grown for the feed production. All the samples were tested under the same conditions, as follows:

- inlet air temperatures of 130, 110 and 90°C;
- outlet air velocity of 1.75 and 2.2 m/s.

During the investigation, the ambient temperature and relative air humidity were also observed.

Comparing the time needed for the maize kernel to get dry by means of its dependence on air temperature and speed, and the technological procedure of kernel perforating, led to the following results:

The first research year

While investigating the Bc 492 maize hybrid kernel, the mean moisture value was 24.86% during drying at the air temperature of 130°C, 25.05% at the air temperature of 110°C, and 24.87% at the air temperature of 90°C. The perforated kernel dried faster than the unperforated one, which was particularly noticeable at lower temperatures. Thus at the air temperature of 130°C, the unperforated kernel dried only 10% longer than the perforated one, whereas at the air temperature of 110°C, the unperforated kernel dried 64.3% longer than the perforated one. At the temperature of 90°C, the difference was 28.6%.

The mathematical modelling used by other authors (*Martins, 1988; Krička, 1993; Krička and Pliestić, 1995*) served to compare in mathematical terms the drying speed of the crops under examination.

After a general analysis of the drying equations, it can be noticed that the coefficient of the variable has the minus sign, which means that the curve is falling, i.e. it shows the tendency of the drying speed. The higher the absolute value of the coefficient, the faster the drying. While analyzing the drying curves of the crops under research, it can be seen that they show different speeds of water evaporation. Derivations of the equations of the mean values for the crops under research were used to compare the curve gradients (*Krička and Pliestić, 1995*) and they are shown in Table 5.

Table 5. **Derivations of equations of mean drying values at different temperatures of unperforated and perforated Bc 492 maize kernel in 1st research year**

Tablica 5. **Derivacije jednadžbi srednjih vrijednosti sušenja perforiranog i neperforiranog zrna kukuruza Bc 4-92 na raznim temperaturama u prvoj godini istraživanja**

Technology Tehnologija	t_z(°C)	Derivations of equations of mean drying values Derivacije jednadžbi srednjih vrijednosti sušenja
Unperforated Neperforirano	130	$dw/d\tau=0,0044\tau-0,3107$
Perforated Perforirano	130	$dw/d\tau=0,0054\tau-0,3416$
Unperforated Neperforirano	110	$dw/d\tau=0,0012\tau-0,1602$
Perforated Perforirano	110	$dw/d\tau=0,0026\tau-0,2398$
Unperforated Neperforirano	90	$dw/d\tau=0,0006\tau-0,123$
Perforated Perforirano	90	$dw/d\tau=0,0014\tau-0,168$

It can be concluded that the biggest changes in moisture coefficient per unit of time were achieved at the air temperature of 110°C.

The second research year

In the second research year, the initial moisture of the Bc 492 maize hybrid kernel was 28.0% at the air temperature of 130°C, whereas at 110 and 90°C it was 28.8%. In comparison with the perforated kernel, the unperforated one dried 9.1% longer at 130°C, 26.3% at 110°C and 36.4% at 90°C.

Table 6 shows the derivations of mean drying values which were used to compare the tendency of maize kernel drying speed in the second research year.

Table 6. **Derivations of equations of mean drying values at different temperatures for unperforated and perforated Bc 492 maize kernel in 2nd research year**

Tablica 6. **Derivacije jednadžbi srednjih vrijednosti sušenja perforiranog i neperforiranog zrna kukuruza Bc 492 na raznim temperaturama u drugoj godini istraživanja**

Technology Tehnologija	t_z(°C)	Derivations of equations of mean drying values Derivacije jednadžbi srednjih vrijednosti sušenja
Unperforated Neperforirano	130	$dw/d\tau=0,0058\tau-0,4187$
Perforated Perforirano	130	$dw/d\tau=0,0058\tau-0,4026$
Unperforated Neperforirano	110	$dw/d\tau=0,002\tau-0,2336$
Perforated Perforirano	110	$dw/d\tau=0,0026\tau-0,2714$
Unperforated Neperforirano	90	$dw/d\tau=0,001\tau-0,1643$
Perforated Perforirano	90	$dw/d\tau=0,002\tau-0,2342$

In the second year, the biggest changes in moisture coefficient per unit of time occurred at the air temperature of 90°C.

The third research year

In the third research year, the average values of maize kernel moisture were 28.5% (at 130°C), 28.8% (at 110°C) and 28.8% (at 90°C). Compared to the perforated kernel, the unperforated one dried 18.2% longer at the air temperature of 130°C, 40% at 110°C, and 25% at 90°C. Table 7 shows the derivations of drying equations for the Bc 492 maize hybrid kernel in the third year.

Table 7. Derivations of equations of mean drying values at various temperatures for unperforated and perforated Bc 492 maize kernel in 3rd research year

Tablica 7. Derivacije jednadžbi srednjih vrijednosti sušenja perforiranog i neperforiranog zrna kukuruza Bc 492 na raznim temperaturama u trećoj godini istraživanja

Technology Tehnologija	t_z(°C)	Derivations of equations of mean drying values Derivacije jednadžbi srednjih vrijednosti sušenja
Unperforated Neperforirano	130	$dw/d\tau=0,0027\tau-0,3904$
Perforated Perforirano	130	$dw/d\tau=0,0052\tau-0,3936$
Unperforated Neperforirano	110	$dw/d\tau=0,0024\tau-0,2529$
Perforated Perforirano	110	$dw/d\tau=0,0054\tau-0,3806$
Unperforated Neperforirano	90	$dw/d\tau=0,001\tau-0,1613$
Perforated Perforirano	90	$dw/d\tau=0,0018\tau-0,2268$

Similar to the second year, the biggest changes in moisture coefficient per unit of time occurred at the air temperature of 90°C.

On the basis of the 3-year research and comparing the Bc 492 maize kernel drying values, it can be concluded that the technological procedure of perforating maize shell is applied to facilitate water evaporation from the kernel and as such it is more acceptable at lower air temperatures (*Vlahović, 1987*).

By comparing the values achieved with the depth of a perforation, it can be noticed that the depth itself is not essential for the speed of water evaporation from the kernel (*Kričica, 1993*). What really matters is that the maize shell is perforated and the kernel's morphological structure is essential for such technological procedure (*Dubravec, 1993*).

After the kernel (both unperforated and perforated) had been dried at the air temperature of 130°C, its dynamic strength was tested in the centrifugal drum which can simulate the conditions that the kernel is exposed to during its mechanical harvesting, transportation, storage, etc. When the breakage level of the dried Bc 492 maize kernel is compared with the naturally dried one, it can be noticed that the technological procedure of drying significantly affects the kernel dynamic strength – after drying, the level of breakage increased by 100%.

Furthermore, the technological procedure of perforating maize kernel additionally reduces its dynamic strength, i.e. it increases the level of breakage. It can, therefore, be concluded that while applying the mentioned technological procedure in industrial plants, extra attention should be paid to transport lines (*Kričica, 1993; Pliestić and Kričica, 1993*).

The basic nutritive values of the investigated maize kernel after drying, and after perforating and drying, were tested simultaneously with the research into the kernel breakage. It turned out that the process of perforating had no effect whatsoever on raw protein, raw fat, raw ash and raw fibre. It can, therefore, be concluded that perforations do not reduce maize nutritive values.

CONCLUSION

On the basis of our 3- year-long research on the Bc 492 maize hybrid kernel and the effect of perforating the kernel (its pericarp, seed testa and endosperm) on the speed of drying, plus the influence of dynamic burdening on mechanical injuries of unperforated and perforated maize kernel and the impact of perforations on the kernel basic nutritive values, the following conclusions have been drawn:

The speed of water evaporation is higher due to perforating, under the same conditions at approximately the same initial moisture of the kernel, with 3.56 holes per kernel on average. Application of perforating achieved the best results at the drying temperature of 110°C. Depth of a perforation is not relevant to faster water evaporation. The technological procedure of perforating caused some additional reduction in kernel resistance. Perforations have no effect whatsoever on raw protein, raw fat, raw ash and raw fibre.

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SAŽETAK

Istraživanje je provedeno u laboratorijskim uvjetima tijekom tri godine. Postupak sušenja obavljen je u laboratorijskom sušilu s vagom. Perforacija kukuruzne ljuske obavljena je pomoću "ježa" - laboratorijske naprave. Perforirana i neperforirana zrna kukuruza sušena su u istim uvjetima na temperaturi od 130, 110 i 90 °C, te brzini zraka od 1,75 m/s do 2,2 m/s. Sve dobivene vrijednosti statistički su analizirane i uspoređene primjenom polinomijalnih i eksponencijalnih jednadžbi. Kad je postupak sušenja perforiranih i neperforiranih zrna kukuruza dovršen analizirane su osnovne hranidbene vrijednosti i dinamička svojstva, naročito razine loma.

Perforacije nisu djelovale na sirove bjelančevine, sirovu vlakninu, sadržaj sirovog pepela i sirove masnoće, što dokazuje da takav postupak ne smanjuje hranidbenu vrijednost kukuruza, a prouzročio je nešto dodatnog smanjenja otpora zrna.

Ključne riječi: sušenje, perforacija, zrno kukuruza, lom, hranidbena vrijednost