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CHEMICAL COMPOSITION OF CORN KERNELS AFTER A HYDROTHERMAL "COOKING" PROCEDURE

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The influence of a hydrothermal "cooking" procedure on the starch, protein and oil contents was investigated on two corn hybrids of the same vegetation group (Bc 354 and Bc 394). The "cooking" procedure was started at the moisture contents of 32.73% (for Bc 354) and 31.67% (for Bc 394), which were increased after the "cooking" procedure by 7.36% (for Bc 354) and by 2.96% (for Bc 394). The chemical characteristics of the corn kernels, i.e. starch, protein and oil content, were analysed after drying the kernels at air temperatures of 70°C, 90°C, 110°C and 130°C with or without the prior "cooking" procedure . The results obtained led us to the conclusion that hybrid Bc 354 kernel took a longer time to dry after the "cooking" procedure than hybrid Bc 394 kernel at all selected temperatures, whereas without the "cooking" procedure, hybrid Bc 354 kernel dried more slowly than hybrid Bc 394 kernel only at the temperature of 70°C. After the drying and "cooking" procedures, both hybrids showed an increase in starch content and a decreases in protein and oil content in the kernel when compared to naturally dried kernels. In the same way, starch content increased and oil and protein contents decreased in kernels treated by the "cooking" procedure in comparison to kernels that were only dried.

Key words: corn kernel, "cooking" procedure, temperatures, starch, protein, oil.

INTRODUCTION

Due to its favourable composition, corn is an irreplaceable basic component in livestock feed production in the Republic of Croatia and particularly in this region as a whole. Namely, corn kernel is a high-calorie feed as it contains oil, carotene, easily digestible carbohydrates and a small content of cellulose (Antunović *et al*., 2002).

In recent years, research on various processing procedures and hydrothermal treatment of kernels has been conducted in order to obtain a kernel of higher quality and digestibility (Katić *et al*., 1994; Mujumdar, 2000, Krička *et al*., 2003). The digestibility of carbohydrates in naturally dried kernels is relatively low, so various thermal processing procedures are aimed at increasing starch content

and, consequently, improving digestibility. The pysical characteristics of starch as the main component of corn kernel, are exceptionally important (Grbeša *et al*. 2003). Thus, Grbeša *et al*. (2003) established that flint corn hybrids have a higher nutritive value than dent hybrids. Svihus (2003) found that starch digestibility was not as high as supposed, and that it is subject to considerable variations depending on the structure, i.e. ratio of amylopectin and amylose, degree of endosperm crystallinity and the size of the starch granules.

Corn kernels are usually dried after harvesting in order to decrease kernel moisture until hygroscopic equilibrium is achieved, when it can be stored for a longer period of time. Depending on the air temperature, the content of amino acids or proteins decrease while the level of starch gelatinization increase (Pupavac, 1999; Mujumdar, 2000). Energy is required for hydrothermal processing of corn kernels as well as for drying. In thermal processing and in the "cooking" procedure, the usual technology is drying – "cooking"- drying of corn kernels with the purpose of increasing starch content, which requires double drying (Krička *et al*., 2001).

The consumption of energy plays a significant role in all heat treatments. Depending on the heat treatment applied, energy consumption may range from 2 to 4 kg of petroleum per 100 kg of dried kernels (Katić, 1997). For all these reasons, the objective of this study was to establish whether it is possible to maintain the digestibility of corn kernels by treating them before drying. The ultimate goal was to omit one drying treatment by "cooking" corn kernels immediately after harvesting and, then to dry them. The nutritive value of a kernel is indicated by the degree of starch gelatinization and by the levels of available starch and protein (Brouillet-Fourmann *et al*., 2003; Nayouf *et al*., 2003).

This is particularly important for young animals (e.g. hogs), where enzyme activity for the breakdown of starch is not well developed, or for animals in which nutritive starch cannot be exploited to a great extent because of the short digestion process (e.g. cats, fish, furry animals).

Based on the above mentioned, the aim of this study was to determine the influence of a hydrothermal "cooking" treatment of corn kernels (dried with different regimes of air temperature) on the content of starch, protein and oil in comparison with classically dried kernels.

MATERIAL AND METHODS

The research involved two corn hybrids, which have been introduced in Croatia only in the last couple of years – Bc 354 and Bc 394 (Botinec – Zagreb, Croatia). Bc 354, a dent hybrid, FAO group 300, is a high yielding hybrid with a loose husk and very thin cob that enables a fast water release rate from the kernel; the kernel is large and reddish. Its main application is in production with lower levels of agrotechnology. Bc 394, a dent hybrid, FAO group 300, is also a high yielding hybrid with a tight husk and light yellow kernel used exclusively in conditions of intensive agrotechnology (Katić *et al*., 1994; Grbeša *et al*., 2003).

At the Zagreb Faculty of Agriculture, a device was designed for steaming kernels – a process known as the "cooking" treatment. It was carried out in a

pressure vessel instead of a “cooking” column. The basic difference is that, in the process of treating a maize kernel, the steam does not come from the outside. The kernel is steamed by water vapour originating from the water which lies on the bottom of the vessel and which does not come into contact with the kernel. This vessel contains another cylindrical vessel with a perforated bottom, beneath which there is a ceramic plate with drill holes of 16 mm in diameter to avoid direct conductive contact between the kernel and the metal bottom and linings of the pressure vessel, and to avoid convection contact with water. The water vapour can pass freely and treat the kernel. The pressure vessel is heated by an electric heater and the temperature is controlled by a voltage regulator with a variable resistor. The vessel contains a thermometer and a manometer to measure the temperature and pressure inside the vessel, a valve for the release of surplus steam and a safety valve. The “cooking” treatment was applied to a kernel sample of 1500 g which had previously been rehydrated to 32.73% (Bc 354) and 31.67% (Bc 394) moisture content. For each treatment, 500 ml of distilled water was poured into the pressure vessel. The kernels were treated for 10 minutes at a temperature higher than 100^{o}C and at a steam pressure of 0.5 bars. During the entire treatment, the readings of the temperature and the pressure inside the vessel were checked every minute. After the “cooking” treatment, the kernels were dried in a laboratory model drier, constructed in such a way as to be kinetically similar to a real-life industrial drier. Before drying, the moisture of the samples was determined and their total mass was weighed. To monitor the decrease in moisture, the samples were weighed every two minutes during the drying process until their moisture content reached 13.5% (Putier, 1993).

Kernels of both hybrids were dried at air temperatures of 70 ^{o}C; 90 ^{o}C; 110 ^{o}C and 130 ^{o}C with an air velocity of 1.0 m/s. These air temperatures were selected for their practical value – namely, in the first phase of drying in Croatia, kernels are treated at air temperatures of 130 ^{o}C and 110 ^{o}C, and in the second phase of drying to end-state moisture, the air temperatures are reduced to 90 ^{o}C and 70 ^{o}C (Gupta *et al*., 2002).

After kernels were dried at the given temperatures (with or without the “cooking” procedure), starch, protein and oil contents were determined using an NIR analyzer (“Cropscan 2000" Australia). The control was conducted by means of classic etalon methods (Pen, 1991).

The obtained results were statistically processed. The drying rate of the corn kernels was mathematically presented with polynomial equations (Krička *et al*., 2001).

RESULTS

The average temperature in the laboratory during the investigation was t_o = 19.80^{o}C, while the relative air humidity in storage averaged 75.1%.

After the “cooking” procedure, the samples were immediately dried at different temperatures (70, 90, 110 and 130^{o}C). So the duration of the process of drying from the input to the output moisture varied (table 1).

Table 1. Average time of drying Bc 354 and Bc 394 hybrid corn kernels to 13.5% moisture at various air temperatures with and without the “cooking” procedure

Hybrid	Input air temperature (°C)	Drying procedure	With cooking		Without cooking	
			Air temperature (°C)	Duration of drying (min)	Air temperature (°C)	Duration of drying (min)
Bc 354	70	Average	70.84	306	70.52	209
		min	66	300	68	200
		max	74	315	73	220
		s.d.	1.481	6.519	0.922	8.944
	90	Average	90.32	207	90.69	113
		min	87	205	89	105
		max	94	210	93	120
		s.d.	1.168	2.138	1.158	5.701
	110	Average	110.71	92	110.81	64
		min	109	90	109	60
		max	114	95	113	65
		s.d.	1.232	2.738	0.981	2.236
	130	Average	130.36	56	130.50	29
		min	129	50	129	25
		max	132	60	123	30
		s.d.	0.841	4.183	0.925	2.236
Bc 394	70	Average	70.21	301	70.18	202
		min	69	290	69	200
		max	72	310	71	205
		s.d.	0.826	7.416	0.601	2.738
	90	Average	90.37	144	91.19	123
		min	89	140	89	120
		max	92	150	93	125
		s.d.	0.877	4.183	1.077	2.738
	110	Average	110.38	82	110.88	73
		min	109	80	109	70
		max	112	85	112	80
		s.d.	0.864	2.739	0.857	4.472
	130	Average	130.20	39	130.62	36
		max	129	35	129	35
		min	132	40	132	40
		s.d.	0.788	2.236	0.916	2.236

It can be noticed that the “cooking” procedure extended the duration of drying in hybrid Bc 354 by 97 minutes (70 °C); by 94 min (90 °C) by 28 min (110 °C) and for 27 min (130 °C). In hybrid Bc 394 the “cooking” procedure extended the drying process by 99 min (70 °C), by 21 min (90 °C); by 9 min

Table 2. Polynomial equations of the drying process of corn kernels exposed or not to prior “cooking” treatment.

Hybrid	Air temp. (°C)	w_1 (%)	Drying Equation of drying	R^2	w_1' (%)	Cooking + drying Equation of drying	R^2
Bc 354	70	32.73	$y=0.0003x^2-0.138x+29.782$	0.99	38.96	$y=0.0001x^2-0.108x+33.069$	0.97
	90	32.73	$y=0.001x^2-0.255x+35.666$	0.98	41.30	$y=0.0003x^2-0.179x+35.666$	0.98
	110	32.73	$y=0.0035x^2-0.496x+30.559$	0.97	39.89	$y=0.0017x^2-0.390x+35.368$	0.97
	130	32.73	$y=0.0177x^2-1.166x+31.269$	0.98	40.21	$y=0.0059x^2-0.779x+37.845$	0.98
Bc 394	70	31.67	$y=0.0001x^2-0.097x+29.784$	0.99	34.89	$y=0.0003x^2-0.136x+28.967$	0.99
	90	31.67	$y=0.0008x^2-0.227x+29.018$	0.98	34.36	$y=0.0006x^2-0.216x+30.826$	0.98
	110	31.67	$y=0.0024x^2-0.399x+30.043$	0.98	34.41	$y=0.002x^2-0.3984x+32.259$	0.98
	130	31.67	$y=0.0139x^2-0.967x+29.931$	0.99	34.86	$y=0.01x^2-0.952x+33.846$	0.99

(110 °C) and by 3 min (130 °C). However, if the process of "cooking" was conducted in the classical way (drying – "cooking" – drying), it would last considerably longer; but this also depends on the morphological properties of the kernel.

The obtained data relating to the drying rate of the corn kernels were mathematically fitted with polynomial equations. Table 2 shows the drying rates of kernels exposed or not to the "cooking" treatment before being dreid at different temperatures.

If the obtained polynomial equations are compared, it can be seen that the corn kernels of hybrid Bc 354 dried faster than hybrid Bc 394 kernels, except at the air temperature of 70 °C. This characteristic can be attributed to its kernel features, i.e. the pericarp is somewhat thinner.

The "cooking" procedure itself increased the kernel moisture in hybrid Bc 354 from 32,73% to an average of 40,09%, i.e. by 7,36%, whereas the kernel moisture in hybrid Bc 394 increased from 31,67% to an average of 34,63, i.e. by 2,96%. If the polynomial equations are compared, it can be stated that, after the "cooking" procedure, the Bc 354 corn kernels dried more slowly than the Bc 394 corn kernels at all selected temperatures, which can also be attributed to their hybrid features.

Starch, protein and oil contents in the kernels after drying with or without the "cooking" treatment are displayed in Table 3. Naturally dried samples were taken for the purpose of comparison.

Table 3. Average values of starch, protein and oil contents before and after the "cooking" and drying procedures.

Treatment	Bc 354			Bc 394		
	Starch	Protein	Oil	Starch	Protein	Oil
0-sample before cooking and drying (naturally dried)	57.0	11.6	6.7	57.9	11.3	6.8
Drying only 70 °C	56.1	11.9	6.8	57.0	10.9	6.8
Drying and cooking 70 °C	59.8	10.3	5.4	59.5	9.9	5.8
Drying only 90 °C	57.0	11.6	6.5	58.1	10.8	6.8
Drying and cooking 90 °C	60.7	10.0	5.3	59.8	9.5	5.6
Drying only 110 °C	58.1	11.1	6.4	57.6	10.4	6.9
Drying and cooking 110 °C	61.3	9.6	5.2	60.7	9.4	5.3
Drying only 130 °C	58.3	10.7	6.1	58.5	10.2	6.1
Drying and cooking 130 °C	60.6	9.0	5.0	60.6	9.0	5.0

The results show that the "cooking" procedure had a positive effect on the content of starch in the kernels and a negative effect on the content of protein and oil.

DISCUSSION

After the “cooking” treatment, kernel moisture increased by 7.36% in hybrid Bc 354 (from 32.73% to 40.09%) and 2.96% in hybrid Bc 394 (from 31.67% to 34.63%). These data show that the two hybrids are significantly different in water absorption. In this case, the difference in the rate of water absorption is due to the difference in pericarp thickness, as shown already by other authors (Martins and Stroshine, 1987; Nemeny *et al*., 1994). Although they studied the water release rate from the kernel, the absorption of water can be related to the thickness of the pericarp, because there is a difference in absorption and releasing of water, i.e. two equilibria (Katić, 1997).

Thus, the thickness of the pericarp influences water release rate from the kernel as well, which can be seen from the data on the duration of drying in the hybrids. Table 2 shows that, after the “cooking” procedure, hybrid Bc 394 kernels dried faster than hybrid Bc 354 kernel at all drying temperatures. The biggest difference between the hybrids was noticed at 90 ^{o}C and it was 63 minutes, and the smallest difference was found at 70^{o}C. If these values are compared to the data on water absorption, it is clear that hybrid Bc 354 releases and absorbs water faster during drying, since the process of drying after the “cooking” treatment started at a higher input moisture.

The situation was completely different when the kernels were dried without the “cooking” procedure. In that case, hybrid Bc 394, although having a lower level of input moisture (34.63%), dried at a slower pace than hybrid Bc 354, whose input moisture was 40.09%, except at 70^{o}C. Therefore, it can be concluded that hybrid Bc 354 both absorbs moisture faster in the course of rehydration and releases moisture faster during the artificial dry-up process. This is of particular importance, because energy plays an important role in the production of any culture, including corn. The biggest difference between the hybrids (10 minutes) was detected while drying at the temperature of 90^{o}C without the “cooking” procedure. However, while hybrid Bc 354 took a longer time to dry in the drying process including the “cooking” treatment, hybrid Bc 394 took longer to dry in the process of drying without the “cooking” procedure. The analysis of chemical features of the corn kernel (starch, protein, oil) showed that hybrids Bc 354 and Bc 394 had an increased starch content after the “cooking” procedure at all of the drying temperatures.

Starch content increased in samples treated by “cooking” by approximately 5.32% when compared to samples not treated by “cooking” in hybrid Bc 354, whereas samples of hybrid Bc 394 showed an increase in starch content by an average of 3.90%, which is in harmony with earlier data (Mujumdar, 2000). Namely, an increase of air temperature for drying in a shortens the time necessary for starch degradation. Many samples (with or without the “cooking” treatment) showed an increased starch content in comparison to the samples dried in a natural way.

The “cooking” treatment had a contrary effect on the protein content in the kernel. Thus, a decrease in protein content was detected in all samples subjected to the “cooking” treatment. It amounted to an average of 16.53% in hybrid Bc 354

and 11.94% in hybrid Bc 394. When compared to protein content of the samples dried naturally, hybrid Bc 354 showed an increase of 2.37% in protein content in samples that were not treated by “cooking”. An average decrease of 16.16% in protein content was detected in samples, which were not subjected to the "cooking" treatment. Hybrid Bc 394 showed a decline in protein content in samples not treated by "cooking" by 6.41% and in samples treated by "cooking" by 16.37%. These data are comparable to earlyer findings (Katić *et al*., 1994) which indicate a decrease in content of total proteins and amino acids with increase of drying temperature.

The same can be applied to the oil content in the kernels. A decrease was detected both in kernel samples that were thermally processed and in those that were not. The decline in oil content in relation to the samples subjected to the “cooking” procedure was found to 23.41% in hybrid Bc 354, and 22.71% in hybrid Bc 394. In comparison to the sample which was naturally dried, a decrease of oil content by 3.73% was detected in hybrid Bc 354 when not subjected to the “cooking” procedure, whereas the samples subjected to the “cooking” treatment showed a decrease of 22.01%. In hybrid Bc 394 the percentage decline for not treated samples amounted to 4.41%, and for treated samples 22%.

CONCLUSION

From the resilts obtained for the influence of the technological procedure of “cooking” on corn kernel properties in hybrids Bc 354 and Bc 394 the following conclusion can be drawn: the “cooking” treatment increases average corn kernel moisture for Bc 354 from 32.73% to 40.09%. This hybrid Bc 394 the kernel moisture increased from 31.6% to 34.63%. It indicates that the “cooking” procedure is influenced by hybrid properties of kernels.

When corn kernels of the different hybrids were dried with or without the “cooking” treatment at air temperatures of 70^{o}C, 90^{o}C, 110^{o}C and 130^{o}C with an air velocity of 1.0 m/s, hybrid Bc 394 dried faster irrespectively of the drying temperature, whereas with no prior “cooking” hybrid Bc 354 showed the fastest drying rate, except at the temperature of 70^{o}C. Additionally, it was determined that a kernel subjected to the “cooking” procedure releases moisture at a slower rate during drying if compared to a not treated kernel, which is applicable to both of the examined hybrids.

In accordance with the above, it can be concluded that the “cooking” procedure extends the time necessary for drying, but to a significantly lower degree than standard technology – drying – “cooking” – drying.

Analysis of the chemical properties of corn kernel after the “cooking” and drying and drying alone, in comparison with naturally dried kernels indicates that the “cooking” procedure has a positive effect on starch content in both hybrids. Thus starch content increased in hybrid Bc 354 by 5.32% in treated kernels in comparison to the kernel subjected to drying only, and in hybrid Bc 354 by 3.90%. Moreover, an increase in temperature has a positive effect on total starch content.

Quite to the contrary, the “cooking” procedure has a negative influence on protein and oil content in both hybrids. Decrease in protein content in hybrid Bc

354 amounted to 16.53% in thermally processed kernel samples in comparison to those not processed, and in hybrid Bc 394 the decrease was 11.94%. A reduction in oil content was also detected, being 23.41% in hybrid Bc 354 for treated samples in comparison to not treated samples, while in hybrid Bc 394 the oil content reduction amounted to 22.71%.

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after a hydrothermal "cooking" procedure

HEMIJSKI SASTAV JEZGRA KUKURUZA NAKON PROCEDURE HIDROTERMALNOG "KUVANJA"

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SADRŽAJ

U ovom radu su izneti rezultati ispitivanja uticaja hidrotermalne procedure "kuvanja", sprovedenih na dva hibrida kukuruza iste vegetativne grupe (Bc 354 i Bc 394), na zastupljenost skroba, proteina i ulja. Početna vlažnost od 32,73 % (za Bc 354) i 31,67% (za Bc 394), je nakon procedure "kuvanja" smanjena na 7,36% (za Bc 354) i na 2,96% (za Bc 394). Analize hemijskih karakteristika zrna kukuruza obavljene su pre i posle procedure "kuvanja" i procesa isušivanja kukuruza na temperaturama od 70 ^{o}C, 90 ^{o}C, 110 ^{o}C i 130 ^{o}C. Podaci, dobijeni u ovom istraživanju dovode do zaključka, da hibridnom kukuruzu Bc 354 treba više vremena za sušenje nakon procedure "kuvanja" u odnosu na hibridni kukuruz Bc 394 na svim temperaturama, dok se, bez "kuvanja" hibridni kukuruz 354 suši duže od hibridnog kukuruza 394 samo na temperaturi od 70 ^{o}C. Nakon procesa sušenja i "kuvanja", u oba hibridna kukuruza je došlo do smanjenja sadržaja skroba, a povećanja sadržaja proteina i ulja u poređenju sa kukuruzom koji je sušen na prirodan način. Isto tako, sadržaj skroba se smanjuje, a sadržaj proteina i ulja povećava kod kukuruza, koji je podvrgnut proceduri "kuvanja" u odnosu na kukuruz, koji je samo sušen.

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