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PHYSICAL AND CHEMICAL PROPERTIES OF VARIOUS CORN GENOTYPES AS A CRITERION OF TECHNOLOGICAL QUALITY

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Physical properties, such as test weight, 1000-kernel weight, kernel density, flotation index, water absorption index and kernel hardness and chemical properties: protein, starch and oil contents, of twenty the most widely grown ZP corn hybrids of different genetic background and utilization purposes were studied. The results showed wide ranges of chemical and physical properties among the selected corn hybrids. Protein, starch and oil contents ranged from 8.9 to 13.5%, 67.5 to 73.7%, and 4.1 to 6.5%, respectively. The test weight was within the range of 771.8-897.7 kg m^{-3}, while the 1000-kernel weight ranged from 121.6 to 392.7 g. The kernel density, i.e. flotation index was within the range of 1.23-1.34 g cm^{-3}, i.e. 0-71 %, respectively, while the water absorption index ranged from 0.155 to 0.278. Kernel hardness, expressed as a milling response, and a hard fraction portion varied in the tested samples from 9.4 to 19.9s and 49.6 to 75.2%, respectively. The correlation analysis points to a very great interdependence among certain physical and chemical properties. Obtained high correlation coefficients could be used to predict not so eas-

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ily measurable parameters based on the known value of the corresponding easily measurable parameter. A wide scope of tested quality parameters offers many possibilities in selection and estimation of hybrids for certain purposes.

Key words: corn, grain quality, hybrids, physical and chemical properties

INTRODUCTION

Corn is the most important and abundant crop produced in Yugoslavia (RADOSAVLJEVIĆ and BEKRIĆ, 1999). Based on kernel characteristics there are five general types of corn known as dent, flint, floury, pop and sweet corn (WATSON, 1987). Dent corn is the predominant corn type grown in Yugoslavia, and is characterised by hard dense (horny) endosperm at the sides and back of the kernel surrounding a soft (floury) core. Flint corn, the second most widely grown type, has smaller and rounder kernels than dent types, and its thick and hard endosperm surrounds a small soft centre. Floury corn differs from other types by a very soft endosperm throughout the kernel and is remarkably easy to grind. Popcorn is a small flint corn type used exclusively as a snack food. Sweet corn is a genetic variant of corn, which inhibits the conversion of sugar into starch during kernel filling. Sweet corn is consumed as a food vegetable.

There are many ways of the corn use and application (JOHNSON, 1991). The widest application of corn is in animal feeding and for the industrial preparation of animal feed. However, the fastest growing are industrial uses (CORN ANNUAL, 2000). Corn is processed by three major industries: wet milling, dry milling and distilling. Wet milling of corn separate the kernel into four principal components: starch, protein (gluten meal), germ and fiber. Starch, as a primary product of wet milling, may be processed further to obtain modified starches and sweeteners, ethanol, etc (JOHNSON, 1994). Wet-millers in Yugoslavia used to process 150.000 t of corn per year, but since 1990 they have been using not more than 30% of their capacity. So far, two different approaches have been used in corn dry milling: degerming and nondegerming. Today's dry milling systems are designed to recover as much of the endosperm as possible in large clean particles. In good years, Yugoslav dry-millers can process around 100.000 t of corn. Interest in corn, as an ethanol-producing crop, was renewed during the 1970s due to the energy crises. The expert estimation is that 160.000 t of corn per year can be sufficient for the ethanol production in Yugoslavia.

The growing importance of the corn-processing industries has emphasized interest in the relation of the grain quality to the end-use value (JOHNSON and BAUMEL, 1998). The most recent concept in grain marketing is to identify specific, rigorous quality needs of individual users. Current grading standards do not relate well to the estimated end-use value of industrially processed corn. By most estimates, the value of corn could be increased if quality was more closely matched to user needs.

Corn hybrids generally have been developed to have increased field yields rather than quality related to milling, storage, and shipping characteristics. During recent years more and more attention has been paid to the development of new types of corn specifically adapted to industrial utilization (HALLAUER, 1994). Various users will have different preferences in quality factors. There are three general groups of grain quality factors: 1) defects, 2) shipment and storage factors and 3) end-user related factors. Properties that determine end-use value are intrinsic (ECKOFF, 1996). Grains that meet individual user's needs through one or more enhanced properties are value-added grains (VA) (JARBOE, 1998).

Wet millers prefer soft corn grain that usually requires less steeping and gives a better starch-protein separation. On the other hand, dry millers request hard endosperm dent corn as it provides a maximum recovery of the primary products of low-fat grits and meal. The starch content in corn is the most important quality criterion for distillers. In order to obtain 37-40 litters of pure ethanol from 100 kg of the grain, this content should be over 70%.

Objectives of this study were to determine physical and chemical properties of the most widely grown ZP corn hybrids and to correlate physical and chemical properties and identify easily measurable parameters that relate to technological quality of corn.

MATERIAL AND METHODS

The following twenty hybrids of different maturity groups (FAO 300-800) and various endosperm types were studied: eleven normal dent hybrids (ZP 324, ZP 360, ZP 434, ZP 480, ZP 570, ZP 580, ZP 677, ZP 680, ZP 704, ZP 735, ZP 804), two high-oil hybrids (ZP 702u, ZP 703u), one waxy hybrid (ZP 704wx), two white endosperm hybrids (ZP 300b, ZP 811b), two flint hybrids (ZP 633, ZP 709t) and two popcorn hybrids (ZP 601k, ZP 611k).

All hybrids were grown at Zemun Polje in the vincinity of Belgrade under the equal conditions in two subsequent years. Twenty-five randomly selected ears of each hybrid were taken for the analyses and then dried naturally in net bags. Ears, selected for the analyses, were shelled by hand and kernels were placed in to special containers.

The determinations of physical and chemical properties were done on selected representative corn samples. The corn kernel physical properties were evaluated by the following analyses: test weight (bulk density), 1000-kernel weight (absolute weight), kernel density, flotation index, water absorption index and kernel hardness.

The chemical properties were determined by the following standard quantitative methods: micro-Kjeldahl method for proteins, Ewers method for starch and Soxhlet method, with diethyl ether as solvent, for oil.

The test weight (bulk density) was determined by Shoperg's scale.

The 1000-kernel weight (absolute weight) was evaluated by counting and weighing of 5x200 unbroken kernels.

The kernel density was calculated from the weight and volume of 100 kernels. The 100-kernel volume was determined by using 96% ethanol in the column test described by CRONJE *et al.* (1991).

The flotation index was measured by soaking 100 randomly selected kernels into a sodium nitrate solution of 1.25 g cm^{-3} and by weighing floating kernels.

The water absorption index is a measure of the amount of water absorbed by kernels during the 4-hr period.

The kernel hardness was measured by modified Stenvert-Pomeranz method by milling 20 g of corn in the micro hammer-mill at 3600 rpm. Results are expressed as a milling response, mill lot volume, hard fraction lot volume, soft fraction lot volume and hard fraction portion. The milling response index as a parameter of kernel hardness presents the time necessary for grain grinding in the hammer-mill (3600 rpm, 2-mm sieve) until the top level of the material collected in a glass cylinder (125x25 mm) reaches the level of 17 ml. Relative to the milling response, there are four other parameters for the degree of kernel hardness.

RESULTS AND DISCUSSION

The optimal utilization of cereal grains requires knowledge of their structure and composition.

Table 1. Chemical properties of twenty ZP corn hybrids

Hybrid	Protein content (%)	Starch Content (%)	Oil Content (%)
ZP 324	10.5	70.2	4.4
ZP 360	9.5	70.5	4.5
ZP 434	10.7	68.9	4.9
ZP 480	10.4	72.2	-
ZP 570	9.1	73.2	4.8
ZP 580	10.0	73.6	-
ZP 677	8.9	73.7	4.5
ZP 680	9.2	73.2	4.5
ZP 704	9.7	72.0	4.4
ZP 735	10.1	71.6	4.8
ZP 804	9.7	73.0	4.6
ZP 709t	9.4	72.4	4.8
ZP 633	10.1	71.5	5.0
ZP 300b	9.8	69.3	6.5
ZP 811b	10.6	69.2	5.4
ZP 702u	10.6	70.1	6.3
ZP 703u	9.5	71.3	-
ZP 704wx	10.5	71.7	4.8
ZP 601k	13.3	67.5	4.5
ZP 611k	13.5	67.6	4.1
Mean	10.3	71.1	4.9
Min	8.9	67.5	4.1
Max	13.9	73.7	6.5
SD	1.2	1.9	0.6

Chemical composition. - The chemical composition is one of the most easily recognizable intrinsic properties of grain. Protein, starch and oil contents were determined in corn samples. The results are shown in Table 1.

Chemical properties widely differed among twenty selected corn hybrids. The results show that protein, starch and oil contents ranged from 8.85 (ZP 677) to 13.49% (ZP 611k), 67.54 (ZP 611k) to 73.68% (ZP 677), and 4.14 (ZP 601k) to 6.48% (ZP 702u), respectively.

Physical properties. - The results of tested corn physical properties such as the test weight, 1000-kernel weight, kernel density, flotation index and water absorption index, which are also very important from the point of view of corn utilization and quality are presented in Table 2. The physical properties of twenty studied ZP corn hybrids also widely ranged similar to chemical compositions.

Table 2. Selected physical properties of twenty ZP corn hybrids

Hybrid	Test weight (kg m^{-3})	1000-kernel weight (g)	Kernel dendity (g cm^{-3})	Flotation index (%)	Water absorption index
ZP 324	789.3	359.8	1.25	60	0.185
ZP 360	772.6	378.0	1.24	71	0.215
ZP 434	809.4	392.8	1.26	26	0.216
ZP 480	807.3	373.2	1.27	29	0.195
ZP 570	800.1	371.7	1.25	37	0.220
ZP 580	771.8	380.6	1.23	58	0.217
ZP 677	795.2	358.6	1.26	46	0.155
ZP 680	801.3	363.4	1.25	30	0.160
ZP 704	800.0	321.3	1.24	47	0.259
ZP 735	822.8	323.9	1.26	12	0.222
ZP 804	812.0	364.6	1.25	42	0.207
ZP 709t	830.5	283.6	1.31	1	0.217
ZP 633	835.5	319.1	1.29	7	0.219
ZP 300b	819.8	314.2	1.26	38	0.207
ZP 811b	869.0	344.9	1.30	2	0.208
ZP 702u	791.7	363.3	1.28	11	0.255
ZP 703u	851.5	282.1	1.27	9	0.226
ZP 704wx	818.3	335.2	1.26	23	0.279
ZP 601k	880.5	121.6	1.34	3	0.224
ZP 611	897.7	153.4	1.34	0	0.220
Mean	818.8	320.2	1.27	28	0.215
Min	771.8	121.6	1.23	0	0.155
Max	897.7	392.8	1.34	71	0.279
SD	33.9	72.1	0.03	22	0.029

Test weight. - The test weight measures the bulk density as the weight of a known grain volume. For corn, test weight is considered to be a general parameter of quality because it is reduced by stress conditions of all kinds. This measure is important for the storage capacity of transport units, container sizes and machine capacities, and at the same time, it is the eldest indicator of corn grain quality. The test weight of studied hybrids ranged from 771.8 to 897.7 kg m^{-3} in ZP 580 and ZP

611k, respectively. Popcorns showed the highest test weight (880.5-897.7 kg m^{-3}), since it reflects the kernel mass density depending on shape, size and kernel density. The kernel shape and size form the inter-kernel space in a heap filled up with air. This inter-kernel space in typical dents ranges from 40 to 45%. The American Standard for corn relates the test weight to the corn class, so the US No 1 has to have at least 700 kgm^{-3}, while the US No. 5 has 550 kg m^{-3}. The current Yugoslav regulation JUS E.B.3 516 does not relate the test weight to the classes, but it limits this weight to 650 kg m^{-3}. The test weight is not a very reliable criterion of corn quality as it expresses more the pattern of grain packing regardless of the kernel shape and size.

Thousand kernel weight. - The 1000-kernel weight is a function of both kernel size and density. Some users prefer large to small kernels. In certain situations, kernels of a certain size can be better processed or handled. This parameter ranged from 121.6 g in the hybrid ZP 601k to 392.7 g in the hybrid ZP 434. Understandably, popcorns with the highest test weight had the lowest 1000-kernel weight (122.6 and 153.4 g) what is distinctive property of this type of hybrid.

Kernel density. - The kernel density presents the actual density. It is also a measure of hardness. In this study, the kernel density ranged from 1.23 g cm^{-3} n the hybrid ZP 580 to 1.34 g cm^{-3} in the popcorns ZP 601k and ZP 611k, as typical flints.

Flotation index. - The flotation index is a trait pointing out the degree of kernel hardness. Corn with a low percentage of floaters is denser than corn with a high percentage of floaters and tends to have more vitreous, horny endosperm, which is harder and more resistant to breakage than less dense, softer floury endosperm. Hence, this index ranged from 0 to 71% in ZP 611k and ZP 360, respectively. According to the obtained flotation indexes studied hybrids could be classified as it follows:

- Hybrids of a very hard endosperm with the flotation index below 10 % (ZP 611k, ZP 709t, ZP 811b, ZP 601k, ZP 633 and ZP 703u)
- Hybrids of hard kernels with the flotation index ranging from 10 to 30 % (ZP 702u, ZP 735, ZP 704wx, ZP 434, ZP 480)
- Hybrids with kernels of a medium hard endosperm and the flotation index ranging from 30 to 60 % (ZP 680, ZP 570, ZP 300b, ZP 804, ZP 677, ZP 704, ZP 580)
- Hybrids with kernels of a soft endosperm and the flotation index over 60 % (ZP 324, ZP 360)

Water absorption index. - The water absorption index could be used as a measure for evaluation of corn grain steeping properties. Steeping is a first critical step in providing a clean separation of germ, endosperm and fiber in corn wet milling. Obtained results point out that the water absorption index of twenty studied hybrids ranged from 0.155 (hybrid ZP 677) to 0.278 (hybrid ZP 704wx).

Table 3. Kernel hardness of twenty ZP corn hybrids

Hybrid	Milling response (s)	Mill lot volume (ml)	Hard fraction lot volume (ml)	Soft fraction lot volume (ml)	Hard fraction portion (%)
ZP 324	14.3	35	11	24	56.6
ZP 360	13.0	37	11	26	51.8
ZP 434	12.7	37	11	26	57.1
ZP 480	11.5	37	11	26	59.8
ZP 570	9.4	38	12	26	55.9
ZP 580	11.2	38	10	28	49.6
ZP 677	11.7	35	12	24	52.1
ZP 680	10.7	35	10	25	55.8
ZP 704	10.2	37	11	26	54.3
ZP 735	10.5	35	11	25	59.2
ZP 804	9.6	37	11	29	51.7
ZP 709e	11.4	34	9	25	61.7
ZP 633	16.4	34	11	22	63.6
ZP 300b	16.9	35	9	26	58.8
ZP 811b	14.3	34	10	24	63.5
ZP 702u	14.1	30	10	23	63.4
ZP 703u	11.6	35	10	26	58.8
ZP 704wx	10.4	36	12	24	52.6
ZP 601k	16.8	29	10	19	74.4
ZP 611k	19.9	29	9	20	75.2
Mean	12.8	35	10	25	58.8
Min	9.4	29	9	19	49.6
Max	19.9	38	12	29	75.2
SD	2.9	3	1	2	6.9

Kernel hardness. - Another very important physical property of corn is hardness, the proportion of dark yellow to white soft endosperm. Hardness is the most important to the dry milling and alkaline cooking industries that flake and/or soak corn to make breakfast cereals, snack foods, etc. Moreover, harder corn produces larger grits and better flakes. Harder kernels are generally denser. Grain density is positively correlated with yields of certain dry mill fractions. Hardness is an intrinsic characteristic that can be altered by genetics and environment. The selected hybrids also greatly differed in hardness. In this study, the results of corn hardness are expressed by the following five parameters: milling response index, mill lot volumes (total, hard and soft) and hard to soft milling fraction ratio (Table 3). The milling response and hard fraction portion as essential parameters for the degree of kernel hardness varied in the tested samples from 9.4 s (ZP 570) to 19.9 s (ZP 611k) and 49.6% (ZP 580) to 75.2% (ZP 611k), respectively.

This range of physical and chemical properties of selected ZP hybrids offers many possibilities in matching quality and desired properties of corn to the end-user's needs and requirements.

Table 4. Correlation coefficients among physical and chemical properties of twenty ZP corn hybrids

	Starch	Oil	Test weight	1000-kernel weight	Kernel density	Flotation index	Water absorption index	Hard fraction portion
Proteins	-0.80**	-0.11	0.68**	-0.78**	0.73**	-0.46*	0.25	0.81**
Starch		-0.24	-0.62**	0.62**	-0.63**	0.39	-0.23	-0.74**
Oil			-0.04	-0.01	-0.03	-0.22	0.34	0.09
Test weight				-0.76**	0.87**	-0.81**	0.13	0.59**
1000-kernel weight					-0.84**	0.63**	-0.29	-0.86**
Kernel density						-0.82**	0.1	0.93**
Flotation index							-0.26	-0.76**
Water absorption index								0.12

*, **-Significant at the 0.05, 0.01 level, respectively

Correlation among physical and chemical properties. - The correlation coefficients among the properties are given in Table 4. The results indicate a very high dependence, expressed by high correlation coefficients among test weight, 1000-kernel weight, kernel density, flotation index, hard fraction portion, protein and starch contents. The water absorption index and oil content were not highly correlated with any other parameter. Correlation coefficients for parameter pairs with $r > 0.80$ represent a relationship that might be consistent enough to have a predictive value.

Quality factors previously listed that are of simple, rapid, and reliable testing procedures are the test weight and 1000-kernel weight. Factors that are time-consuming and hard to measure are the chemical composition (protein, starch and oil), kernel density, flotation index, water absorptivity and hardness. However, a rapid and reliable determination of the chemical composition of corn can be performed by the near-infrared reflectance (NIR) method, as it estimates protein, starch and oil contents.

Obtained high correlation coefficients suggest that the test weight and 1000-kernel weight could be used as easily measurable parameters for determination of technological quality.

The results gained in this study are in agreement with ones previously published (BEKRIĆ *et al.*, 1993; BEKRIĆ *et al.*, 1994; BEKRIĆ *et al.*, 1995). POMERANZ *et al.* (1986) found out a very significant correlation between the test weight, flotation index and indicators of kernel hardness, as well as, the degree of breakage susceptibility. DORSEY-REDDING *et al.* (1991) observed protein, starch and oil contents, test weight, kernel density, water absorption index, kernel hardness, 1000-kernel weight and breakage susceptibility in 189 and 195 hybrids during 1987 and 1988, respectively, and found out that indicators of hardness were in significant correlation with the protein content, test weight and kernel density. The oil content was correlated with the kernel density and the starch content, while the correlation between the oil content and the test weight and the kernel hardness was much lower. WU and BERQUEST (1991) and WU (1992) established a positive correlation between kernel hardness and dry milling grits yield. FAX *et al.* (1992) observed effects the correlation between the chemical content and physical properties of corn such as the test weight, 1000-kernel weight, kernel density, breaking susceptibility, Stenvert hardness, water apsorbance index on starch content in the we milling processing.

CONCLUSION

Obtained results showed that physical and chemical properties of selected hybrids varied over hybrid genotypes and growing conditions. Protein, starch and oil contents ranged from 8.9 to 13.5%, 67.5 to 73.7%, and 4.1 to 6.5%, respectively. The test weight was within the range of 771.8-897.7 kg m^{-3}, while the 1000-kernel weight ranged from 121.6 to 392.7 g. The kernel density, i.e. flotation index was within the range of 1.23-1.34 g cm^{-3}, i.e. 0-71 %, respectively, while the water absorption index ranged from 0.155 to 0.278. Kernel hardness, expressed as a milling response, and a hard fraction portion varied in the tested samples from 9.4 to 19.9s and 49.6 to 75.2%, respectively.

The correlation analysis revealed a very high interdependence of the following quality parameters (r > 0.80): hardness-kernel density; hardness-1000-kernel weight; hardness-protein; test weight-kernel density; test weight-flotation index; kernel density-1000-kernel weight; kernel density-flotation index; protein-starch. These high correlation coefficients for the parameter pairs could be used to predict not so easily measurable parameters based on the known value of the corresponding easily measurable parameter.

The wide range of quality parameters provides many possibilities to bring corn properties into compliance with the end-user's needs and requirements.

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