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GRAIN PROPERTIES OF YELLOW AND RED KERNEL MAIZE HYBRIDS FROM SERBIA

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Abstract

Physical traits, kernel structure and chemical composition of five yellow and five red kernel maize hybrids were the subjects of this study. The 1000-kernel weight, a physical indicator of grain quality, ranged from 325.76±7.47 g (ZP 555 red) to 375.63±4.18 g (ZP 606). The hard endosperm fraction content varied between 57.66±0.93% (ZP 4007) and 67.08±0.42% (ZP 366 red). Regarding chemical composition, starch was predominant constituent ranging from 66.80±0.18 (ZP 4007 red) to 72.96±0.37 (ZP 606). The highest protein content was detected in ZP 606 (10.72±0.11) and the lowest in ZP 7007 red hybrid (8.63±0.04%). Milling response was highly influenced by hard endosperm fraction content (0.81**), and starch content was strongly correlated to 1000-kernel weight (0.77**). Whole-grain maize flours produced from yellow and red kernels without removing the germ are naturally gluten-free and can be used as functional food ingredients. All yellow and red kernel maize hybrids investigated in this study showed good quality parameters regarding physical properties and variations in chemical composition which makes them suitable for different industrial uses, primarily for food and feed production.

Key words**:** chemical composition, maize hybrids, physical traits, whole-grain maize flour.

Introduction

Since it was first domesticated from ancient grass teosinte between 5000 and 7000 years ago, cultivated maize spread worldwide after Columbus arrived in the New World and brought maize to Europe. Maize (*Zea mays* L.) is now one of the most important staple crops and its production ranks as the third in the world after wheat (*Triticum aestivum*) and rice (*Oryza sativa*) (Liu et al. 2020).

Maize grain, in average, consists of 71.3% starch, 9.91% protein, 4.45% fat, 1.42% ash, 6.62%, and 2.66% crude fiber (Eckhoff and Watson, 2009). Depending on the genetic background that affects the colour of the pericarp, aleurone, germ and endosperm, the colour of maize grains can vary from white and yellow, through orange, red, burgundy, blue and purple to brown. The whole kernel of coloured maize contains many secondary metabolites, such as carotenoids and phenolic compounds, of which phenolic acids and flavonoids represent their predominant form, with a number of types that exist as soluble, free and conjugated or insoluble, bound configurations (Žilić et al., 2012).

First hybrid maize (double - cross hybrid) was created by Donald F. Jones in 1918 and was later developed and introduced on a trial basis in 1924 by Henry Agard Wallace, but it wasn't until 1933 that long drought in rural parts of the USA made farmers consider starting using

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these novelty seeds (Sutch, 2011). The breeding of maize has recently been particularly focused on creating specialty hybrids with altered and improved nutritional properties.

The increasing awareness about the strong relationship between nutrition and human health has led to considerable changes in many people's dietary preferences worldwide in recent years. Dietary fiber, proteins, and bioactive phytochemicals from whole-grain maize flour, which could be either incorporated into the diet or be a part of the food itself, can be the source for gaining many health benefits. Both yellow and red whole-grain maize flours can be used as functional food ingredients. Whole-grain maize flour, obtained by grinding kernels without removing the germ first, is naturally gluten-free, and therefore suitable for persons suffering from celiac disease. Red kernel maize hybrids have a high content of phenolic compounds and can, therefore, be very beneficial from the nutritional point of view (Vančetović et al., 2012).

The quality of maize is determined by the joined effects of the cellular structure, physical and biochemical properties of the components in the grain (Paulsen et al., 2003). A multitude of factors, including environment, genetics, growing and post-harvesting conditions, kernel physical properties, chemical composition, etc., may influence variations in maize quality. In comparison to softer maize kernels that are more suitable for wet-milling, harder maize kernels exhibit better performance during storage, handling, transportation, alkaline cooking, and dry-milling. Correlations between quality properties and end-use processing performance of different maize hybrids may also vary from laboratory to laboratory (Lee et al., 2007).

Research in the field of technological value and grain quality contributes to better valorization of maize in the industrial processing, especially in the production of high-quality functional food, which aims to increase the economic value of this, for our country the most important, carbohydrate raw material.

This study aimed to examine the physical properties and chemical composition of five yellow kernels and five red kernel maize hybrids created in the Maize Research Institute, Zemun Polje, in order to assess and compare their technological value and select the best hybrids for further studies of their nutritional potentials.

Material and methods

Ten maize hybrids developed at the Maize Research Institute, Zemun Polje, were investigated in this study. The two-replicate trial was set up according to the randomized complete block design in the experimental field of the Maize Research Institute. The plot size was 21 m^2, while the sowing density was 60,000 plants ha^{-1}. Maize ears of each replicate were harvested in the full physiological maturity stage from the area of 7 m^2 (two inner rows). Twenty average ears per replicate were selected for further analysis. Whole grain maize flour was obtained by a dry grind process on a laboratory mill (Perten Instruments, Hägersten, Sweden) for fine samples preparation (mash 0.5 mm).

Methods applied for determining physical properties (1000-kernel weight, test weight, milling response, soft and hard endosperm portion, water absorption index), were described in detail in previously published paper (Radosavljević et al., 2001). In order to determine the kernel structure of the maize hybrids, 100 kernels were dissected by hand in two replicates.

Dry matter content in the maize flour was determined by the standard drying method in an oven at 105 °C to constant mass. The starch content was determined by Ewers polarimetric method (ISO 10520, 1997). The protein content was determined by the Kjeldahl method as the total nitrogen multiplied by 6.25 (AOAC, 1990). The oil content was determined according to the Soxhlet standard method (AOAC, 2000). Crude fiber content was determined by Weende method adjusted for Fibretec™ Systems, Foss, Denmark (Agricultural food products, 1993). The ash content was determined by the slow combustion of the sample at 650 ˚C (AOAC, 1990). The results are expressed in the percentages per dry matter (d.m.).

All analyses were performed in two replicates. Results are presented as means ± standard deviation (SD) and Pearson's coefficients of correlation between certain physical and chemical parameters were calculated in IBM SPSS Statistics.

Results and discussion

The kernel physical properties of the investigated ZP maize hybrids are represented in *Table 1.*

The 1000-kernel weight, an important physical indicator of grain quality, ranged from 325.76±7.47 g (ZP 555 red) to 375.63±4.18 g (ZP 606). Higher 1000-kernel weight is a preferred wet-milling characteristic because it is associated with greater starch and protein yield and lesser yields of fiber. Somavat et al. (2016) found that 1000-kernel weight for purple and yellow dent maize was lower for blue maize. Test weight is the oldest standard and easily measurable important indicator of maize grain quality. It is used in determining maize grade and significantly influences its selling price in the market, although it is a poor indicator of maize quality for processing and milled products (Paulsen et al., 2003, Lee et al., 2007). Test weight of the assayed ZP maize genotypes ranged from 777.10±2.64 kg m^{-3} (ZP 4007 red) to a maximum of 860.08 kg m^{-3} (ZP 366). These results are in accordance with the findings of Lee et al. (2007). All maize hybrids used in this study had test weights greater than 650.0 kg m^{-3}, which is required for animal feed according to Serbian regulations (Pravilnik o kvalitetu hrane za životinje, 2016), and 69.50 kg hl^{-1} (695.0 kg m^{-3}) required for US Grade No. 2 corn (Somavat et al., 2016), while in Serbia, there is no minimal request for this parameter for maize grain quality for human food consumption. Milling response and the share of hard and soft fractions of the endosperm are parameters of grain hardness which, observed from the aspect of the industrial application of maize, starch processing, in particular, represent its most important

Table 1. Kernel physical properties of maize hybrids
Tabela 1. Fizičke karakteristike zrna hibrida kukuruza

Genotype	1000-kernel weight (g)	Test weight (kg m^3)	Milling response (s)	Hard endosperm (%)	Soft endosperm (%)	Water absorption index
			Yellow kernel hybrids			
ZP 366	345.50±3.15	860.08±10.08	12.07±0.09	62.67±1.15	37.33±1.15	0.221±0.012
ZP 388	339.30±0.33	819.22±3.14	10.04±0.52	62.01±0.14	37.99±0.14	0.223±0.002
ZP 4007	332.91±17.76	798.12±7.08	8.87±0.28	57.66±0.93	42.34±0.93	0.228±0.004
ZP 555	337.31±7.04	822.59±9.04	10.44±0.05	63.31±0.34	36.69±0.34	0.208±0.001
ZP 606	375.63±4.18	818.82±4.13	10.83±0.42	64.36±0.46	35.64±0.46	0.207±0.002
			Red kernel hybrids			
ZP 366 red	357.76±0.30	838.88±0.08	11.60±0.28	67.08±0.42	32.92±0.43	0.233±0.028
ZP 388 red	343.87±0.15	812.99±0.04	9.40±0.14	60.88±0.21	39.12±0.21	0.226±0.014
ZP 4007 red	329.10±5.94	777.10±2.64	8.30±0	59.28±0.12	40.72±0.09	0.262±0.03
ZP 555 red	325.76±7.47	806.70±2.55	10.10±0.71	63.03±0.16	36.97±0.16	0.217±0.05
ZP 7007 red	367.21±5.80	806.65±3.56	9.70±0.92	61.61±1.21	38.39±1.21	0.227±0.006

physical properties. The milling response (i.e. time-to grind), assayed by a Stenvert hardness test according to Pomeranz et al. (1985) is a measure of kernel hardness which presents the time (s) needed for kernel grinding until the top level of the material collected in a glass cylinder (125 × 25 mm) reaches the level of 17 ml. The milling response results obtained in these analyses ranged from 8.30±0 s for the ZP 4007 red hybrid to 12.07±0.09 s for the ZP 366 yellow kernel hybrid. Milašinović Šeremešić et al. (2019) reported that milling responses of ten differently coloured maize hybrids from Serbia ranged from 12.10 to 25.40 s. Kernel hardness is closely related to the ratio of hard (glassy, horny) and soft (floury) endosperm (Milašinović, 2005). Maize hybrids that contain softer endosperm facilitate easy extraction of starch due to weaker protein matrix around starch granules and are therefore more suitable for wet-milling whereas maize hybrids with harder endosperm are more adequate for dry-milling as they yield grits with larger sizes (Lee et al., 2007). The share of hard and soft fractions in the kernel depends on different factors such as the genetic background and the environmental conditions. Chen et al. (2017) found that purple, blue and red maize kernels had softer endosperm composition in comparison with yellow dent maize, however, our results did not show significant differences in endosperm composition between yellow and red kernel maize. The hard endosperm fraction content ranged from 57.66±0.93% (ZP 4007) to 67.08±0.42% (ZP 366 red), and soft from 32.92±0.43 % (ZP 366 red) to 42.34±0.93% (ZP 4007). Water absorption index ranged from 0.207±0.002 (ZP 606) to 0.262±0.03 (ZP 4007 red). Water absorption index is an important parameter for the wet milling of the maize grain that aims to separate the maize kernels into their basic components (starch, protein, oil, and fibers). During the steeping (soaking or hydration) step of the process, the morphological and biochemical changes that occur are responsible for all subsequent stages of the process and, therefore, for the final quality of the product (Botelho et al., 2013). No significant differences regarding the physical properties of the investigated yellow and red kernel hybrids were detected.

Analyses of the grain structure performed by manual dissection showed that the grain in the phase of physiological maturity of the examined 10 genotypes consisted of 6.41±0.14%

Table 2. Kernel structure of the investigated maize hybrids
Tabela 2. Struktura zrna ispitivanih hibrida kukuruza

Genotype	Pericarp (%)	Germ (%)	Endosperm (%)
Yellow kernel hybrids			
ZP 366	7.58±0.28	12.77±0.49	79.65±0.76
ZP 388	7.08±0.40	12.70±0.22	80.22±0.18
ZP 4007	6.49±0.03	13.12±0.28	80.39±0.29
ZP 555	7.38±0.20	13.08±0.05	79.54±0.24
ZP 606	6.41±0.14	11.14±0.13	82.45±0.01
Red kernel hybrids			
ZP 366 red	8.31±0.47	12.73±0.19	78.96±0.66
ZP 388 red	7.95±0.20	12.24±0.47	79.81±0.28
ZP 4007 red	8.06±0.11	12.7± 0.20	79.24±0.08
ZP 555 red	8.49±0.08	13.12±0.65	78.39±0.57
ZP 7007 red	6.50±0.11	11.82±0.15	81.68±0.26

(ZP 606) to 8.49±0.08% (ZP 555 red) pericarp, from 11.14±0.13% (ZP 606) to 13.12±0.65% (ZP 555 red) germ, and from 78.39±0.57% (ZP 555 red) to 82.45±0.01% (ZP 606) endosperm (Table 2). No significant differences were detected regarding kernel structure between yellow and red maize hybrids. The results of the physical traits and kernel structure of red and yellow kernel hybrids are in accordance with previous findings on ZP maize hybrids (Milašinović Šeremešić et al., 2019, Semenčenko et al., 2015a, 2015b).

Results of the chemical composition analyses of the whole-grain flour obtained from five yellow and five red coloured kernel maize hybrids are represented in Table 3.

Dry matter content of the whole-grain maize flour ranged from 89.77±0.10% (ZP 7007 red) to 90.77±0.16% (ZP 4007). Moisture content, and therefore dry matter content influence most grain quality properties, such as kernel weight and volume, density, stress crack, breakage susceptibility, as well as chemical composition (Lee et al., 2007). Starch content ranged from 66.80±0.18% (ZP 4007 red) to72.96±0.37% (Z P606). Different authors (Johnson and May, 2003; Somavat et al., 2016) found that mean starch yields of purple, blue and red maize kernels ranged between 61.2 and 61.8% and were lower compared to conventional yellow dent maize due to the fact that breeding was mostly directed towards the increase in starch content of yellow maize at the expense of other constituents. The highest protein content was detected in ZP 606 (10.72±0.11) and the lowest in ZP 7007 red hybrid (8.63±0.04%). The protein content of ZP hybrids previously studied was in similar ranges (Milašinović Šeremešić et al., 2019, Semenčenko et al., 2015a, 2015b). Hybrid ZP 366 red had the highest oil content (6.22±0.24%), while hybrid ZP 7007 red had the lowest oil content 5.52±0.06%. Crude fiber ranged from 2.22±0.22% (ZP 606) to 2.65±0.23 (ZP 366 red).

Somavat et al. (2016) found that coloured kernels had higher crude fiber content than conventional yellow dent hybrids. Ash content was similar in all hybrids and ranged from 1.41±0.01% (ZP 7007 red) to 1.72±0.04% (ZP 4007 red). The results of the chemical composition of red and yellow kernel hybrids are in accordance with results of the studies previously conducted in the Maize Research Institute

Table 3. Kernel chemical composition of the investigated maize hybrids
Tabela 3. Hemijski sastav zrna ispitivanih hibrida kukuruza

Genotype	**Dry matter** (%)	**Starch** (%)	**Protein** (%)	**Oil** (%)	**Crude** (%)	**Ash** (%)
Yellow kernel hybrids						
ZP 366	90.76±0.15	67.18±0.31	9.70±0	5.62±0.05	2.42±0.01	1.56±0.01
ZP 388	90.42±0.20	69.01±0.25	9.10±0.11	5.83±0.04	2.44±0.07	1.54±0.02
ZP 4007	90.77±0.16	68.18±0.07	8.97±0.06	6.08±0.03	2.32±0.09	1.61±0.04
ZP 555	90.41±0.35	70.19±0.05	9.88±0.03	5.84±0.23	2.56±0.04	1.54±0.01
ZP 606	90.22±0.27	72.96±0.37	10.72±0.11	6.19±0.01	2.22±0.22	1.44±0.02
Red kernel hybrids						
ZP 366 red	90.48±0.27	68.53±1.12	9.86±0.06	6.22±0.24	2.65±0.23	1.58±0.06
ZP 388 red	90.15±0.15	69.00±0.06	9.19±0.11	5.75±0.03	2.43±0.05	1.53±0.04
ZP 4007 red	90.22±0.45	66.80±0.18	9.30±0	6.17±0.08	2.53±0.26	1.72±0.04
ZP 555 red	90.19±0.09	66.91±0.78	9.92±0.08	6.01±0.01	2.61±0.04	1.55±0.05
ZP 7007 red	89.77±0.10	70.08±0.01	8.63±0.04	5.52±0.06	2.36±0.23	1.41±0.01

(Milašinović Šeremešić et al., 2019, Semenčenko et al., 2015a, 2015b).

Insignificant differences between physical traits and chemical composition of yellow and red kernel hybrids can be attributed to the fact that red grain hybrids were created from their yellow analogues, and therefore inherited most of their parental properties.

Correlations between certain physical properties and chemical composition are represented in Table 4.

A very strong or high correlation was determined between test weight and milling response, and between test weight and hard endosperm content (0.95** and 0.66*, respectively). According to the results, there was very strong co-dependence between 1000-kernel weight and starch (0.77**) and endosperm content (0.76**), as well as a very strong negative correlation between 1000-kernel weight and germ content (-0.86**). Milling response was highly influenced by hard endosperm content (0.81**), and correlated to protein content (0.56*). Likewise, Milašinović Šeremešić et al. (2019) found that milling response was very highly negatively correlated to soft endosperm content (-0.99*). The crude fiber was in significantly negative correlation with the endosperm content (-0.89**), and in high positive correlation with pericarp and germ content (0.86** and 0.66*, respectively). Some of the results shown in Table 4 are in accordance with the findings of other authors (Milašinović Šeremešić et al. 2019, Lee et al. 2007), however, correlations between different physical and chemical parameters of maize hybrid grain can vary from year to year depending on many factors such as genotype, drought, soil, fertilizer and laboratory techniques used in the analyses.

Conclusion

All yellow and red kernel maize hybrids investigated in this study showed good quality parameters regarding physical properties and chemical composition, which represent a starting point for further research of possibilities for their industrial utilization. The results in-

Table 4. Correlation coefficients between physical traits and chemical composition of the investigated maize hybrids
Tabela 4. Koeficijenti korelacije između ispitivanih fizičkih svojstava i hemijskog sastava ispitivanih hibrida kukuruza

Traits	*1000 kernel weight*	*Milling response*	*Hard endosperm*	*Oil*	*Protein*	*Starch*	*Crude fiber*	*Pericarp*	*Germ*	*Endosperm*
Test weight	0.34	0.95**	0.64*	-0.31	0.36	0.10	0.07	0.08	0.002	-0.05
1000- kernel weight		0.44	0.50	-0.09	0.27	0.77**	-0.50	-0.45	-0.86**	0.76**
Milling response			0.81**	-0.13	0.56*	0.18	0.12	0.11	-0.09	-0.02
Hard endosperm				0.16	0.65*	0.33	0.36	0.29	-0.21	-0.07
Oil					0.51	0.02	0.17	0.21	0.05	-0.16
Protein						0.38	0.05	0.16	-0.24	0.02
Starch							-0.58*	-0.66*	-0.76**	0.81**
Crude fibre								0.86**	0.66*	-0.89**

* and ** significance at 0.05 and 0.01 probability levels, respectively

dicate that genetic variability of these hybrids opens up various paths for their technological processing and use, primarily for obtaining the gluten-free whole-grain maize flour for the production of functional food, as well as components for animal feed. However, further study of their biochemical properties is needed in order to assess the complete nutritive potentials of these maize hybrids.

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FIZIČKO-HEMIJSKA SVOJSTVA ZRNA ŽUTIH I CRVENIH HIBRIDA KUKURUZA IZ SRBIJE

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Sažetak

Fizičke karakteristike, struktura zrna i hemijski sastav pet hibrida kukuruza žutog i pet crvenog zrna, bili su predmet ovog istraživanja. Masa 1000 zrna, važan fizički pokazatelj kvaliteta zrna, kretala se u rasponu od 325,76±7,47 g (ZP 555 crveni) do 375,63±4,18 g (ZP 606). Sadržaj tvrde frakcije endosperma bio je od 57,66±0,93% (ZP 4007) do 67,08±0,42% (ZP 366 crveni), a meke od 32,92 ± 0,43% (ZP 366 crveni) do 42,34 ± 0,93% (ZP 4007). Skrob, kao najzastupljenija hemijska komponenta, varirao je od 66,80±0,18 (ZP 4007 crveni) do 72,96±0,37 (ZP 606). Najviši udeo proteina određen je u zrnu hibrida ZP 606 (10,72±0,11%), a najniži u ZP 7007 (8,63 ± 0,04%). Otpornost na mlevenje bila je u visokoj pozitivnoj korelaciji sa udelom tvrdog endosperma (0.81**), a sadržaj skroba sa hektolitarskom masom (0,77**). Integralna kukuruzna brašna, dobijena mlevenjem celog zrna žutih i crvenih hibrida, su prirodno bezglutenska i mogu se koristiti kao sastojci funkcionalne hrane. Svi hibridi kukuruza žutog i crvenog zrna ispitivani u ovom istraživanju pokazali su dobre parametre kvaliteta u pogledu fizičkih svojstava i varijacija u hemijskom sastavu što ih čini pogodnim za različite industrijske namene, prvenstveno za proizvodnju hrane za ljude i životinje.

Ključne reči: hemijski sastav, hibridi kukuruza, fizičke osobine, integralno kukuruzno brašno.

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