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MAIZE PROCESSING AND UTILISATION TECHNOLOGY - ACHIEVEMENTS AND PROSPECTS

TEHNOLOGIJA PRERADE I KORIŠĆENJE KUKURUZA – DOSTIGNUĆA I PERSPEKTIVE

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ABSTRACT

Since its establishment the Maize Research Institute, Zemun Polje has been having an extremely important role in the improvement of maize production and utilisation. The aim of this manuscript is to present results of studies on chemical composition, physical and technological grain traits, i.e. utilisable value of the most widely grown ZP maize hybrids. Previous achievements and prospects of the development of chemistry and processing technology of maize grain as a highly valuable renewable raw material for industrial processing, different technical purposes and the food and feed production are presented. Results gained in many decades of studies show that maize hybrids developed at the Maize Research Institute, Zemun Polje are the unique initial material for the production of starch, bioethanol and highly-valuable food and feed, as well as a reliable sign-post for researchers performing maize breeding and selection in order to direct future studies within this field.

***Key words**: maize, grain quality, processing technology, utilisation*

REZIME

Od svog osnivanja pa sve do danas, Institut za kukuruz „Zemun Polje“ imao je izuzetno važnu ulogu u unapređenju proizvodnje i korišćenja kukuruza. Uporedo sa ispitivanjem i ocenom kvaliteta hibrida kukuruza namenjenih proizvodnji zrna vrši se selekcija, ispitivanje i ocena silažnih formi kukuruza, odnosno ocena upotrebne vrednosti i kvaliteta kukuruzne biljke za ishranu životinja. Selekcionisani su hibridi kukuruza koji se na osnovu ispitivanih parametara kvaliteta zrna mogu svrstati u hibride visokog potencijala rodnosti, visokog tehnološkog i nutritivnog kvaliteta, konkurentni hibridima kukuruza domaćih i inostranih selekcionih kompanija. U našoj zemlji Institut za kukuruz „Zemun Polje“ je jedina naučna ustanova u kojoj se već više od pola veka sveobuhvatno radi na istraživanjima unapređenja tehnologije prerade i korišćenja kukuruza. U okviru ovog naučnoistraživačkog programa postignuti su izuzetno značajni rezultati, kao u retko kojoj naučnoj oblasti.

Cilj ovog rada je bio da se prikažu rezultati ispitivanja hemijskog sastava, fizičkih i tehnoloških svojstava zrna, odnosno upotrebne vrednosti zrna najšire gajenih zemunpoljskih hibrida kukuruza. Opisana su dosadašnja dostignuća i perspektive budućeg razvoja hemije i tehnologije prerade zrna kukuruza kao visoko vredne prirodno obnovljive sirovine za industrijsku preradu, različite tehničke namene i proizvodnju raznovrsne hrane za ljude i životinje. Rezultati višedecenijskih istraživanja su pokazali da hibridi kukuruza stvoreni u Institutu za kukuruz „Zemun Polje“ predstavljaju jedinstven polazni materijal za proizvodnju skroba, bioetanola i visokovredne hrane za ljude i životinje, kao i pouzdani putokaz istraživačima koji se bave njegovom selekcijom, u kom pravcu usmeriti buduća istraživanja u ovoj oblasti.

***Ključne reči**: kukuruz ,kvalitet zrna, tehnologija prerade, upotreba*

INTRODUCTION

Achievements in maize breeding provide its successful mass production, as well as directed growth of hybrids of standard chemical composition and hybrids with specific grain properties. The Republic of Serbia is one of the most important producers of maize, both in Europe and in the world. In recent years, studies on the improvement of the application of maize and other field crops have been gaining increased importance not only in the leading research centres but also in the Maize Research Institute, Zemun Polje (*Johnson and White, 2003; Medić, 2011; Radosavljević and Demin, 2012*). Dr. Miroslava Mihajlović was an initiator of these studies that have been following the research and scientific work on maize breeding and hybrid development at the Maize Research Institute, Zemun Polje (Mihajlović 1978). At its earliest stage of development, which lasted just a little over 20 years, only maize grain quality, i.e. its chemical composition and physical traits, were primarily observed within this scientific and research programme. Then in the 1970s when Dr. Vitomir Bekrić, Dr. Đorđe Pejić and Dr. Zoran Bebić joined the Maize Research Institute, Zemun Polje, previously performed studies were modernised and significantly broadened.

Taking into account the gained results, as well as, prospects for the research and development work on the improvement of maize utilisation at the Maize Research Institute, Zemun Polje, the Laboratory for Technological Research was established and a new scientific and research programme has been defined encompassing the most important fields of utilisation of field crops, first of all maize (*Radosavljević 2007; Radosavljević et al., 2015*; *Semenčenko et al. 2015; Milašinović-Šeremešić 2017*). Quality (chemical composition, physical and technological traits) and utilisable value of grain and plant of maize were determined. Fundamentally, even today such defined scientific and research concept is carried out within this field (*Group of authors, 2015*). These studies have been implemented and presented within previous five-year scientific and research projects of the Maize Research Institute, Zemun Polje, as well as within five national projects financed by the Ministry of Science and Technological Development. Several hundreds scientific papers, a great number of project reports and studies and three books (*Bekrić 1997 and 1999; Pejić 1994*) have been published. Dr. Vitomir Bekrić, a scientific advisor of the Maize Research Institute, Zemun Polje and a long-time supervisor of scientific and research work within the field of the technology of maize

processing and utilisation, is an author of the monograph titled "The Utilisation of Maize", which is according to assessments of leading experts within this field in our country, so far the most important publication in Serbian language (*Bekrić, 1997*). Moreover, 10 PhD and six MSc theses have been defended.

The aim of this study is to present previous achievements and prospects of further research on maize utilisation, i.e. chemistry and technology of maize processing.

MATERIAL AND METHODS

Grain quality of the most widely grown ZP maize hybrids of different maturity groups and various endosperm types were observed. The selected hybrids were grown under the same conditions with the application of the same cropping practices in the experimental field of the Maize Research Institute in Zemun Polje. Physical properties (test weight or hectolitre mass, 1000-kernel weight or absolute weight, density, flotation index, milling response, the proportion of hard and soft endosperm fractions, water absorption index) and chemical composition (content of starch, protein, oil, fibre and ash) were determined. In addition, technological properties and utilisable value of grain of observed maize hybrids to be used in starch and bioethanol production were determined.

All methods used in the present study have been already described in previously published manuscripts (*Bekrić 1997; Milašinović 2005; Milašinović-Šeremešić 2011; Semenčenko 2013*).

RESULTS AND DISCUSSION

The most recent results on grain quality (chemical composition and physical traits) testing of 55 ZP maize hybrids of various growing seasons and different endosperm types showed in Table 1 and 2.

Table 1. Chemical composition of 55 ZP maize hybrids

Chemical composition	Starch (%)	Protein (%)	Oil (%)	Fibre (%)	Ash (%)
Min	53.00	8.04	4.87	1.90	1.16
Max	74.41	13.34	10.25	3.24	1.77
Average	67.67	9.85	6.33	2.45	1.36
SD	3.93	1.26	1.21	0.29	0.12

According to gained results, there was a significant negative correlation between contents of protein and starch (r=-0.78) and oil and starch (r=-0.65) in maize grain (*Radosavljević et al., 2012*). These results, as well as previously achieved results on chemical traits of grain in dependence on the maize hybrid properties, pointed out that the greatest number of observed traits depending on the genetic base, i.e. on the type of hybrid, growing and environmental conditions, varied in a very wide range (*Radosavljević et al., 2015*). The variability of tested quality parameters provides wide possibilities for selecting maize hybrids as a raw material for certain purposes, as well as for selection of new hybrids (*Radosavljević et al., 2010*). Results obtained in this study are in accordance with results gained by foreign authors (*Johnson and White, 2003; Ketthaisong et al., 2015*).

At the Maize Research Institute, Zemun Polje, Dr. Zoran Bebić has initiated studies within the field of chemical, technological and biotechnological processing of maize, as well as technological and utilisable value of maize grain (*Bebić, 1974*). Maize grain with soft, i.e. floury endosperm is more suitable for wet milling, because steeping/soaking is easier and shorter, while separation of starch and gluten is better (*Radosavljević et al., 2000*).

A method based on the starch processing simulation under laboratory conditions was introduced to the Maize Research Institute, Zemun Polje in 2004 (*Milašinović, 2005*). The most important parameters for the estimation of the technological value of maize grain in wet milling are as follows: yield, recovery and purity of starch, i.e. the protein content in isolated starch. High starch recovery and yields are the principal parameters of a well performed maize wet milling procedure. Tables 3 and 4 present results obtained by the application of the laboratory method of the wet milling procedure to five selected maize hybrids.

According to results presented in Tables 3 and 4 starch yield varied from 60.55% (hybrid ZP 758) to 63.48% (hybrid ZP 600), which corresponds to starch recovery of 87.53% and 90,01%. The highest yields of gluten (11.54%), germ (10.51%) and bran (12.26%) were recorded in hybrids ZP 648, ZP 600 and ZP 758, respectively

Long-term studies on technological properties of selected maize hybrids by a modified laboratory wet milling method of 100-g kernels have shown that ZP maize hybrids satisfied criteria regarding recovery, purity (<0.30% protein) and quality of isolated starch (*Milašinović-Šeremešić et al., 2012*). High recovery and yield of starch, as well as a low content of proteins are the fundamental parameters of a well performed maize wet milling procedure. It was determined that hybrids with the increased starch content and a lower hectolitre mass and density, and a greater proportion of soft endosperm fraction had higher yields and recovery of starch in wet milling (*Milašinović, 2005; Milašinović et al., 2007*).

Native maize starch, as a basic product of the primary starch processing, is an initial raw material for numerous transformation processes in further industrial production, i.e. higher stages of starch processing. According to the amylase content, starches isolated from the selected ZP maize hybrids can be classified into two groups: normal, containing about 24% of amylose and waxy maize starches containing approximately 1% of amylose (*Radosavljević et al., 1995; Milašinović, 2005; Milašinović-Šeremešić, 2011*). Extraordinary nutritional and functional properties make maize starch a raw material of special importance not only for today's needs but also for future food production and the wide industrial application. There is a whole range of commercial goods obtained from maize starch, such as: starch derivates, starch sweeteners and biotechnological products (*Radosavljević, 2007*).

*Table 2. Physical traits of 55 ZP maize hybrids**

Physical traits	KWt (g)	TWt (kgm^{-3})	Den (gcm^{-3})	IF (%)	MRes (s)	HE (%)	WAI	Pericarp (%)	Endosperm (%)	Germ (%)
Min	104.1	590.0	1.16	0	7.4	42.6	0.200	5.1	71.1	8.4
Max	342.5	902.3	1.38	100	19.5	75.1	0.400	11.8	83.3	21.2
Average	249.1	764.6	1.25	58.631.4	10.6	58.4	0.250	6.9	80.6	12.6
SD	61.0	56.5	0.04		3.0	6.8	0.040	1.4	2.6	2.3

**KWt - 1000-kernel weight (g), TWt - test weight (kgm^{-3}), ADen - absolute density (gcm^{-3}), IF - flotation index (%), MRes - milling response (s), HE - hard endosperm (%), WAI - water absorption index.*

Resistant starches (RS) are a special group of dietary fibres that have been intensively studied in recent times, not only because of their significant effects on human health, but also due to effects on properties of products to which they had been added. Resistant starches may be categorised into four types: RS1 - physically protected, inaccessible (fully or partially processed milled whole grains, seeds, legumes); RS2 - ungelatinised resistant granules with the type-B crystallinity slowly hydrolysable by α-amylase (raw potatoes, green/unripe bananas, some legumes, high amylase maize); RS3 - retrograded starches (cooked and cooled potatoes, bread, cornflakes, food products with repeated moist heat treatment); RS4 - chemically modified starches (foods containing starch derivates (bread, cakes)) (*Milašinović-Šeremešić, 2011*). Resistant starch is defined as a starch fraction that resists enzyme hydrolysis in the small intestine, but can be degraded (fermented) in the large intenstine (colon). Therefore, resistant starch, due to its very low glycemic index, may be defined as a dietary or "functional" fibre. A positive effect of resistant starch in diet is actually based on the result of the fermentation process during which short-chain fatty acids, primary acetates, propionates and butyrates, are produced. The studies carried out with the hybrid ZP 434 indicated that the starch of this hybrid was suitable for pullalanse debranching and producing of resistant starch of the type 3 (*Milašinović-Šeremešić, 2011; Milašinović et al.,2010, 2009*).

Table 3. Characteristics of wet milling of ZP maize hybrids

Genotype	Steeping/soak water (%)	Germ (%)	Bran (%)	Starch (%)	Gluten (%)	Process water (%)
ZP 600	4.68	10.51	9.70	63.48	6.00	0.12
ZP 606	4.34	8.76	9.34	61.70	11.02	0.13
ZP 648	4.40	8.59	7.96	60.72	11.54	0.18
ZP 758	4.58	8.39	12.26	60.55	8.55	0.17
ZP 802	4.12	7.56	10.31	63.45	8.05	0.17
Min	4.12	8.39	7.96	60.55	6.00	0.12
Max	4.68	10.51	12.26	63.48	11.54	0.18
Average	4.42	8.76	9.91	61.98	9.03	0.15
SD	0.22	1.08	1.57	1.42	2.27	0.03

From a technological point of view, resistant starch produces better results than other "traditional" natural fibres. Resistant starch may be practically used in many food systems, and its addition can affect the structure, texture and other properties of newly derived products. The use of resistant starch of types 3 and 4 in small pasta formulation resulted in a product of improved sensory and nutritional quality (*Milašinović-Šeremešić et al., 2013*). Gained results point out to a good potential of resistant starch as a functional ingredient from the aspect of its application in the production of cakes and fibre-rich related products (*Milašinović-Šeremešić*, 2011).

Currently in Serbia, maize is the most suitable plant for the production of bioethanol. The most important criterion for maize-based alcohol production is the grain starch content, which should be above 70% in order to get 37-40 litres of ethanol out of 100 kg of maize (*Radosavljević, 2007*). At the Maize Research Institute, Zemun Polje, in addition to the stated parameters of quality: chemical composition, physical traits and technological properties of maize grain wet milling, in recent times studies aimed on further development of ethanol production have been carried out. Due to ampleness of various maize hybrids, national raw matrials were used to test the suitability of selected hybrids for the production of bioethanol.

Table 4. Content, yield and recovery of starch of ZP maize hybrids

Genotype	Starch (%)	Starch yield (%)	Starch recovery (%)
ZP 600	70.52	63.48	90.01
ZP 606	69.28	61.70	89.05
ZP 648	70.34	60.72	86.32
ZP 758	69.17	60.55	87.53
ZP 802	70.55	63.45	89.93
Min	69.17	60.55	87.53
Max	70.55	63.48	90.01
Average	69.97	61.98	88.57
SD	0.69	1.42	1.60

Bioethanol is biofuel that is globally mostly used as a substitute for fossil fuels. The production of this fuel has been increasing, and maize is one of the best renewable raw materials for its production due to the high starch content in grain (*Medić 2011*; *Medić et al., 2015)*.

In the process of separate hydrolysis and fermentation, under the optimum reaction conditions: maize flour to water ratio of 1:3; concentration of α-amylase Termamyl SC 0.02% (v/w), glucoamylase SAN Extra L 0.12% (v/w) and concentration of yeast inoculum *Saccharomyces cerevisiae* var. *ellipsoideus* 2% (v/v); fermentation temperature of 30˚C and fermentation time of 44h, high yields of this biofuel were achieved (Figure 1).

The bioethanol content after 44-h fermentation ranged from 8.36% (ZP 588) to 9.13% (ZP 555), while achieved percentage of maximum theoretical yield of bioethanol varied from 87.33% to 93.59% for hybrids ZP 505 and ZP 606, respectively. The highest (2.08 g l^{-1} h^{-1}), i.e. lowest (1.90 g l^{-1} h^{-1}) volumetric productivity was recorded in the hybrid ZP 555, i.e. ZP 588, respectively. The hybrid ZP 606 expressed the best fermentation properties and can be characterised as the most suitable for the bioethanol production.

Results obtained in previous studies showed that out of 27 observed hybrids, the hybrid ZP 434 had the highest yield of bioethanol of 94.5% of the theoretical bioethanol content in the process of separate hydrolysis and fermentation. The high bioethanol yield of this hybrid was attributed to the high starch content in grain, as well as to a high proportion of soft endosperm fraction that is more susceptible to the action of enzymes that hydrolyses starch. Furthermore, high yields of bioethanol were also recorded in the following hybrids: ZP 377, ZP 548, ZP 606, ZP 666 and ZP 747 (*Semenčenko, 2013*). Studies performed on ZP hybrids indicated that bioethanol yields depended, to a certain extent, on a genotype, i.e. particular physical and chemical traits of maize hybrids (*Semenčenko et al*., 2015).

Maize pulp is an important by-product in the bioethanol production and an excellent source of proteins and energy for animals, which is why it is most often use as an ingredient in feed mixtures. Studies carried out at the Maize Research Institute, Zemun Polje on samples of maize pulp obtained by the

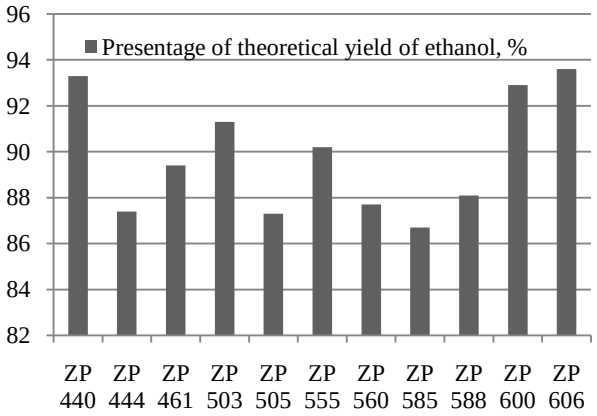

Fig. 1. Comparative presentation of yields of bioethanol produced from ZP hybrids

production of bioethanol from grain of ZP hybrids, showed that these samples had favourable properties regarding physical traits, chemical composition, presence of mineral matters, contents of digestible and metabolic energy, as well as, the percentage of dry matter digestibility (*Semenčenko et al., 2014*).

CONCLUSION

Maize hybrids selected at the Maize Research Institute, Zemun Polje, according to tested quality parameters may be estimated as hybrids with high technological and nutritional quality of grain. Chemical composition, physical and technological traits of grain of observed maize hybrids varied in a very wide range. Obtained results are in accordance with results previously published by Serbian and foreign authors. Based on observed quality parameters, the ZP maize hybrids may be estimated as hybrids of high quality for the production of starch, bioethanol and highly-valuable food and feed. The ZP hybrids are also highly competitive with maize hybrids developed by other domestic and foreign companies.

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