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BREEDING OF SPECIALITY MAIZE FOR INDUSTRIAL PURPOSES

Zorica PAJIĆ[1], Milica RADOSAVLJEVIĆ[1], Milomir FILIPOVIĆ[1], Goran TODOROVIĆ[2], Jelena SRDIĆ[1] and Milovan PAVLOV[1]

[1]Maize Research Institute, Zemun Polje, Belgrade, Serbia
[2]Institute for Medicinal Plant Research "Dr Josif Pančić", Belgrade, Serbia

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The breeding programme on speciality maize with specific traits was established at the Maize Research Institute, Zemun Polje, several decades ago. The initial material was collected, new methods applyingto breeding of speciality maize, i.e. popping maize, sweet maize and white-seeded maize, were introduced. The aim was to enhance and improve variability of the initial material for breeding these three types of maize. Then, inbred lines of good combining abilities were developed and used as components for deriving new superior popping maize hybrids, sweet maize hybrids and white-seeded maize hybrids. Breeding was aimed at the increase of the

Corresponding author: Zorica Pajić, Maize Research Institute, Zemun Polje, S. Bajića 1, 11185 Belgrade, Serbia. E mail: zpajic@mrizp.rs

popping volume of new inbred lines and hybrids of popping maize, then at the improvement of quality of popped kernels - flakes, and at yield increasing. Furthermore, the aim was to improve quality of sweet maize for different purposes, industrial processing and consumption as fresh food and also to improve yield and quality of white-seeded maize. As a result of such breeding, 28, 11 and 9 sweet maize, popping maize and white-seeded maize hybrids were released, respectively.

Key words: breeding, genotypes, popping maize, sweet maize, white-seeded maize

INTRODUCTION

Maize is our most important agricultural crop and the pillar of the national economy that should be used in making as many products of various purposes as possible. The actual value of maize is determined by the mode of its use; each new application results in the increase of its value. Globally, the participation of maize not only in processing of feed, bioethanol and other products, but also in the food industry has been increasing during the last decades. Maize and wheat are the major source of carbohydrates and proteins for almost a half of the world's human population. At the same time, it is a main source of plant proteins in feed. The structure of its utilisation has been changing over both, time and countries, but its value remained high.

A great diversity of maize grain properties provides the alteration of the grain composition in relation to quantity and quality of certain components. This is achieved by the breeding process. Maize is primarily grown as an energy crop, but the use of different specific types such as sweet maize, popping maize and white-seeded maize is quite extensive. Due to certain traits and the modes of genetic control of these traits, the mentioned specific types of maize require a special attention in the process of breeding, seed production, commercial production and processing.

MATERIALS AND METHODS

The objectives of studies within breeding of speciality maize (sweet, popping and white-seeded maize) are the development of hybrids of high genetic yield potential and grain quality. The studies are also aimed at the improvement of the utilisation of the mentioned types of maize. In order to achieve set goals, genetic variability of the initial material of the stated maize types should be as high as possible, then, inbred lines should be classified into heterotic groups and combining values for desirable traits should be evaluated.

The methods that are applied in selection programmes on sweet, popping and white-seeded maize depend on specific aims of the programmes and the available breeding material. The aim of the current programme on the development and improvement of selection populations is the improvement of the initial material that is used as a source for the development of new inbred lines. The synthetic population ZPSyn I*su* was derived from 16 early maturity inbred lines. The second, late maturity population ZPSyn II*su* was developed by crossing 15 inbred lines. Each of these populations has its internal structure, that is, each inbred that is included into the population is a sub-population. The selection procedure is based on the recurrent selection, four years per a cycle, with phenotypic selection within sub-populations (ear appearance and size, kernel appearance, colour and size, plants without tillers). A total of 20 to 30 progenies is selected from each population for the further work. The selection intensity amounts to approximately 15%. Progenies of each sub-population are recombined for each population separately, and each progeny-inbred is used as a female component, while a mixture of the equal amounts of seeds of each of these inbreds is used as a male component. Self-pollination and combining ability tests are performed after two recombination processes per a cycle. The inbreds expressing any of desirable traits are included into the inbred developmental programme in order to evaluate them additionally, and the best inbreds will be used for the development of new hybrids Tab.1., MIŠOVIĆ *et al.* (1990); PAJIĆ (1990); BABIĆ and PAJIĆ (1994); DUMANOVIĆ amd PAJIĆ (1998); PAJIĆ and SRDIĆ (2007).

The sweet maize synthetic population ZPSynIII*su* was derived from five sweet maize inbred lines with particularly deep kernels. The selection procedure is the same as in previous populations. A special attention is paid to the progeny selection, as beside other desirable traits, these progenies have also to be characterised by deep kernels.

The popping maize population ZPSyn Ipc was developed from 12 full season yellow pearl-shaped popping maize inbred lines. The second early maturity popping maize population ZPSyn IIpc was derived from eight early maturity inbred lines. The selection process is the same as in sweet maize synthetics. The only difference relates to traits for which selection is done (grain yield, popping volume, flake quality, plant appearance and stability), PAJIĆ (1990); DUMANOVIĆ and PAJIĆ (1998); PAJIĆ *et. al*.(2000); PAJIĆ and SRDIĆ (2007). Two popping maize synthetics, ZPSynIIIpc (Supergold) and ZPSynIVpc (South American), were developed from inbreds of a different origin. The selection procedure is the same as in the previous two popping maize synthetics.

Two white-seeded synthetic populations of different types, BSSS and Lancaster, were derived. The selection procedure is similar to the procedure of the previous synthetic populations. The pure white colour of the kernel, the plant appearance and stability are the traits that are important, PAJIĆ *et. al*. (2000); PAJIĆ and SRDIĆ (2007).

In recent time, not only traditional methods, but also protein and molecular-genetic markers methods have been applied. The classification of a certain number of popping and sweet maize inbred lines into heterotic groups has been performed by the application of protein and molecular-genetic markers. The application of genetic markers provides processing of a greater number of inbreds for a shorter period of time, and in such a way efficiency of any breeding programme is improved, ERIĆ *et al*. (2003); DRINIĆ *et al*. (2006); SRDIĆ *et al*.(2008).

RESULTS AND DISCUSSION

The best inbreds (progenies) derived by the programme on the development and improvement of synthetic populations are used to derive new inbred lines, which will be components of new, superior hybrids. The highest number of commercial sweet maize hybrids are based on one or several recessive alleles that alter endosperm carbohydrate composition, TRACY, (2001). Sweet maize grain at the milk stage is used as food or for industrial processing. Quality of immature grain is regulated by genes (mutants) by which sweet maize differs from standard grain maize. They cause the accumulation of water soluble polysaccharides (WSP) twice as much than standard maize at the immature grain stage when it is consumed, BOYER and SHANNON (1984); BOYER (1985). Sweet maize is often used directly in ears (sweet maize fresh market). Some traits that are relatively insignificant in other types of maize are very important for fresh sweet maize consumption. The trait ear appearance encompasses the number of kernel rows per ear, row configuration (direction and setting), kernel set, kernel width and depth and the ear size. The hybrids intended for fresh sweet maize market should produce a great number of attractive ears per area unit. The most important traits for sweet maize hybrids intended for industrial processing, i.e. for kernel cutting, are those affecting the kernel appearance after cutting, as well as, the colour, width and depth of the kernel. Deeper kernels provide better appearance after cutting, and therefore they provide higher yields. The ear shape is also important in sweet maize industrial processing. Breeding provides the development of hybrids for different ways of utilisation, i.e. hybrids required by the market, Tab.1.

Table 1. Yield and organoleptic properties of released ZP sweet maize hybrids

Hybrid	Ear yield (t ha^{-1})	Quality evaluation Total points (100%)
ZPSC 391 su	13.0	90
ZPSC 411 su	16.7	93
ZPSC 424 su	15.6	86
ZPSC 504 su	14.3	96
ZPSC 421 su	12.9	89
ZPSC 424 su	15.8	91
ZPSC 531 su	17.3	83
ZPSC 411 su	16.6	92
ZPSC 462 su	14.1	85

*Source: Commission for the Variety Releasing of the Republic of Serbia

In the process of sweet maize selection, breeding materials are selected from several sources, with, first of all, the elite sweet maize material, adapted breeding material not belonging to the sweet maize type (Corn Belt Dent) and non-adapted (tropical) populations. The adapted germplasm that does not belong to the sweet maize type is a good source of genes that improve a plant type, resistance to diseases and stress, but there is a risk of loosing the flavour and sweetness that are very important for sweet maize grain quality. On the other hand, the tropical material that is directly used as human food has already undergone the selection for grain flavour and sweetness, and can be a better source for the improvement of sweet maize traits, BREWBAKER (1977). Fourteen out of many known mutants affecting the endosperm development are studied in order to be used in sweet maize breeding, while eight mutants are commercially used. Sucrose is a dominant sugar in sweet maize grain, which provides sweetness of grain. The sucrose content changes during the endosperm development and reaches its peak 23-25 days after pollination when grain is consumed, PAJIĆ and RADOSAVLJEVIĆ (1987); TRACY (2001); VIDENOVIĆ *at al.* (2003).

The evaluation of combining abilities of inbred lines is done by testing these inbreds with several tester inbreds whose combining ability is known. The estimation of obtained test crosses, that is, new hybrid combinations is done in trials with replications. The yield and/or yield components, such as the kernel depth and the ear size, and quality properties, are evaluated. The aim is to identify the best hybrids. The hybrids with the potential for processing are frozen or tinned, or both, during the last stage of evaluation. Many traits can be rapidly, efficiently and subjectively evaluated. In order to estimate traits such as the sugar content, tenderness and succulence of grain specific equipment is necessary. Since these analyses are expensive and time consuming, they are usually performed at the last stage of testing. The yield and yield components are determined during all testing stages, BREWBAKER (1977); PAJIĆ and RADOSAVLJEVIĆ (1985); PAJIĆ *et al.* (1994).

The grain yield (economically most important) and the popping volume are traits equally important for popping maize. Similar to sweet maize, popping maize germplasm does not have broad genetic variability such as germplasm of standard grain quality maize. A great attention is paid to the trait popping volume. Genotypes with desirable agronomic traits and at the same time a high popping volume are selected by the evaluation of progenies and experimental hybrids. The popping expansion, defined as a volume of popped kernels in relation to the volume of kernels that are not popped, is one of the most important tasks in the popping maize selection programme, HOSENEY *et al.* (1983); ROBBINS and ASHMAN (1984); PAJIĆ *et al* (2006). The evaluation of popping maize hybrids encompasses the yield, popping volume and quality of popped kernels. At harvest, a sample is drawn, naturally dried and manually shelled not to damage the pericarp and is used to determine the popping volume. In order to obtain a maximum genetic potential of the popping volume of a certain type (hybrid) it is necessary to perform harvest at the stage of grain full maturity. Only volume of popped kernel can be easily measured, Tab.2. DOFING *et al*. (1990); PAJIĆ and BABIĆ (1991); ZIEGLER (2001); PAJIĆ *et al* (2006).

The evaluation of relatedness and the classification of a certain number of popping maze and sweet maize hybrids into heterotic groups were done by the application of protein (biochemical) markers and molecular genetic markers (RAPD method), BAUER *et al.* (2006); DRINIĆ *et al*. (2006); SRDIĆ *et al.* (2008); PAJIĆ *et al*. (2009).

Table2. Grain yield and popping volume of released ZP popping maize hybrids

Hybrid	Grain yield (t ha^{-1})	Popping volume (cc g^{-1})
ZPSC 614 k	6.8	42
ZPSC 611 k	6.4	42
ZPSC 601 k	4.9	43
ZPTC 501 k	5.3	37
ZPSC 622 k	5.2	43
ZPTC 615 k	4.9	39
ZPTC 621 k	5.1	40

*Source: Commission for the Variety Releasing of the Republic of Serbia

Besides the yield, a pure white colour of kernels is a trait important for white-seeded maize. The breeding material does not have great genetic variability as germplasm of standard yellow grain quality maize. White-seeded maize is a type of maize with the endosperm of the clear white colour without hues of the yellow colour. The white colour is controlled by a recessive gene *y*. If a dominant allele *Y* is present, instead of the recessive one, the kernel colour is yellow. Modern technological processing of white kernels requires that anthocyanin pigments producing yellow, red or blue colours must not be even traceable, PONELEIT (2001). Only inbreds with *y* allele without any modifiable loci are acceptable in the development and evaluation of white-seeded maize inbred lines. The yellow endosperm elite inbreds and their recognised heterotic pairs have a significant role in the white-seeded maize breeding programme. The conversion of yellow kernel germplasm into the white colour was successful in the development of new white endosperm elite inbreds and hybrids, Tab. 3. , PAJIĆ *et al.* (2009).

Due to this, some grain properties (pure white colour without a trace of pigmentation, large, uniform kernel of a high density, as strong as possible absence of dentiness, easy pericarp-endosperm separation, white cob) have become so important that the attention paid to it during selection has equalled the attention paid to yield. Moreover, resistance to grain diseases, is one of important conditions for high grain quality of white-seeded maize intended for industrial processing, RADOSAVLJEVIĆ *et al.* (2009).

Besides standard physical and chemical properties, kernel usability was observed in a greater number of different ZP maize hybrids, popping and white-seeded maize. The most important parameters for the evaluation of wet milling properties of white-seeded and popping maize hybrid grain are grain yield, starch purity, i.e. the protein content in isolated starch, Tab, 4 and Tab. 5. The starch yield presents a relationship between an amount of obtained starch and the initial amount of grain, while starch recovery is a percentage participation of obtained starch in relation to the total amount of starch. Results on starch yield and recovery obtained by the laboratory method of wet milling can be of exceptional importance in selection of speciality maize hybrids, that is of white-seeded and popping maize hybirds, RADOSAVLJEVIĆ *et al*. (2009).

Table 3. Yield and other traits of white-seeded hybrids (Results of the Commission for the Variety Releasing)

Hybrid	2006			2007		
	Grain yield (t ha^{-1})	% moisture	% Lod./break. plants	Grain yield (t ha^{-1})	% moisture	% Lod./break. plants
Standard 1	7.64	27.3	11.09	7.90	29.03	1.71
Standard 2	8.63**	25.39	3.12	8.79*	26.45	1.46
ZPSC 620b	9.63**	26.97	2.91	9.91**	28.64	0.21
ZPSC 718b	9.86**	26.61	1.30	10.74**	26.79	1.47
ZPSC 766b	10.71**	27.56	3.86	10.67**	30.09	0.21
ZPSC 785b	8.37*	30.55	15.27	7.05	36.59	1.88
ZPSC 791b	9.18**	31.56	4.32	7.67	38.74	0.83
Cv	10.35			11.37		
Lsd 0.05	0.67			1.052		
Lsd 0.01	0.88			1.403		

*,** - significant at the probability level of 95%, i.e. 99%, respectively

Table 4. Physical grain properties of ZP speciality maize genotypes

Genotype	HM	AM	G	IF	OM	TF	MF	IAV
2008								
ZP 718b	822.2	301.0	1.29	3.7	12.6	70.8	29.2	0.202
ZP 766b	826.0	304.0	1.29	10.4	12.0	69.1	30.9	0.189
2007								
ZP 74b	801.9	338.7	1.29	2.9	14.8	65.6	34.4	0.222
ZP 300b	803.2	282.1	1.26	21.8	12.1	63.2	36.8	0.207
2005								
ZP 74b	774.4	350.4	1.27	9.3	17.3	61.9	38.1	0.258
ZP 300b	729.6	296.9	1.23	50.5	13.5	59.5	40.4	0.220

* HM– test weight, ($kg \cdot m^{-3}$); AM–absolute weight (g); G–density, ($g \cdot cm^{-3}$); IF– floatation index (%); OM– milling response, (s); TF– hard milling fraction, (%); MF– soft milling fraction, (%); IAV– water absorption index.

Table 5. Chemical grain composition of ZP maize hybrids

Hybrid	Starch (%)	Oil (%)	Proteins (%)	Crude fibre (%)	Ash (%)
ZP-74b	71.54	4.74	10.08	1.58	1.36
ZP-434	70.92	5.10	9.68	1.80	1.35
ZP 551b	69.60	5.10	10.40	2.50	1.40
ZP-611k	69.88	4.80	12.44	1.90	1.51
ZP-633	73.99	4.99	9.53	1.50	1.23
ZP-677	74.39	4.90	8.64	1.56	1.20
ZP-704wx	72.65	5.11	9.62	1.69	1.51

CONCLUSION

The development of new speciality maize hybrids (sweet, popping and white-seeded maize) encompasses not only agronomic traits that are important as in standard grain quality maize, but also traits of quality. Selection methods applied in breeding of standard grain quality maize are, with certain changes, also applied in breeding of speciality maize. Each type of maize is characterised by certain specificities depending on the trait for which breeding is done. Speciality maize hybrids with good agronomic properties and, at the same time, with excellent properties of quality can be developed by breeding.

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OPLEMENJIVANJE KUKURUZA SPECIFIČNIH SVOJSTAVA ZA INDUSTRIJSKE POTREBE

Zorica PAJIĆ[1], Milica RADOSAVLJEVIĆ[1], Milomir FILIPOVIĆ[1], Goran TODOROVIĆ[2], Jelena SRDIĆ[1] i Milovan PAVLOV[1]

[1] Institut za kukuruz „Zemun Pole“, Beograd, Srbija
[2] Institut za proučavanje lekovitog bilja „Dr Josif Pančić“, Beograd, Srbija

I z v o d

U Institutu za kukuruz “Zemun Polje”, Beograd, je pre nekoliko decenija zasnovan program oplemenjivanja kukuruza specifičnih svojstava. Prikupljan je početni materijal, radilo se na upoznavanju najnovijih metoda koje se koriste u oplemenjivanju kukuruza specifičnih osobina, tj. kokičara, šećerca i kukuruza belog zrna. Cilj je bio povećanje i poboljšanje varijabilnosti početnog materijala za oplemenjivanje ova tri tipa kukuruza. Zatim, stvaranje samooplodnih linija visoke kombinacione vrednosti koje se koriste kao komponente za stvaranje novih superiornijih hibrida kukuruza šećerca i kokičara i kukuruza belog zrna. Oplemenjivanje je usmereno na povećanje zapremine kokičavosti novih samooplodnih linija i hibrida kokičara, kvaliteta iskokanog zrna «kokica» i prinosa zrna. Zatim, poboljšanju kvaliteta kukuruza šećerca za različite načine korišćenja, industrijska prerada i potrošnja u svežem stanju i povećanju prinosa i kvaliteta hibrida belog zrna. Rezultat dosadasnjeg rada je veći broj priznatih hibrida kukuruza šećerca (28), kokičara (11) i kukuruza belog zrna (9).

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