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CHARACTERISTICS OF NEW MAIZE INBRED LINES AND THEIR HYBRIDS WITH HIGH NUTRITIONAL AND FEED QUALITIES

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Breeding and selection of inbred lines ZPPL 146 and ZPPL 159 and hybrids developed from them (ZP 633, ZP 735 and ZP 737, primarily intended for feed) have been carried out for almost three decades. These inbred lines and hybrids have high nutritive values, they are rich in pigment properties, have efficient photosynthesis and other relevant parameters characteristic for standard hybrids. Observed maize hybrids are very important as carbohydrate rich nutrients. Feed produced from these hybrids is of high productivity and high quality. Due to their high productivity of total dry matter per area unit, these hybrids represent one of the most important forage products. Moreover, the study presents the importance of the chemical composition of maize hybrid grain in essential biogenic substances particularly pigments that have antioxidant properties.

Key words: Zea mays L., maize, inbred lines, hybrid, thylakoid membrane, photosynthetic model, delayed chlorophyll fluorescence, pigment properties, nutritive value, feed.

The period from 1954 to the present day have become historically significant, because a tremendous success in maize breeding and high quality hybrid seed production was achieved. As a result of such activity over 1500 grain and silage hybrids have been derived [8, 10, 13, 14, 48, 50]. Modern technical and technological prerequisites were provided for successful carrying out the process of breeding, efficient production of hybrid maize seed and significant amounts of seeds of commercial and silage hybrids [3, 5—7, 9, 14—17, 19, 25, 26, 35]. The studies on maize photosynthesis carried out in the previous period did not have a more important application in breeding and the maize hybrid seed production. Although, some research revealed sufficient genetic variability among maize inbred lines for physiological traits [4], it was almost impossible to pre-

*The authors dedicate this work to memory of the academician D.M. Grodzinskij and Dr. B.S. Dinić.

sent practical results and a clear and direct interrelationship among photosynthesis, breeding and the production of maize hybrid seed by an old and traditional approach. The way out was found in the functional connection of photosynthetic functions with fluorescence [19, 21].

In the context of the stated development dynamics, interdependent studies of many scientific disciplines (physiology, biochemistry, biophysics, biotechnology, breeding, photosynthesis and Raman spectroscopy) have been linked with the aim of modernizing and efficient implementation of up-to-date programmes on maize breeding and seed production [20, 24, 29, 36, 39, 41, 42]. In addition to outstanding results achieved in selection of standard grain and silage maize hybrids, there was a pressing need to develop new inbred lines and better quality maize hybrids intended for livestock feeding that would have improved chemical composition of grain, especially in essential bioactive compounds [3, 5—7, 9, 15—17, 22, 25, 46, 49].

To meet many demands, justifiable and great needs for functional and quality nutrition of people (mainly children and the elderly) and domestic animals (primarily cows and sheep) it was necessary to select new maize inbred lines with significantly richer pigment-complex properties and the exceptional nutritional value. This aim was achieved with the increased content of carotenoids and other bioactive compounds. With such inbred lines, it was possible to develop high-quality maize hybrids, which would meet established medicinal and veterinary criteria and be necessary for healthy food and feed, which was the objective of the present study.

Material and Methods

Plant material. The 30-year studies were performed with two maize inbred lines: ZPPL 146 and ZPPL 159 and three high yielding and high quality maize hybrids derived from these inbreds: ZP 633, ZP 735 and ZP 737. The observed maize inbreds and hybrids belong to the collection of the Maize Research Institute, Zemun Polje, Belgrade, Serbia. As these are inbred lines with improved chemical properties and high quality maize hybrids with their use in nutrition of people (ZP 633) and domestic animals (ZP 735 and ZP 737), their traits were separately analyzed.

Overall studies of the stated inbred lines and high-quality hybrids with erect top leaves developed from these inbreds encompassed several series of experiments in which new and standard methods and procedures were applied.

Chemical composition of inbred lines and high-quality maize hybrids. Methods applied to determine the grain chemical composition of maize inbred lines and hybrids are generally accepted and standardized and already described in detail in previous papers [1, 5, 43, 46, 47, 49, 52].

Resonance Raman spectroscopy method applied to maize inbred lines. Measures of resonance Raman spectroscopy of maize inbred line leaves were done in accordance with the procedure and the method described in our previously published manuscripts [30—33, 46].

The measure of the angle and the leaf area of maize inbred lines. This series of experiments was related to studying the erect position of top leaves in maize inbred lines. A specially designed protractor was used to measure the angle between the position of the above-ear leaf and the position of the plant stalk on observed maize inbred lines. The leaf area was measured by the LI-3000 portable leaf area meter (LI-COR Biosciences, USA). Measures of the angle between the above-ear leaf and the stalk and the leaf areas were carried out on

122 plants for each maize inbred line. These methodical procedures had been described in previously published papers [42, 43, 46].

Photosynthetic fluorescence measurements. This series of the experiments was related to photosynthetic fluorescence studies, including thermal processes of delayed chlorophyll fluorescence (DF), critical temperatures (phase transitions) and activation energies. The test maize inbreds were grown in the experimental field of the Maize Research Institute, Zemun Polje. Plants were brought from the experimental field to the laboratory between 7 a.m. and 8 a.m. These plants sampled in the field were transversally cut in the ground internode. In the laboratory, plants were placed in water along the length of one internode. Prior to the fluorescence experiment, all plants were kept under the black ball glass for two hours. A segment of intact above ear leaves was taken from such plants and placed into a chamber of the phosphoroscope. The intact leaf segments were kept in the chamber (in the dark) for at least 15 minutes, and then thermal processes of DF were measured. These tests were performed on 111 plants of each maize inbred line. An improved, non-invasive photosynthetic fluorescence method was applied for these measurements. This method was developed at the Maize Research Institute and was described in previously published manuscripts [36, 37, 39, 40, 41, 43, 44].

Survey of breeding and seed production properties of maize inbred lines. Since these maize inbred lines with efficient photosynthesis, rich in pigments and with exceptional nutritive qualities are promising, the broad survey of their relevant breeding and seed production properties, traits and parameters obtained by standard methods of ranking [40—42, 44], are presented in this manuscript.

Functional dependence of the yield of studied maize grain and silage hybrids. Numerous and long-term studies on yields (t ha^{-1}) of the three high-yielding and high-quality grain and silage maize hybrids (ZP 633, ZP 735 and ZP 737) were performed in many locations in Serbia and other countries of South-Eastern Europe. Standard methods for maize production, tinning and processing were applied in these studies [3, 5—7, 11, 15—17, 25, 44, 51].

Agronomic and veterinary estimation on need for animal feeding with maize silage. After 1,150 years of the initial processes of plant ensilage, food tinning technology started flourishing during the second half of the 20th century (1955—1965). Contemporary, intensive and lucrative production in cattle husbandry cannot be imagined without silage feed. Furthermore, the advantages of such feed is also obvious in sheep and goat breeding and to a smaller extend in pig breeding [7, 11, 15—17, 25, 45]. The authors of this study became interested in this topic at the beginning of the 21th century [38]. At that time, a great number of high-quality maize hybrids were developed for the production of high-quality silage with the aim to control of metabolic processes of domestic animals, and thereby their rate of gain and quality of meat and milk.

Results and discussion

1. Chemical composition and physical traits of grain of maize inbred lines and high-quality maize hybrids. Results on studies of the chemical composition and physical traits of grain of observed maize inbred lines and hybrids are presented in Table 1. Obtained results relate to important chemical and physical constituents.

2. Conformational changes in carotenoid molecules in the leaf of maize inbred lines. Raman spectra are very suitable for studying photosynthetic pig-

TABLE 1. Results obtained in analyses of chemical composition and physical traits of grain of maize inbred lines and hybrids

Grain chemical composition of maize inbred lines and hybrids	Range of the chemical composition given in literature*	Average of the chemical composition given in literature*	Average grain chemical composition of observed maize inbred lines and hybrids				
			Inbreds		Hybrids		
			ZPPL 146	ZPPL 159	ZP 633	ZP 735	ZP 737
Moisture (%)	7—23	16	10.24	10.12	9.90	9.84	10.15
Starch (%)	61—78	71.7	67.80	66.26	68.23	64.39	67.86
Protein (%)	6—12	9.5	10.22	12.57	11.11	12.27	11.57
Fat (oil) (%)	1—5.7	4.3	7.53	5.38	6.11	5.82	7.16
Ash (%)	1.1—3.9	1.4	1.48	1.45	1.51	1.54	1.47
Cellulose (%)	—	3.0	2.26	2.33	2.37	2.43	2.00
Soluble carbohydrates (%)	—	—	0.20	0.25	0.40	0.46	0.20
Yellow pigments (μgβCE/g d.m.)**			19.0	18.10	27.30	21.90	21.60
Total carotenoids (mg/kg)	12—36	26	33.2	31.8	32.4	28.3	27.8
1000 kernel weight (g)	217—438	343.7	277.45	283.03	333.82	295.81	296.95
Test weight (kg/m^3)	693—843	791	829.84	844.96	809.03	808.27	817.07
Density (g/cm^3)	1.21—1.38	1.26	1.27	1.29	1.27	1.28	1.28
Floatation index (%)	0—68	27.1	10.56	10.68	25.12	13.36	7.91
Milling response (%)	7—25.8	15.9	8.77	14.33	15.8	13.27	11.07
Hard endosperm fraction (%)	54.3—71.3	59.2	11.00	10.67	9.67	11.33	9.67
Soft endosperm fraction (%)	45.7—28.7	40.8	23.33	18.66	23.33	21.67	23.33
Water absorption index	0.180—0.284	0.245	0.245	0.237	0.215	0.237	0.227

*Source [52].
** Done according to the [1].

ments in terms of conformational changes of carotenoid molecules. The authors of the present study have been dealing with this topic for a long period of time [30—33, 46]. However, this study will highlight just some conformational changes in molecules of carotenoids in the leaves of observed maize inbred lines. Thus, the following six characteristic resonance Raman spectral bands were established within the 900—1800 cm^{-1} interval of Raman frequencies: 962, 1026, 1160, 1187, 1206 and 1520 cm^{-1}. Four spectral bands with smaller intensities (I_{926}, I_{1026}, I_{1187}, I_{1206}) were caused by conformational changes of phosphates, glycogens, amides III. The remaining two spectral bands with significantly higher intensities (I_{1160}, I_{1520}) have been regularly analyzed in relation to the conformational changes in the carotenoid molecule

[46]. It is common to analyze the differences in the intensities of spectral bands (I_{1520} and I_{1160}), and even more often the differences in their ratio (I_{1520}/I_{1160}). The resonance Raman spectrum of the leaf of the observed inbred lines with dominant spectral bands (I_{1520} and I_{1160}) is presented. This spectrum conditions the carotenoid molecules placed in the non-polar phase of the thylakoid membrane of the leaf of the inbred lines. In this paper, the effort was made to emphasize the application of resonance Raman spectroscopy in studying important vital functions of leaves of maize inbred lines, especially under agroecological conditions atypical for the maize growing region. Carotenoid molecules (β-carotene, $C_{40}H_{56}$, with the activity of vitamin A, but also two xanthophylls: cryptoxanthin $C_{40}H_{56}O$ and zeaxanthin $C_{40}H_{56}O_2$), since localized in non-polar phase of the thylakoid membrane of maize inbred leaves, showed to be a very suitable natural probe, capable to contribute to registering not only higher and more significant, but also smaller and finer conformational changes. These changes in the molecular structure of carotenoids may be expressed in the form of bending, stretching, compressing and physical disruption of chemical bonds, which is caused by intensive actions of environmental factors, first of all of unfavorable critical temperatures. In the end, each conformational change in the carotenoid molecule unconditionally changes the function not only of the carotenoid molecule but also of the thylakoid membrane in leaves of maize inbred lines. Conformational changes in chemical bonds −C=C− are reflected in the spectral band at 1520 cm^{-1}. In addition, conformational changes in chemical bonds =C−C= are reflected in the spectral band at 1160 cm^{-1} [18, 46].

3. The measure of the angle and the area of the above-ear leaf of maize inbred lines. Results on the measures of angles between the above-ear leaf and the stalk, as well as, the average leaf areas are presented in Table 2. Based on obtained results on the measures of angles it can be stated that the observed maize inbred lines belong to the group of contemporary inbred lines with erect top leaves and the status of the photosynthetic model.

4. The exact temperature dependence of the delayed chlorophyll fluorescence intensity for the thylakoid membrane of maize inbred lines with erect top leaves. The experimental measures of changes in intensity of the stationary level of delayed chlorophyll fluorescence (I_{DF}) in dependence on the temperature, ranging from 25 to 60 °C, were performed. The dynamics of changes of the temperature dependence for observed maize inbred lines is presented in Fig. 1*A* and 1*B*.

TABLE 2. Angle between the above-ear leaf and the stalk and the leaf area of maize inbred lines with efficient photosynthesis

Maize inbred line*	FAO maturity group	Heterotic origin of inbred line*	Angle of the above-ear leaf (°)		Leaf area of the above-ear leaf	
			$\bar{X}$	σ	$\bar{X}$	σ
ZPPL 146	650—700	BSSS, USA Zemun Polje	20.8	1.21	3762.7	238
ZPPL 159	550—600	Landrace from Argentina (S13) crossed to the inbred PE25-10-1, Zemun Polje	21.30	1.23	2378.1	241

*Observed maize inbred lines represent good heterotic pairs, have good combining abilities for grain yield and silage, their propagation is well and they are highly yielding. These inbreds are rich in pigments and have extraordinary nutritive qualities.

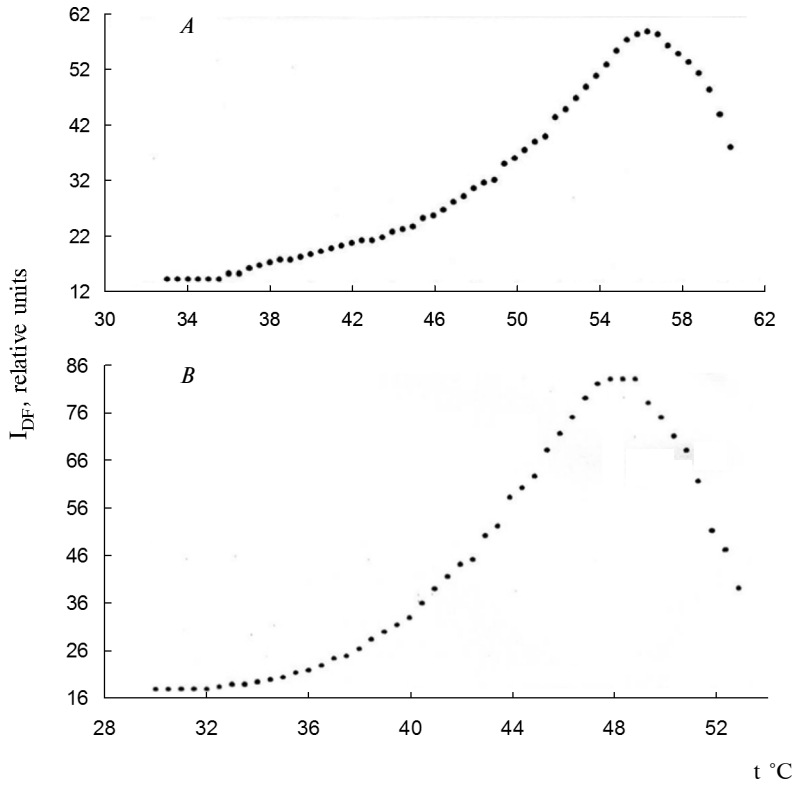

Fig. 1. Dynamics of changes in the intensity of the delayed chlorophyll fluorescence (I_{DF}) of thermal processes in dependence on the effects of temperatures in chloroplasts and the thylakoid membrane of the intact above-ear leaf of maize inbred lines with erect top leaves: ZPPL 146 (*A*) and ZPPL 159 (*B*)

The Arrhenius plot for the determination of critical temperatures and conformational changes in chloroplasts and thylakoid membranes of maize inbred lines with erect top leaves. The Arrhenius plot is based on the linearization of the DF exact temperature dependence of observed maize inbreds. Critical temperatures (phase transition temperatures) at which conformational changes occur in chloroplasts and the thylakoid membrane are determined by the application of the Arrhenius plot. Results of the Arrhenius plot application to observed maize inbred lines are presented in Fig. 2 *A* and 2 *B*.

Activation energy and critical temperatures in the thylakoid membrane of the observed maize inbred lines with erect top leaves. Detailed studies of the thermal processes of DF, and especially of the analysis of the experimental thermal curve, encompassed not only the temperature dependence and the Arrhenius plot, but also the estimation of values of activation energies (E_a) for critical temperatures (phase transition temperatures) in chloroplasts and the thylakoid membranes of the observed maize inbreds with erect top leaves: ZPPL 146 and ZPPL 159. Obtained results are shown in Table 3.

5. Brief survey of breeding and seed production traits of new maize inbred lines with efficient photosynthesis. Observed new maize inbred lines ZPPL 146 and ZPPL 159 are very promising in the process of maize breeding. For these reasons, relevant observations of their selected traits, performances and parameters are presented in Table 4.

6. Functional dependence of the yield of observed grain and silage maize hybrids. High-yielding and high-quality maize hybrids: ZP 633, ZP 735 and

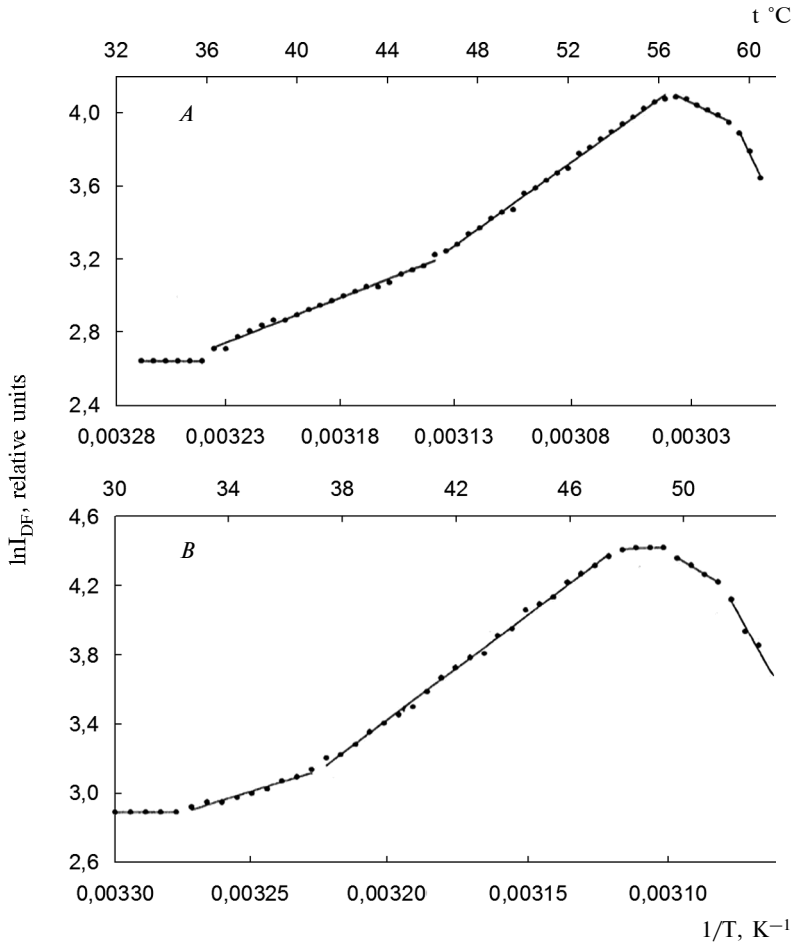

Fig. 2. The Arrhenius plot for the determination of critical temperatures and conformational changes in chloroplasts and the thylakoid membrane of the intact above-ear leaf of observed maize inbred lines with erect top leaves: ZPPL 146 (*A*) and ZPPL 159 (*B*)

ZP 737 are mainly intended for grain and silage production under agroecological conditions of South-Eastern Europe. According to our studies and good agricultural practice, the hybrid ZP 633 is very suitable for human diet. However, hybrids ZP 735 and ZP 737 are significantly better for nutrition of domestic animals through high-quality silage produced from wet grain and the whole plant (Table 7). The important agronomic and morphological traits of these hybrids are presented in Tables 5 and 6.

TABLE 3. Changes in activation energies (E_a) and critical temperatures (t °C) during thermal processes in chloroplasts and the thylakoid membrane of the intact above-ear leaf of maize inbred lines with erect top leaves

ZPPL 146		ZPPL 159	
E_a, kJ/mol	t °C	E_a, kJ/mol	t °C
/	34.5	/	32.5
41.0	46.0	42.1	37.0
74.9	56.5	101.2	47.5
50.7	59.5	6.2	49.0
225.5	/	81.1	51.0
		255.0	/

According to data presented in Tables 5—7, it is noticeable that observed hybrids belong to long-season hybrids with modern architecture and the stay-green trait. Moreover, these hybrids have more than 50 % of grain

TABLE 4. Relevant breeding and seed production traits of new maize inbred lines with photosynthetic efficiency

Name and defining of a trait	Brief description of breeding and seed production traits of maize inbred lines	
	ZPPL 146	ZPPL 159
Heterotic origin	BSSS, USA, Zemun Polje	Landrace from Argentina (S13), crossed to the inbred PE 25-10-1, Zemun Polje
FAO maturity group	650—700	550—600
Grain yield kg ha^{-1} at 14% moisture a) dry land farming b) irrigation	 3500 5000	 2000 3000
Number of plants ha^{-1} at harvest a) dry land farming b) irrigation	 50000 60000	 50000 60000
Stalk properties	Stalk is moderately high with prolific trait. Tassel has elongated central branch with fewer side branches	Stalk is short. Tassel has closed side branches that shed for a long time
Stalk resistance to lodging	Inbred is resistant to lodging	Inbred is resistant to lodging
Erect position of above ear leaves	first leaf < 20.8° second leaf < 17.9° third leaf < 15.3°	first leaf < 21.3° second leaf < 18.1° third leaf < 15.4°
Does the leaf remain green until harvest?	Leaf remained green until harvest	Leaf remained moderately green until harvest
What is tolerance of the inbred to stress factors (drought and high temperatures, etc.)?	Inbred is tolerant to drought and high temperatures	Inbred is tolerant to drought and high temperatures
Kernel traits and cob colour	Semi-dent type, orange kernels, white cob	Semi-flint, orange kernels, red cob
% grain moisture at harvest	20—25	20—25
Dry down rate in the stage of grain maturing	Dry down rate is not fast, but hybrids are suited for silage	Dry down rate is not fast, but hybrids are suited for silage
Is harvest of the inbred easy?	Harvest is easy	Harvest is easy
What does emergence look like?	Inbred emerges well	Inbred emerges well
What does early growth of the inbred look like?	Early growth is moderate	Early growth is moderate
Is grain of hybrids developed from this inbred suitable for nutrition of ruminants and nonruminants?	Grain is suitable for nutrition of ruminants, nonruminants, human nutrition and for industrial processing	Grain is suitable for nutrition of ruminants, nonruminants, human nutrition and for industrial processing
What is the carotene content in inbred grain?	a) 33.2 (mg/kg) b) 19.00 (μg βCE/g d.m.)	a) 31.8 (mg/kg) b) 18.10 (μg βCE/g d.m.)
Is the inbred suitable for developing silage hybrids?	Inbred is very suitable for developing silage hybrids	Inbred is very suitable for developing silage hybrids
Is digestibility of the hybrids developed from this inbred good?	Hybrids developed from this inbred have good digestibility of the whole plant and of milled grain	Hybrids developed from this inbred have good digestibility of the whole plant and of milled grain

TABLE 5. Agronomic traits of observed maize hybrids

Hybrid designation	ZP 633	ZP 735	ZP 737
Hybrid type	SC	SC	SC
FAO maturity group	550—650	750—850	750—850
Plant height (cm)	250	280	290
Ear height (cm)	120	130	135
1000 kernel weight (g)	380	370	370
Kernel type	semi-dent	dent	dent
Sowing density of silage hybrid (10^3 plants/ha)	60—70	70—75	70—75
Leaf position on plant	semi-erect to erect	semi-erect to erect	semi-erect to erect
Tolerance to drought	good	good	good
Tolerance to diseases	good	good	good
Leaf appearance at harvest	stay green	stay green	stay green
Hybrid growing regions (altitude, m)	300-400	250-400	250-400
Hybrid biomass yield (t/ha)	60—65	75—80	75—80
Hybrid grain yield (t/ha)	7.819*	8.108**	12.732**

* Hybrid yield achieved in 30 locations in Serbia in the 2008—2011 period.
** Hybrid yield achieved in 6 locations in Greece in the 2006—2009 period.

TABLE 6. Ear morphological traits of observed maize hybrids with a grain structure

Traits of maize hybrids	Hybrid		
	ZP 633	ZP 735	ZP 737
Grain moisture (%)	18	19	20
Ear length (cm)	22	25	25
Ear weight (g)	252.30	286.42	226.70
Rows per ear	16	18	18
Kernel row number	700	800	850
Kernel weight on ear (g)	228.36	248.35	200.40
% kernel pericarp on ear	5.32	6.55	4.60
% kernel embryo on ear	11.28	12.06	10.70
% kernel endosperm on ear	83.40	81.39	84.70

TABLE 7. Yield of fresh and dry matter of observed maize hybrids

Hybrid	Whole plant dry matter (%)	Fresh matter yield (t/ha)	Dry matter yield			Digestible dry matter yield (t/ha)
			Whole plant (t/ha)	Plant without ear (t/ha)	Ear (t/ha)	
ZP 735	37.38	72.82	28.0	11.6	15.4	14.40
ZP 737	39.20	74.70	30.4	14.3	13.6	18.40

in the whole plant dry matter, which is very important for silage quality. In addition, the embryo content in grain amounts to above 10 %, which is especially important for quality of nutritive values of hybrids in nutrition of people (especially of children and the elderly) [28], but also in nutrition of domestic animals (particularly cows and sheep) [15—17].

7. Agronomic and veterinary estimation on need for animal feeding with maize silage. It is a well known fact that maize is one of the most suitable field crops for the production of silage for ruminants. This is important for many reasons. First of all, maize is characterized by very high yields of fresh mass and by more than 50 % of grain in the whole plant dry matter, due to which silage is of prime quality. Ruminants need lignocellulosic materials for the activity of microflora of the rumens. Lignocellulose is mostly found in maize stalk, leaves, husk and cob, while starch, proteins and oil are found in maize grain. Maize silage with the addition of some micronutrients is a contemporary method of ruminant feeding. It is especially significant that such a method of feeding is cost-effective, because the process of silage preparation is completely mechanized, while storage and taking silage out of storage during its use is simple.

According to previous studies [15—17] it is particularly important that digestibility of hybrids ZP 735 and ZP 737 is better than digestibility of short-season hybrids, and hence they belong to the group of hybrids with silage of the highest quality. Therefore, the usability of silage produced from these two hybrids by animals is great. This fact suggests a higher nutritional value of these hybrids, which directly affects the performance of ruminants. According to results [45] in the vicinity of Leskovac, the fresh mass yield of these two hybrids (ZP 735 and ZP 737), when standard cropping practices had been applied and under dry land farming conditions, amounted to 72.82 and 74.70 t/ha, respectively (Table 7). The presented results point out that fresh mass yield of the hybrid ZP 737 was higher by 1.88 t/ha. However, the final conclusion on which hybrid is more suitable for silage can be drawn when grain yield and silage digestibility are observed. Furthermore, these hybrids belong to the FAO maturity group 750—850, which means that they are long-season hybrids with well developed leaf mass and intensive photosynthetic activity. These properties, among other things, make them most suitable hybrids for silage production under climatic conditions of Serbia and South-Eastern Europe.

As already stated, for the last 60 years, a great success has been achieved in maize breeding and the production of high-quality basic and hybrid seed. Furthermore, a great success has also been achieved in contemporary technology of commercial seed production. Since 1978, thanks to the maize breeding programme, the number of plants per area unit has been significantly increasing. This maize breeding programme was referred to as a «plant density» programme and it further directly affected the yield increase of high quality basic and hybrid seed as well as commercial seed [27, 36, 39]. Some time later, a programme on the development of maize inbred lines with erect top leaves (inbreds with efficient photosynthesis) was established [39—42]. It was considered that these inbreds were the closest to the proposed efficient model of photosynthesis [33].

At the same time, a programme on the development of maize inbred lines rich in pigments and other chemical properties and with extraordinary nutritive values was established [5, 7, 9, 11, 12, 15—17, 21—26, 46, 49].

This study was an attempt to answer the following question by using different interdependent tests and analyses: is there a reliable and dominant trait (one or more) of observed maize inbred lines rich in the pigment complex that would be the basis for the development of new high-quality maize hybrids that would be suitable for human diet and nutrition of domestic animals? The analysis of presented overall results, obtained in the series of experiments, can easily give the positive answer to this question. Consequently, new maize inbred lines (ZPPL 146 and ZPPL 159) and hybrids developed from them (ZP 633, ZP 735 and ZP 737) are the best confirmation of the stated. Selected inbred lines and hybrids developed from them are rich in pigments, have significant nutritive values, especially of carotenoids that give the color to cereal kernels [2] that are used in the nutrition of poultry. Carotenoids positively affect health of both, people and animals [4, 12, 21, 49]. This aspect of observed maize inbred lines and hybrids will get priority within the healthy maize-based diet for people and maize-silage nutrition for animals.

Conclusions

According to the presented numerous and diverse results on studies of new inbred lines (ZPPL 146 and ZPPL 159) and maize hybrids developed from these inbreds (ZP 633, ZP 735 and ZP 737 that have great nutritive values, that are rich in pigments, that are characterized by efficient photosynthesis and other relevant parameters typical for standard maize hybrids), the following can be it concluded:

Selected maize inbred lines (ZPPL 146 and ZPPL 159), rich in carotenoids, yellow pigments, also have significant amounts of other relevant bioactive compounds and good physical traits.

Observed inbred lines have erect top leaves and are classified into a group of maize inbreds with significant properties of the photosynthetic model and are resistant to high temperatures and tolerant to drought.

Spectral bands pointing to conformational characteristics of molecules of carotenoids but also to other compounds (phosphates, glutens and amides III) were established by the resonance Raman spectroscopy method applied to the leaf of maize inbred lines.

Relevant traits, properties and parameters of observed new maize inbred lines that can be used in the process of selection are presented.

These new maize inbred lines were used to develop high-quality and high-yielding maize hybrids (ZP 633, ZP 735 and ZP 737) that are recognizable for their quality. The hybrid ZP 633 is particularly remarkable in human nutrition (children and the elderly). Furthermore, in relation to agronomic and veterinary estimations, hybrids ZP 735 and ZP 737 are the most suitable for feeding domestic animals with programmed use of maize silage.

Relevant agronomic, morphological and nutritive properties of maize hybrids ZP 633, ZP 735 and ZP 737 are presented. Moreover, results on grain structure and grain and silage yields obtained in the regions of Serbia and South-Eastern Europe are also displayed.

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ХАРАКТЕРИСТИКИ НОВИХ ІНБРЕДНИХ ЛІНІЙ КУКУРУДЗИ ТА ЇХНІХ ГІБРИДІВ З ВИСОКИМИ ХАРЧОВИМИ І КОРМОВИМИ ЯКОСТЯМИ

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Селекція і добір інбредних ліній ZPPL 146 і ZPPL 159 та гібридів, створених на їх основі (ZP 633, ZP 735 і ZP 737, призначених насамперед для кормів), тривали протягом майже трьох десятиліть. Ці інбредні лінії і гібриди мають високу поживну цінність, вони багаті на пігменти, мають ефективний фотосинтез та інші відповідні параметри, характерні для стандартних гібридів. Досліджені гібриди кукурудзи багаті на вуглеводи. Корм, вироблений з цих гібридів, має високі поживність і якість. Через високу продуктивність загальної сухої речовини на одиницю площі ці гібриди є одними з найважливіших кормових продуктів. Обговорено важливість хімічного складу біогенних речовин гібридного зерна кукурудзи, зокрема пігментів, які мають антиоксидантні властивості.

ХАРАКТЕРИСТИКИ НОВЫХ ИНБРЕДНЫХ ЛИНИЙ КУКУРУЗЫ И ИХ ГИБРИДОВ С ВЫСОКИМИ ПИЩЕВЫМИ И КОРМОВЫМИ КАЧЕСТВАМИ

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Селекция и отбор инбредных линий ZPPL 146 и ZPPL 159 и гибридов, созданных на их основе (ZP 633, ZP 735 и ZP 737, предназначенных прежде всего для кормов), продолжа-

лись в течение почти трех десятилетий. Эти инбредные линии и гибриды имеют высокую питательную ценность, они богаты пигментами, имеют эффективный фотосинтез и другие соответствующие параметры, характерные для стандартных гибридов. Исследованные гибриды кукурузы богаты углеводами. Корм, изготовленный из этих гибридов, имеет высокие питательность и качество. Вследствие высокой продуктивности общего сухого вещества на единицу площади эти гибриды представляют собой один из важнейших кормовых продуктов. Обсуждена важность химического состава биогенных веществ гибридного зерна кукурузы, в частности пигментов, которые обладают антиоксидантными свойствами.

Ключевые слова: *Zea mays* L., кукуруза, инбредные линии, гибрид, тилакоидная мембрана, фотосинтетическая модель, замедленная флуоресценция хлорофилла, свойства пигментов, питательная ценность, корм.