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THE PRESTIGIOUS MAIZE INBRED LINES AND HYBRIDS WITH ERECT TOP LEAVES ARE CHARACTERISED BY A PROPERTY OF AN EFFICIENT PHOTOSYNTHETIC MODEL AND A SATISFACTORY BASE FOR THE FURTHER PROGRESS IN BREEDING AND SELECTION

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This study conforms the hypothesis that elite maize inbred lines with erect top leaves and hybrids, in which they are included as parents, have a dominant property of an efficient photosynthetic-fluorescence model and that as such are successfully used in breeding and modern production technology of hybrid seed and commercial maize. The displayed results on the erect position of the top leaves, increased density, the dynamics of grain dry-down during the maturation period, seed quality of hybrid and commercial maize and photosynthetic and fluorescent parameters: the temperature dependence of the delayed chlorophyll fluorescence intensity, the Arrhenius criterion for the determination of critical temperatures (phase transition temperatures) and the activation energies, show that properties of observed inbreds and their maize hybrids are based on positive effects and the nature of conformational and functional changes that occur in their thylakoid membranes and other chemical structures of grain and leaf tissues. The present study also encompasses analyses of other relevant breeding and seed properties of observed prestigious maize inbred lines and maize hybrids derived from them (dependence of their yields on the density, and quality of commercial maize over the kernel structure and chemical parameters).

Key words: Zea mays L., inbred line, hybrid, top erect leaf, thylakoid membrane, photosynthetic and fluorescence model, delayed chlorophyll fluorescence.

In recent times, binding complex and interrelated research processes within the field of fundamental sciences, multidisciplinary and applied sciences has become the necessity. This study presents results obtained within the field of breeding, photosynthesis, fluorescence, biophysical chemistry and the seed production in the elite maize inbred lines with erect top leaves.

Maize breeding and the seed production have been intensively developed during the last 60 years. As a result of such an activity, over 1,200 maize hybrids for grain and silage have been developed. Contemporary technical and technological prerequisites for conducting a modern process of breeding were provided [10, 16, 11, 12, 20, 55, 56].

Since 1978, the number of plants per area unit (plant density) has been significantly increasing, which mostly affected the increase in grain yields of both, maize hybrids and commercial maize [24, 25]. At the same time, a programme on breeding and the seed production of maize hybrids with erect leaves has been performed [4, 13, 34, 45, 46, 47, 48, 49, 50]. It seems, according to our hypothesis, that these observed maize inbred lines with erect leaves are the closest to the assumptive photosynthetic fluorescence model [41].

The studies on maize photosynthesis carried out in the previous period did not have a more important application in modern breeding and the maize hybrid seed production. It was almost impossible to present a clear and direct interrelationship between photosynthesis, breeding and the maize seed production. Such a state is probably a result of the existence of several functional interrelations that unite conformational and dynamic changes within chloroplasts and their thylakoid membranes as well as the effects of numerous environmental factors [4, 45, 48, 49, 50]. During the last 35 years, new and important studies within the field of bioluminescence and fluorescence phenomena and processes within the plant systems, including maize, have been carried out [1, 2, 3, 5, 8, 14, 15, 17, 18, 19, 21, 22, 23, 27, 28, 29, 31, 32, 33, 35, 36, 37, 38, 39]. The direct dependence of the delayed chlorophyll fluorescence (DF) intensity on changes of photosynthetic processes in thylakoid membranes of maize intact leaves was determined [36, 37, 39]. Conditions which provided monitoring of complex photosynthetic processes in the maize intact leaf over a photosynthetic and fluorescence response in the form of DF were developed [6, 42, 43]. During the last 15 years a group of researches from the Maize Research Institute, Zemun Polje, have been developing a novel semi-non-invasive photosynthetic-fluorescence method that functionally binds processes of photosynthesis, fluorescence and maize breeding [4, 30, 44, 45, 46, 47].

Research methods within the field of biophysical chemistry and chemical technology contributed to diversified connections of studies on photosynthetic and transport processes in the thylakoid membrane and different chemical structures of grain with processes of fluorescence spectroscopy, chemical kinetics and dynamics of grain dry-down in the period of grain maturation [7, 36, 40, 48, 49, 50].

The objective of the present study was to prove that prestigious inbred lines with erect top leaves and high-yielding maize hybrids, derived from them, can be an efficient photosynthetic model, meaning that they can contribute to the functional interrelation of breeding, photosynthesis, fluorescence and the production of high-quality commercial maize.

Methods

Plant material. The studies were carried out with three elite maize inbred lines with erect top leaves, ZPPL 16, ZPPL 218 and ZPPL 62, belonging to the collection of the Maize Research Institute, Zemun Polje. The principal traits of the stated inbreds are presented.

The inbred line ZPPL 16 was derived from the BSSS population and it belongs to the FAO 700 maturity group. The kernel is classified as a dent type, while the cob is pink. This inbred, as a female or a male component, is included into the development of more than 20 maize hybrids. However, out of all developed hybrids only hybrids ZP 578, ZP 677 and ZP 684 have a broad commercial application.

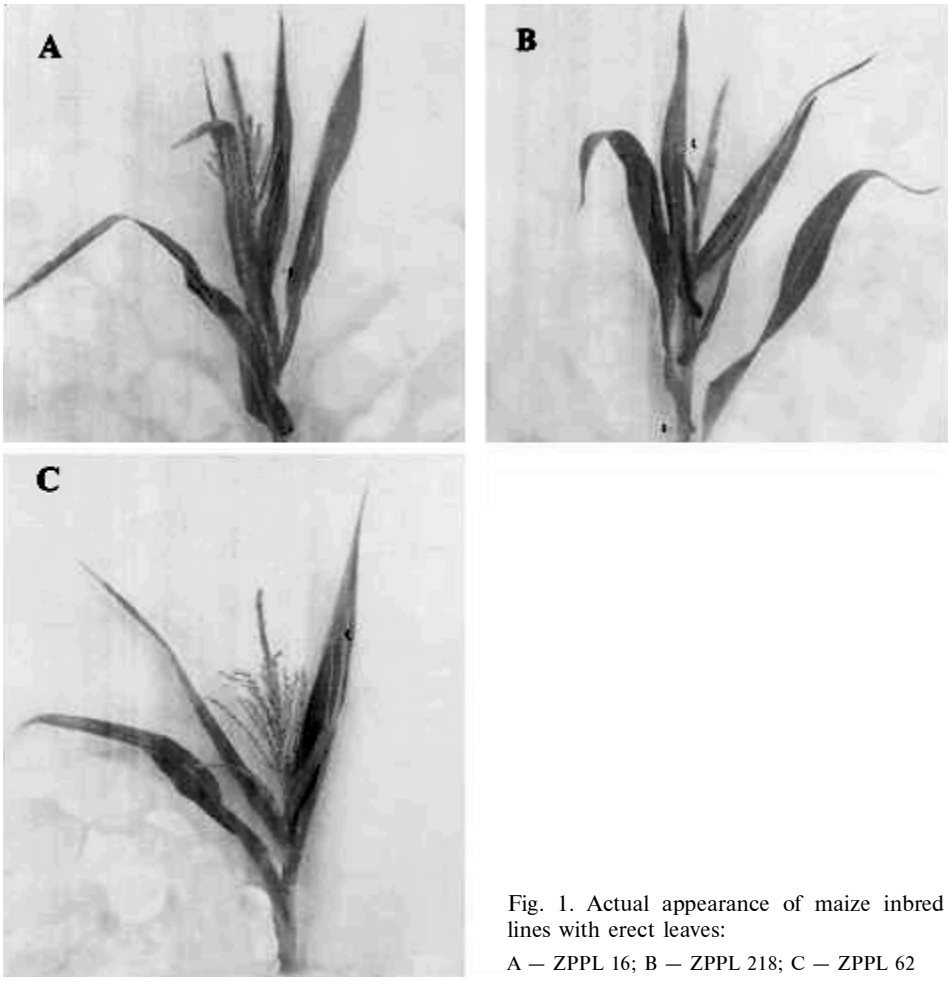

Fig. 1. Actual appearance of maize inbred lines with erect leaves:
A — ZPPL 16; B — ZPPL 218; C — ZPPL 62

The inbred line ZPPL 218 belongs to the Lancaster heterotic group and the FAO 650 maturity group. The kernel is classified as a dent type, while the cob is red. This inbred line is included into the development of more than 10 maize hybrids, including the hybrid ZP 684.

The inbred line ZPPL 62 represents a BSSS heterotic group and belongs to the FAO 350 maturity group. The kernel of this inbred line belongs to dent type and the cob is red. This inbred line, as one of components, is included into 20 hybrids. Actual appearance of maize inbred lines with erect top leaves is given in Fig. 1.

The trait of the efficient photosynthetic model is a prestigious trait of the observed inbreds and high yielding hybrids, as these inbreds and hybrids have erect top leaves. Furthermore, these maize inbred lines and hybrids are characterised by greater grain dry down rates in the maturation period, as well as, by satisfactory tolerance to high and very high temperatures and drought. There is a functional dependence between traits of hybrids with erect top leaves and the plant density on their yield. The studies were carried out with the following densities (D, plants ha^{-1}): D1 = 40,816, growing space (GS, cm^2) GS 70×35 cm, D2 = 50,125, GS 70×28.5 cm, D3 = 59,523, GS 70×24 cm, D4 = 69,686, GS 70×20.5 cm, D5 = 79,365, GS 70×18 cm, D6 = 89,286, GS 70×16 cm, D7 = 98,522, GS 70×14.5 cm.

Overall studies of the stated inbred lines and selected maize hybrids encompassed several series of experiments in which standard and other appropriate methodic (methodological) procedures were applied.

1. The measure of an angle and leaf area. The first series of experiments was related to studying the erect position of top leaves. A specially designed protractor was used to measure the angle between lines of the position of the above-ear leaf and the position of the plant stalk of maize inbred lines. The leaf area was measured using the portable area meter (model LI-3000). Measures of the angle between the above-ear leaf and the stalk and the leaf areas were carried out on 218 plants for each inbred line. These methodic procedures were described in previously published papers [4, 45, 47, 48].

2. Photosynthetic fluorescence measurements. The second series of the experiments was related to photosynthetic-fluorescence measurements, including thermal processes of delayed fluorescence (DF), critical phase transition temperatures and activation energies. The test maize inbreds grown in the experimental field of the Maize Research Institute, Zemun Polje, were brought to the laboratory during morning hours (between 7 a.m. and 8 a.m.). Plants sampled in the field were transversally cut in the ground internode. In the laboratory plants were internode lengthwise placed in distilled water. Prior to the fluorescence experiment, the 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. These tests were performed on 268 plants of each inbred line.

The improved non-invasive photosynthetic fluorescence method used to measure DF is schematically presented in Fig. 2. This method, developed at the Maize Research Institute, Zemun Polje, have been improved several times. Photosynthetic fluorescence measurements were performed after a method that had been both, in principle and details, described in previous papers [4, 6, 30, 36, 37, 43, 44, 47, 48, 49, 50].

3. Dynamics of water status changes in grain. The third series of the experiments was related to the water status and the dynamics of grain dry-down rate in the maturation period, which was observed by the application of the thermal method of oven-drying at 105 °C to the constant weight.

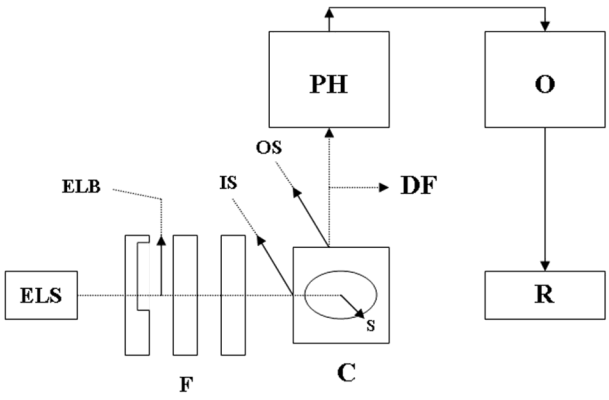

Fig. 2. Experimental setup of the photosynthetic fluorescence method and the measuring equipment for delayed chlorophyll fluorescence:

ELS — excitation light source; F — filters; ELB — excitation light beam; IS — input dark chamber slot; C — dark chamber with a sample stand; s — sample (intact leaf segment); OS — output dark chamber slot; DF — luminescent light (delayed fluorescence); PH — photo-multiplier; O — oscilloscope; R — printer

An average kernel sample drawn from five ears was used to perform these measurements. In order to observe the water status, the plants were picked up at the black layer maturity, i.e. at the physiological maturity. Measurements of the grain water status changes were done seven days later and lasted for 35 days. The dynamics of transport processes (grain dry down) at the grain maturation was observed in the course of five years, because of a great instability of this trait in the majority of maize inbred lines [49, 50].

4. Functional dependence of the yield of the selected maize hybrids with erect top leaves on their crop density. In order to determine the functional dependence of the yield of the selected maize hybrids with erect top leaves on their crop density, the standard maize growing practices with seven sowing densities were applied under irrigation and rainfed conditions [58, 59].

5. Chemical composition, physical properties and grain structure of maize hybrids with erect top leaves. Methods used for the determination the chemical composition, physical properties and grain structure of maize hybrids with erect top leaves were described in previous papers [9, 51, 52].

Results and discussion

1. The measure of the angle and the area of the above-ear leaf of maize inbred lines with erect top leaves. Results on the measures of angles between the above-ear leaf and the stalk, as well as, average leaf areas are presented in Tab. 1. Based on obtained results on the measures of angles it can be stated that the observed prestigious maize inbred lines belong to the group of inbred lines with erect top leaves.

2. Results of photosynthetic-fluorescence studies on the above-ear leaf of maize inbred lines with erect top leaves. The detailed studies on thermal processes of DF of observed maize inbred lines with erect top leaves were carried out. The thermal curve is a curve that shows the dynamics of changes in the stationary DF level intensity in dependence on a temperature. The trend of its formation is most often analogous to segments in seconds designated with *a, b, c, d, e, f* and *g,* Fig. 3.

The observation of the thermal curve course and the analysis of the duration of certain segments point out to the existence of several critical temperatures (phase transition temperatures) at which smaller or greater conformational and functional changes occur in the thylakoid membrane of the observed maize inbreds with erect top leaves.

TABLE 1. The angle of the above-ear leaf and the leaf area of maize elite inbred lines with erect top leaves

Inbred line	FAO maturity group	Heterotic origin of the inbred*	Angle of the above-ear leaf		Area of the above-ear leaf, cm^2	
			$\bar{x}$	σ	$\bar{x}$	σ
ZPPL 16	700	Zemun Polje — BSSS	18.3	1.12	3.63	328
ZPPL 218	650	Zemun Polje — Lancaster	22.1	1.36	3.91	412
ZPPL 62	350	Zemun Polje — BSSS	20.3	1.21	3.33	318

*Studied inbred lines represent good heterotic pairs, they are characterised as *good general* combiners for *grain yield*, they increase well and they are high yielding.

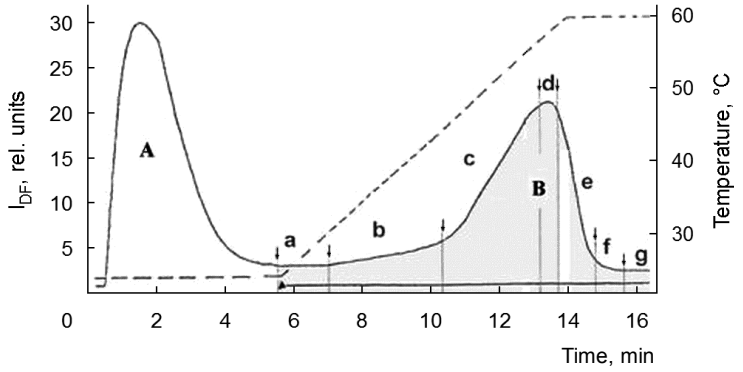

Fig. 3. Schematic presentation of typical changes in DF intensities (I_{DF}) on the intact above-ear leaf of the observed prestigious maize inbred lines (solid line) and changes in temperatures (dashed line):

curve A indicates induction processes of DF, while curve B encompasses photosynthetic fluorescence thermal processes of DF. Typical temporal segments (a, b, c, d, e, f and g) on the thermal curve B correspond to dynamics of I_{DF} changes at the time of a DF formation. Conformational and functional changes in the thylakoid membrane of observed maize inbred lines with erect top leaves occur at interception points of typical temporal segments

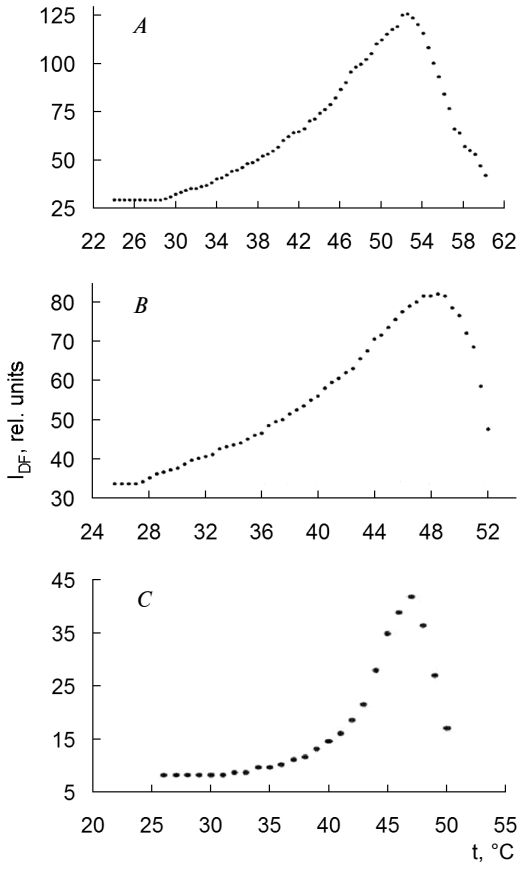

Fig. 4. Changes in the intensity of the delayed chlorophyll fluorescence (I_{DF}) of thermal processes in dependence on the effects of temperatures in the thylakoid membrane of the intact above-ear leaf of the prestigious maize inbred lines with erect top leaves:

A — ZPPL 16; *B* — ZPPL 218; *C* — ZPPL 62

2.1. The temperature dependence of DF intensity for the thylakoid membrane of the maize inbred lines with erect top leaves. Fig. 4, A, B, C, presents changes in the stationary DF level in a function of the temperature, ranging from 25 to 60 °C, in the thylakoid membrane of the maize inbred lines with erect top leaves: ZPPL 16, ZPPL 218 and ZPPL 62.

2.2. The Arrhenius plot for the determination of critical temperatures and conformational changes in the thylakoid membrane of the maize inbred lines with erect top leaves. The Arrhenius plot is based on the linearisation of the DF temperature dependence of observed maize inbred lines. Critical temperatures (phase transition temperatures) at which conformational changes occur in the thylakoid membrane (intersection points of straight lines) are determined by the application of the Arrhenius plot. Results of the Arrhenius plot application to prestigious maize inbreds with erect top leaves are presented in Fig. 5, A, B and C.

2.3. Activation energies and critical temperatures in the thylakoid membrane of the observed maize inbred lines with erect top leaves. Studies on the thermal curve of DF encompassed not only the temperature dependence with temporal parameters and Arrhenius plot, but also the estimation of values of activation energies and critical temperatures (phase transition temperatures) in the thylakoid membranes of the studied prestigious maize inbreds with erect top leaves: ZPPL 16, ZPPL 218 and ZPPL 62. Obtained results are shown in Tab. 2.

3. Dynamics of changes in the grain water status in the maturation period of the studied maize inbred lines with erect top leaves. Dynamics of changes in the grain water status and dry down during the maturation period of the studied maize inbred lines with erect top leaves are prestigious properties of these inbreds to which a great attention is paid in the process of contemporary breeding and the production of high-quality commercial maize. Obtained results are presented in Fig. 6.

4. Functional dependence between the yield of the selected maize hybrids with erect top leaves and their crop density. Results on functional dependence of the yield of the selected maize hybrids with erect top leaves on their crop density are presented in Tab. 3 and 4.

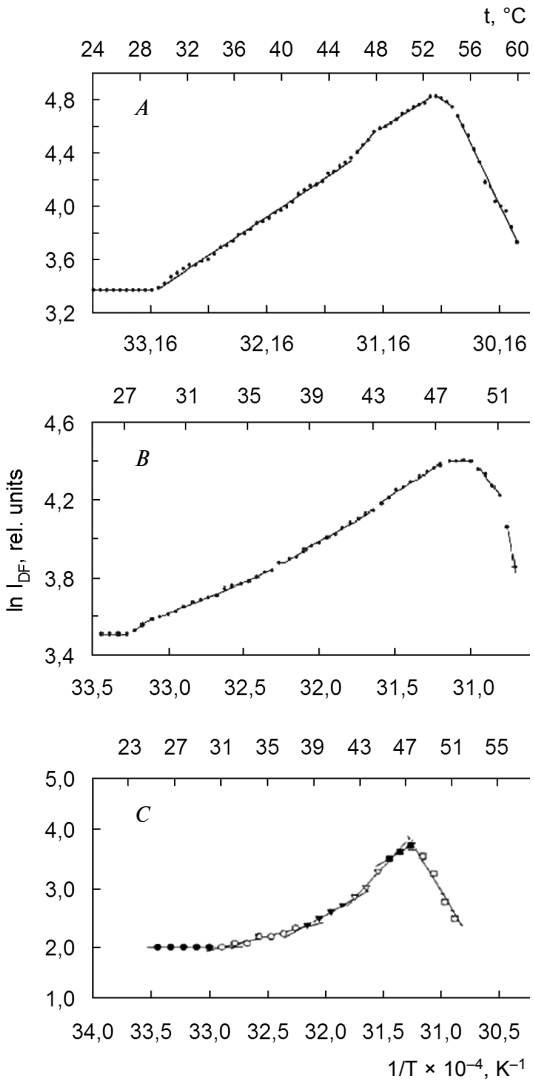

Fig. 5. The Arrhenius plot for the determination of critical temperatures (intersection of two straight lines) and conformational changes in the thylakoid membrane of the above-ear leaf of observed prestigious maize inbred lines with erect top leaves:
A — ZPPL 16; *B* — ZPPL 218; *C* — ZPPL 62

Yields obtained in the six-year period under conditions of both, rainfed and irrigation, reliably indicate a high genetic yielding potential of observed maize hybrids. There are no significant differences among hybrids, hence it may be concluded that all of them have a high genetic yielding potential. Yields of all hybrids were higher under irrigation than under rainfed conditions. The yield was the lowest in dry years, such as 2007.

5. Chemical composition, physical properties and grain structure of maize hybrids with erect top leaves. Results obtained on grain structure, physical properties and chemical composition of maize hybrids with erect top leaves are presented in Tab. 5, 6 and 7.

TABLE 2. Changes in activation energies (Ea) and critical temperatures (t, °C) in the course of thermal processes in the thylakoid membrane of the intact above-ear leaf of studied maize inbred lines with erect top leaves

ZPPL 16		ZPPL 218		ZPPL 62	
Ea, kJ/mol	t, °C	Ea, kJ/mol	t, °C	Ea, kJ/mol	t, °C
—	29.5	—	27.0	—	28.0
48.4	45.9	43.1	29.0	45.0	36.0
84.3	48.0	27.3	36.9	91.8	41.0
46.7	53.0	37.0	43.5	119.7	46.9
49.2	54.8	42.5	47.8	132.0	49.0
—	60.0	51.1	49.9	—	—

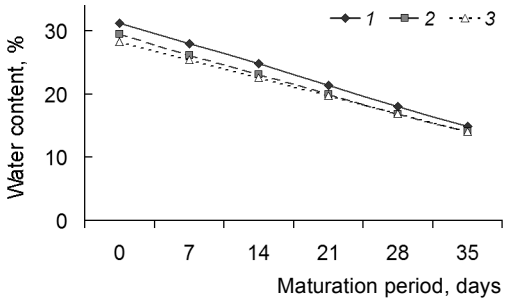

Fig. 6. Dynamics of dry down during the grain maturation period for the maize inbred lines with erect top leaves:

1 — ZPPL 16 Y = 0.47, *2* — ZPPL 218 Y = 0.45, *3* — ZPPL 82 Y = 0.40

The second half of the 20th and the first decade of the 21st century are characterised by a great success achieved in maize breeding and the production of basic and certified seed. The number of plants per area unit has been growing since 1978. This trend in maize breeding was referred to as a «plant density» programme and it further affected the yield increase of high quality certified seed [34]. In addition, a programme on the development of maize inbred lines with erect top leaves was established at the same time as the «plant density» programme. It was considered that these inbreds were the closest to the proposed efficient photosynthetic model [6, 34, 41, 42, 45, 47]. These two programmes in maize breeding and the seed production were not only complementary, but they have also been expanded. Their implementation led to new results in both, maize breeding and the hybrid seed production [10, 20, 25, 56]. New and numerous hybrids with high grain and silage yields were developed and grown on large areas [10, 12, 16, 20, 25, 54].

Based on obtained results, the Maize Research Institute, Zemun Polje, intensively studies and develops maize inbred lines with erect top leaves [4, 34, 41, 43, 45, 46, 47, 49, 50]. The initial studies on the erect leaves were performed on the leaves below the ear, and then they were performed on ear leaves [4, 45, 47, 48]. Contemporary studies are performed on top leaves. The most efficient and the longest photosynthetic processes necessary for the maize plant are achieved in these leaves [41]. According to the stated, a new hypothesis about top leaves (above-ear leaves) having the efficient role of the photosynthetic model has been proposed.

This study was an attempt to answer the following questions by using different tests and analyses: 1) are there reliable and dominant traits of maize inbred lines with erect top leaves by which planned and satisfactory progress in maize breeding and the high-quality hybrid seed production can be achieved? and 2) which traits maize inbred lines should have?

*TABLE 3. Yields (t ha^{-1}) of maize hybrids with erect top leaves under rainfed conditions of Zemun Polje obtained in seven plant densities**

Plant density in 1000 per ha	ZP 341 FAO 300	ZP 434 FAO 400	ZP 578 FAO 500	ZP684 FAO 600
40,8	9.3	10.1	9.8	10.8
50,1	11.0	11.1	10.7	12.1
59,5	11.5	11.4	11.5	12.8
69,7	12.5	12.4	11.9	13.1
79,4	12.1	12.3	12.0	13.3
89,3	12.3	11.3	12.6	12.5
98,5	11.8	11.6	11.9	12.2
$\bar{x}$	11.5	11.5	11.5	12.4

*Results obtained in the 2003—2008 period.

*TABLE 4. Yields (t ha^{-1}) of maize hybrids with erect top leaves under irrigation conditions of Zemun Polje obtained in seven plant densities**

Plant density in 1000 per ha	ZP 341 FAO 300	ZP 434 FAO 400	ZP 578 FAO 500	ZP684 FAO 600
40,8	10.02	10.90	11.32	11.16
50,1	12.01	11.95	12.67	12.96
59,5	12.73	12.04	13.10	13.80
69,7	13.48	13.17	14.18	13.49
79,4	13.55	13.89	15.00	13.84
89,3	13.48	13.61	14.90	13.86
98,5	13.34	13.36	14.67	14.00
$\bar{x}$	12.66	12.70	13.69	13.30

* Results obtained in the 2003—2008 period.

TABLE 5. Grain structure of maize hybrids with erect top leaves

Hybrid	Pericarp, %	Germ, %	Endosperm, %
ZP 341	6.49	12.05	81.46
ZP 434	6.49	11.86	81.65
ZP 578	6.08	11.35	82.56
ZP 684	6.39	11.79	81.82

*TABLE 6. Physical properties of maize hybrids with erect top leaves**

Hybrid	AM	HM	G	IF	OM	TF	MF	IAV
ZP 341	331.4	784	1.25	33.7	19.9	57.3	42.7	0.231
ZP 434	355.1	780	1.26	22.3	16.6	58.8	41.2	0.225
ZP 578	304.8	751	1.27	30.2	16.9	61.9	38.2	0.242
ZP 684	344.8	772	1.26	18.9	13.7	54.5	45.5	0.246

* AM = 1000-kernel weight (g); HM = test weight (kg m^{-3}); G — density, (g cm^{-3}); IF — floatation index (%); OM — milling response, (s); TF — hard endosperm fraction, (%); MF — soft endosperm fraction, (%); IAV — water absorption index.

TABLE 7. Grain chemical composition of maize hybrids with erect top leaves

Hybrid	Starch, %	Protein, %	Oil, %	Fibre, %	Ash, %
ZP 341	69.00	9.33	5.75	1.98	1.33
ZP 434	69.02	9.42	5.87	1.99	1.37
ZP 578	72.99	8.64	5.08	1.82	1.33
ZP 684	70.52	8.84	4.82	2.06	1.37

The stated experimental studies can offer at least a partial answer to asked questions. The overall studies on maize inbred lines with erect top leaves encompassed several series of experiments. The first series of experiments included the measure of the angle and the leaf area of observed prestigious maize inbred lines with erect top leaves. The results obtained on these traits (Tab. 1) classifies them into important seed breeding and seed production traits [49, 50]. The second series of experiments included photosynthetic fluorescence studies on conformational and functional changes in the thylakoid membrane of the intact above-ear leaf of studied prestigious maize inbred lines. The temperature dependence of thermal processes of DF for the studied maize inbred lines is presented in a form of their establishment (Fig. 3). The results of the temperature dependence of DF for each of the three tested prestigious maize inbred lines with erect top leaves are presented in Fig. 4, *A, B, C*. The presented results show that the temperature dependence of DF in each of the three maize inbred lines with erect top leaves is characterised with typical intersection points of two segments on the thermal curve (Fig. 3). The first typical point occurred on the intersection of the segment *a* and the segment *b* and it represented the lowest critical temperatures at which the initial change in the DF intensity was observed. The second typical point occurred on the intersection of the segment *b* and the segment **c** and it was related to a linear monotony with the angle of the increasing part of the DF intensity curve. Evident changes in the structure of the thylakoid membrane occurred in this region. The third typical point reflected a smaller or a greater rotundity of DF intensity peaks. The «breaking» conformational changes occurred in two intersection points of the segments *c* and *d* and the segments *d* and *e*. The fourth typical point was related to the linear monotony and the inclination angle of the declining part of the DF intensity curve. This segment of the thermal curve bore the last conformational changes that had occurred in the thylakoid membrane. These changes can hardly be described as characters of functioning of a living leaf. The typical intersection points designated as *f* and *g* almost had no physiological role. The analysed typical intersection points (Fig. 3 and Fig. 4 *A, B, C*) can be considered the points characterising inbred lines with erect top leaves, as these points are precisely the points of conformational and functional changes in the thylakoid membrane [4, 45, 46, 47, 48].

All critical temperatures (phase transition temperatures) at which even the slightest conformational changes had occurred in the thylakoid membranes of studied maize inbred lines with erect top leaves were determined by the Arrhenius criterion and the linearisation of the DF temperature dependence. The value of critical temperatures (°C), their frequency and intermediate distance characterise observed maize inbred lines with erect top leaves in relation to their tolerance, resistance and adaptation not only to increased and high temperatures, but also to drought [6, 43, 44, 45]. The Arrhenius criterion is based on the existence of straight lines. Each Arrhenius straight line represents its

activation energy (Ea). The intersection point of two straight lines is determined by a critical temperature. Results of the Ea values in the inclining and declining part of the thermal curve are explained by lesser or greater conformational changes that occur in the molecules of pigments (chlorophyll) in the thylakoid membrane with the temperature increase. Due to such changes these molecules become more reactive and thereby gain the additional energy that is used in the recombining process of the DF occurrence (Tab. 2) [4, 36, 37, 45, 46, 47].

Presented photosynthetic fluorescence traits of studied maize inbred lines with erect top leaves can contribute to more exact, rational and expeditious proceedings of breeding and the production of high-quality hybrid seed, which makes them exceptionally important.

The third series of experiments encompassed the thermal studies of the specific grain water status and grain dry down rates in the maturation period. Transport processes and dry down rates at grain maturation are very important and prestigious properties to which a great economic and scientific importance is ascribed, not only in the process of studying and the development of maize inbreds and hybrids with erect top leaves, but also in the organisation of the hybrid maize seed production [40]. The grain dry down rate in the maturation period is a very complex process and depends on the following several parameters: a) the osmotic pressure in the grain in the maturation period; the osmotic pressure is prone to the external atmospheric pressure, as well as frequency and intensity of air currents and significant changes in relative humidity; furthermore, the osmotic pressure in the grain depends on the structural properties of chemical compounds and the nature of their chemical bonds with water; b) the pericarp structure and thickness and its water permeability, that is water transport capacity through such a structure; c) the content and structure of starch grains and protein bodies, including their binding affinity to water; d) morphological properties of the ear; e) morphological properties of the grain; and f) other physical and chemical parameters of a chemical structure of the grain, which interact with water.

This study encompasses the six-year observation of yields of the following maize hybrids with erect top leaves: ZP-341, ZP-434, ZP-578 and ZP-684. According to results presented in Tab. 3 and 4 it is obvious that hybrids have high and stable yields under conditions of both, rainfed and irrigation. Studied maize hybrids with erect top leaves are well adapted to the density of 70,000 plants ha^{-1}. Higher densities reduce yield and require significantly higher inputs and expenses [26, 58, 59].

Gained results presented in Tab. 5, 6 and 7, point out to structural grain parameters (pericarp, germ and endosperm), physical traits and chemical composition that indicate exceptional quality of commercial maize of observed hybrids with erect top leaves. Commercial maize is of appropriate quality that provides diversified utilisation [9, 51, 52].

According to the achieved results it can be established that non-invasive photosynthetic fluorescence method can be applied in breeding and the maize hybrid seed production and that the estimation of prestigious maize inbred lines for their resistance and adaptability to increased and high temperatures, as well as to drought, can be performed. The application of the stated method provided the determination of many properties and parameters of photosynthetic apparatus of observed prestigious maize inbred lines with erect top leaves:

- Temperature dependence in the range from 24 to 60 °C;

• Temperatures at which smaller or greater conformational and functional changes in the thylakoid membrane occur;

• Values of activation energies (Ea, kJ/mol) along straight lines before and after the occurrence of critical temperatures in the thermal process;

• Different monotony of the increasing part of the thermal curve, which points out to uneven resistance and adaptability to increased and high temperatures, as well as to drought;

• It was shown that observed inbred lines have a trait of the erect position of top leaves and a greater dry down rate in the grain maturation period.

The following relevant properties of maize hybrids, developed from the stated maize inbred lines with erect top leaves, were analysed: dependence of their yields on the crop density, and quality of commercial maize of observed maize hybrids. It was presented that observed maize hybrids tolerated crop densities up to 70,000 plants ha^{-1}. It was shown that commercial maize of observed maize hybrids with erect top leaves was of exceptional quality that provided its diversified utilisation.

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ПЕРСПЕКТИВНІ ІНБРЕДНІ ЛІНІЇ ТА ГІБРИДИ КУКУРУДЗИ З ВЕРТИКАЛЬНО РОЗТАШОВАНИМИ ВЕРХНІМИ ЛИСТКАМИ, ЩО ВІДПОВІДАЮТЬ ВЛАСТИВОСТЯМ ЕФЕКТИВНОЇ ФОТОСИНТЕТИЧНОЇ МОДЕЛІ, СТАНОВЛЯТЬ ОСНОВУ ПОДАЛЬШОГО ПРОГРЕСУ В СЕЛЕКЦІЇ І ТЕХНОЛОГІЇ

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У роботі підтверджено припущення про те, що елітні інбредні лінії кукурудзи з вертикально розташованими верхніми листками і гібриди, отримані на їхній основі, мають домінантну ознаку ефективного фотосинтетично-флуоресцентного типу і тому так успішно використовуються в селекції та сучасних технологіях виробництва гібридного насіння й товарної кукурудзи. Наведені результати досліджень вертикального положення верхніх листків, збільшеної густоти посіву, динаміки підсушування зернівок у період їхнього дозрівання, якості насіння гібридної і товарної кукурудзи, а також фотосинтетичних і флуоресцентних параметрів: температурної залежності інтенсивності уповільненої флуоресценції хлорофілу, критерію Арреніуса для визначення критичних температур (температур фазового переходу) і енергій активації, показують, що властивості розглянутих інбредних ліній та їхніх гібридів базуються на позитивному ефекті й природі конформаційних і функціональних змін, що відбуваються в їх тилакоїдних мембранах, інших хімічних і структурних характеристиках тканин листків і зерна. Проаналізовано інші важливі селекційні й насінні властивості досліджених перспективних ліній, гібридів кукурудзи на їхній основі (залежність урожаю від густоти, якість товарної кукурудзи як похідної структури зернівки та її хімічних характеристик).

ПЕРСПЕКТИВНЫЕ ИНБРЕДНЫЕ ЛИНИИ И ГИБРИДЫ КУКУРУЗЫ С ВЕРТИКАЛЬНО РАСПОЛОЖЕННЫМИ ВЕРХНИМИ ЛИСТЬЯМИ, КОТОРЫЕ ОТВЕЧАЮТ СВОЙСТВАМ ЭФФЕКТИВНОЙ ФОТОСИНТЕТИЧЕСКОЙ МОДЕЛИ, ПРЕДСТАВЛЯЮТ ОСНОВУ ДАЛЬНЕЙШЕГО ПРОГРЕССА В СЕЛЕКЦИИ И ТЕХНОЛОГИИ

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В работе подтверждено предположение о том, что элитные инбредные линии кукурузы с вертикально расположенными верхними листьями и гибриды, полученные на их основе, имеют доминантный признак эффективного фотосинтетически-флуоресцентного типа и поэтому так успешно используются в селекции и в современных технологиях производства гибридных семян и товарной кукурузы. Представленные результаты исследований вертикального положения верхних листьев, увеличенной густоты посева, динамики подсушивания зерновок в период их созревания, качества семян гибридной и товарной кукурузы, а также фотосинтетических и флуоресцентных параметров: температурной зависимости интенсивности замедленной флуоресценции хлорофилла, критерия Аррениуса для определения критических температур (температур фазового перехода) и энергий активации, показывают, что свойства рассмотренных инбредных линий и их гибридов основаны на положительном эффекте и природе конформационных и функциональных изменений, происходящих в их тилакоидных мембранах, других химических и структурных характеристиках тканей листьев и зерна. Проанализированы другие важные селекционные и семенные свойства исследованных перспективных линий и гибридов кукурузы на их основе (зависимость их урожая от густоты, качество товарной кукурузы как производное структуры зерновки и ее химических характеристик).

Ключевые слова: Zea mays L., инбредные линии, гибриды, вертикальный верхний лист, тилакоидная мембрана, фотосинтетическая и флуоресцентная модель, замедленная флуоресценция хлорофилла.