Зборник Матице српске за природне науке / Proc. Nat. Sci, Matica Srpska Novi Sad, № 119, 35—53, 2010

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SIGNIFICANT BIOPHYSICAL AND GENETIC PROPERTIES OF MAIZE INBRED LINES AND HYBRIDS WITH ERECT TOP LEAVES

ABSTRACT: This study confirms the hypothesis that there are elite maize inbred lines and hybrids with erect top leaves, which have a dominant property of an efficient photosynthetic and fluorescent model that is successfully used in modern breeding programmes and the production hybrid seed and commercial maize. This statement is supported by the displayed results on the erect top leaves, the dynamics of grain dry-down during the maturation period and photosynthetic and florescence 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. The presented results show that properties of observed maize inbreds and their hybrids are based on the nature of conformational and functional changes that occur in their thylakoid membranes and other chemical tissues structures of grain and intact leaves, as well as, on positive effects in maize breeding. Moreover, other relevant significant breeding and seed production properties (commercial maize quality over grain structure, physical and chemical parameters) of maize inbred lines and their hybrids were analysed in the present study.

KEY WORDS: *Zea mays* L., inbred, hybrid, erect top leaf, thylakoid membrane, photosynthetic and fluorescent model, delayed chlorophyll fluorescence

INTRODUCTION

The performance of numerous studies requires a connection of complex and interrelated processes in fundamental, multidisciplinary and applied sciences. The present manuscript presents the results of interrelated studies carried out within breeding, photosynthesis, fluorescence, biophysical chemistry and seed production in maize inbred lines with erect leaves and significant breeding properties.

Maize breeding and seed production have been intensively developed during the last 60 years and because of such activity more than 1300 grain and silage hybrids were derived. Modern equipment and technical and technological prerequisites were provided for carrying out the process of breeding and hybrid maize seed production (Duvick, 1984, Sprague, 1984, Trifunović, 1986, Dumanović, 1986, Hallauer, 1988, Ivanović et al., 1995, Radenović et al., 2000).

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 (Radenović et al., 1978, Kojić and Ivanović, 1986, Kojić, 1993). At the same time, a programme on breeding and the seed production of maize hybrids with erect leaves has been performed (Radenović et al., 1978, 2003a, 2003b, 2004a, 2004b, 2007, 2008, Felner et al., 2006). According to our hypothesis, it seems that these observed maize inbred lines with erect leaves are the closest to the assumptive maize photosynthetic and fluorescent model (Radenović and Grodzinskij, 1998).

The studies on maize photosynthesis carried out in the previous period did not have a more important application in breeding and the production of maize hybrid seed. It was almost impossible to present a clear and direct interrelationship among photosynthesis, breeding and the production of maize hybrid seed. On the one hand, 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, but on the other hand, it is a result of effects of numerous environmental factors (Radenović et al., 2000, 2004a, 2004b, 2007).

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. (Govindjee and Papageorgiou, 1971, Barber and Neumann, 1974, Holzapfel and Haug, 1974, Hipkins and Barber 1974, Papageorgiou, 1975, Haveman and Lavorel, 1975, Bukhov et al., 1979, Mccauley and Rubby, 1981, Jurisnić and Govindjee, 1982, Jurisnić, 1986, Marković et al., 1987, 1993, 1996, 1999, Dzhibladze, 1988, Lichtenthaler and Rinderle, 1988, Govindjee et al., 1990, Veselovski and Veselova, 1990, Krause and Weis, 1991, Radenović, 1992, 1994, 1997, 1998, Radenović et al., 1994a, 1994b, Radenović and Jeremić, 1996). The direct dependence of the delayed chlorophyll fluorescence (DF) intensity on changes of photosynthetic processes in thylakoid membranes of maize intact leaves was determined (Radenović, 1994, 1997, Radenović and Jeremić, 1996). Conditions that provided monitoring of complex photosynthetic processes in the maize intact leaf by a photosynthetic and fluorescence model in the form of DF were developed (Radenović et al., 2000, Radenović et al., 2001a, 2001b). During the last 20 years, a group of researchers from the Maize Research Institute, Zemun Polje, have been developing a novel semi-non-invasive photosynthetic-fluore-

scence method that functionally binds processes of photosynthesis, fluorescence and maize breeding (Radenović et al., 2002, Radenović et al., 2003a, Radenović et al., 2004a, 2004b, Marković et al., 1996).

Research methods within the field of biophysical chemistry 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 (Radenović, 1994, 1998, Radenović et al., 2007, 2008, Rubin et al., 1988).

The objective of the present study was to show that inbred lines with erect top leaves, significant breeding properties and high yielding maize hybrids derived from them, can be an efficient photosynthetic model, meaning that they can contribute to the functional connection of breeding, photosynthesis and florescence, and thereby to the total progress of breeding and the production of hybrid seed and commercial maize of high quality.

MATERIAL AND METHODS

Plant material

The studies were performed with four elite maize inbred lines with erect top leaves, ZPPL 16, ZPPL 218, ZPPL 62 and ZPPL 233, belonging to the collection of the Maize Research Institute, Zemun Polje. Only basic properties of these 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 has been included into the development of more than 20 maize hybrids. Hybrids ZP 578 and ZP 684 have been the most widely grown hybrids in this medium-term period.

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 has been included into the development of over 10 maize hybrids including the hybrid ZP 684.

The inbred line ZPPL 62 was derived from the BSSS population and it belongs to the FAO 350 maturity group. The kernel of this inbred belongs to the dent type and the cob is red. This inbred has been included into over 20 hybrids, including, ZP 341and ZP 434.

The inbred ZPPL 233 belongs to the Lancaster heterotic group and to the FAO 500 maturity group. The kernel of this inbred belongs to the semi-dent/ semi-flint type and the cob is red. This inbred has been included into over 10 hybrids out which the hybrid ZP 578 has been the most widely grown.

Observed maize inbred line with top erect leaves and significant breeding properties are characterised as an efficient photosynthetic model. In addition, these maize inbred lines are characterised by greater grain dry down rates in the maturation period, as well as, by a satisfactory tolerance, resistance, flexi-

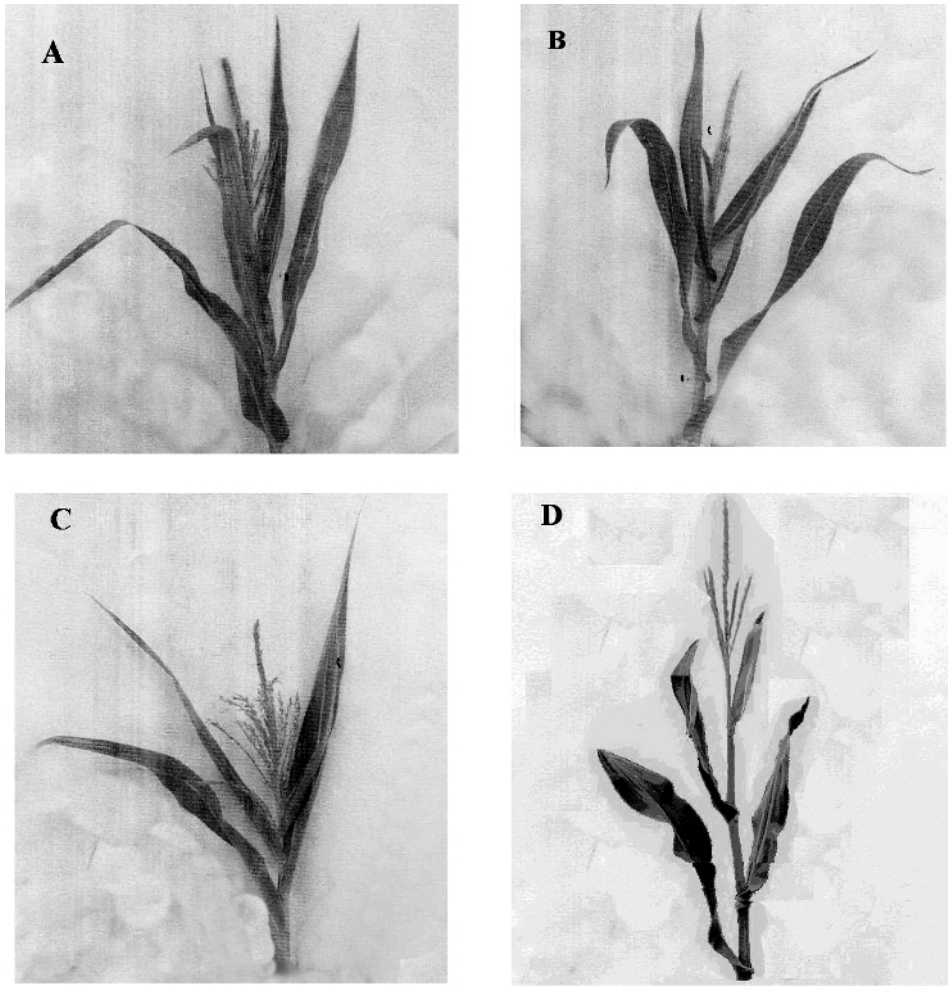

Fig. 1. — Actual appearance of maize inbred lines with top erect leaves and significant breeding properties: ZPPL 16 (A), ZPPL 218 (B), ZPPL 62 (C) and ZPPL 233 (D)

bility and adaptability to high and very high temperatures and drought. The following hybrids were taken into consideration: ZP 341, ZP 434, ZP 578, and ZP 684.

Methods

Overall studies of the stated maize inbred lines with erect top leaves encompassed several series of experiments in which standard and other appropriate 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 during the three-year period. These methodical procedures were described in previously published papers (R a d e n o v i ć et al., 2003a, 2004a, 2004b, 2007).

2. *Photosynthetic fluorescence measurements*

The second series of the experiments was related to photosynthetic-fluorescence measurements, including thermal processes of 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 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

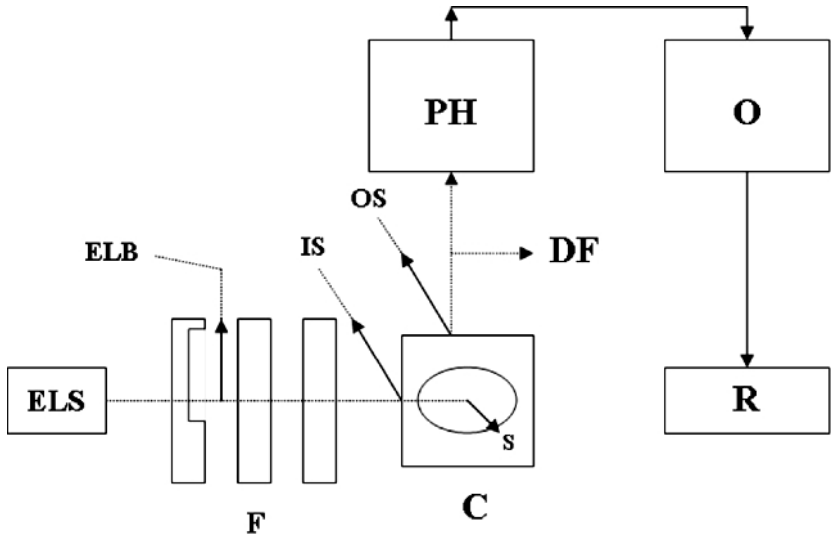

Fig. 2. — Experimental setup of the photosynthetic fluorescence method and the measuring equipment for delayed chlorophyll fluorescence: **ELS** — excitation light source; **F** — filters; **ELB** — excitation light beam, **IS** — input dark chamber slot, **C** — dark chamber with a sample stand; **s** — sample (intact leaf segment), **OS** — output dark chamber slot, **DF** — luminescent light (delayed fluorescence), **PH** — photo-multiplier; **O** — oscilloscope, **R** — printer

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 268 plants of each inbred line.

The improved non-invasive photosynthetic fluorescence method used to measure DF is schematically presented in Figure 2. This method, developed at the Maize Research Institute, Zemun Polje, has been improved several times. Photosynthetic fluorescence measurements were performed after a method that had been described in the monograph (Marković et al 1996) and our previous papers (Radenović, 1994, 1997, Radenović et al., 2001a, 2001b, 2002, 2004a, 2004b, 2007, 2008).

3. *Dynamics of water status changes in grain*

The third series of the experiments was related to the water status and the dynamics of its 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.

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) during the grain maturation was observed in the course of five years. The long-term measurements were done because of a great instability of this trait in the majority of maize inbred lines (Radenović et al., 2008, 2009).

4. *Grain chemical composition, physical properties and structure of maize hybrids with erect top leaves*

Applied standard methods for the determination of the chemical composition, physical properties and grain structure of maize hybrids with erect top leaves were fully described in previous papers (Bekrić, 1997, Radosavljević et al., 2000, 2002).

RESULTS

1. *The measure of the angle and the area of the above-ear leaf*

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 1. Based on obtained results on the measures of angles it can be stated that the observed maize inbred lines with significant breeding properties belong to the group of inbred lines with erect top leaves.

Tab. 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 in degrees		Area of the above-ear leaf (x 10^3 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
ZPPL 233	500	Zemun Polje — Lancaster	24.5	1.34	5.66	613

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

2. *Empirical procedure for photosynthetic fluorescence studies on the above-ear leaf*

The detailed studies on thermal processes of DF of observed maize inbred lines with erect top leaves were performed. The thermal curve is a curve that shows the dynamics of changes in the stationary DF level intensity in depen-

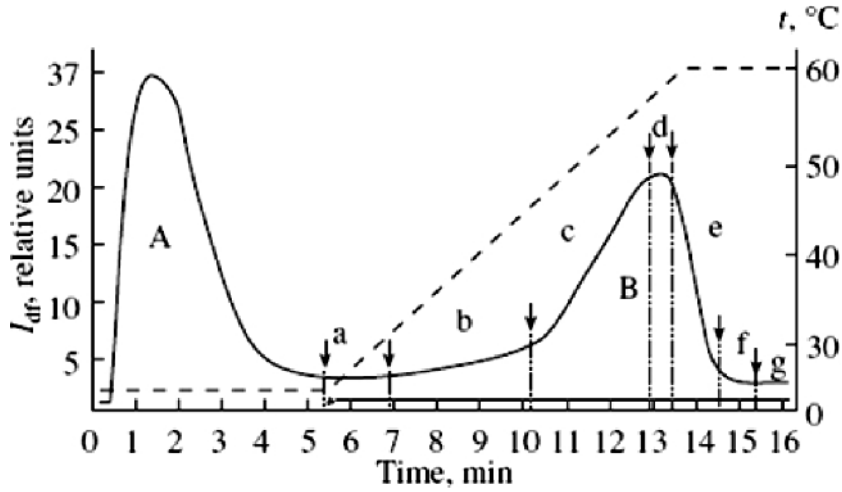

Fig. 3. — Schematic presentation of the empirical procedure for typical changes in DF intensities ($\mathbf{I_{df}}$) on the intact above-ear leaf of the observed maize inbred lines with significant breeding properties (solid line) and changes in temperatures (dashed line): curve **A** indicates induction 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 $\mathbf{I_{df}}$ 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

dence on a temperature. The trend of its establishment is usually analogous to changes in the duration in seconds of segments marked with **a**, **b**, **c**, **d**, **e**, **f** and **g** (Figure 3), which was determined by the empirical procedure (Radenović et al., 2008, 2009)

Monitoring the course of the thermal curve and the analysis of the duration of certain segments provided data on the existence of a greater number of critical temperatures (phase transition temperatures) at which greater or smaller structural and functional changes occurred in the thylakoid membrane of observed maize inbred lines with erect top leaves.

3. *The temperature dependence of the delayed chlorophyll fluorescence intensity for the thylakoid membrane of the maize inbred lines with erect top leaves*

Figure 4 A, B, C and D, 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, ZPPL 62 and ZPPL 233. The temperature dependence of observed inbreds varies over dynamics of increasing and decreasing occurrence, as well as, over the temperature peaks.

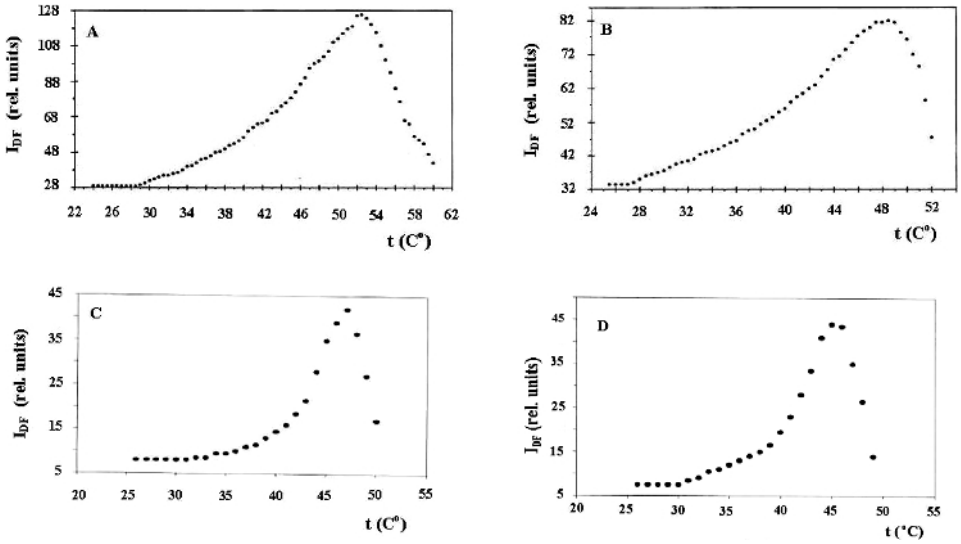

Fig. 4. — A, B, C and D Changes in the intensity of the delayed chlorophyll fluorescence (I_{DF}) of thermal processes in dependence on the effects of temperatures in the thylakoid membrane of the intact above-ear leaf of the maize inbred lines with significant breeding properties and erect top leaves: ZPPL 16(A), ZPPL 218(B), ZPPL 62(C) and ZPPL 233(D)

4. *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 (Figure 5, A, B, C and D). Critical temperatures (phase transition temperatures) at which conformational changes occur in the thylakoid membrane are determined by the application of the Arrhenius plot. Results of the Arrhenius plot application to maize inbreds with significant breeding properties and erect top leaves are presented in Figure 5 A, B C and D. The Arrhenius plot shows the dynamics and spots of critical temperature occurrences of studied inbreds.

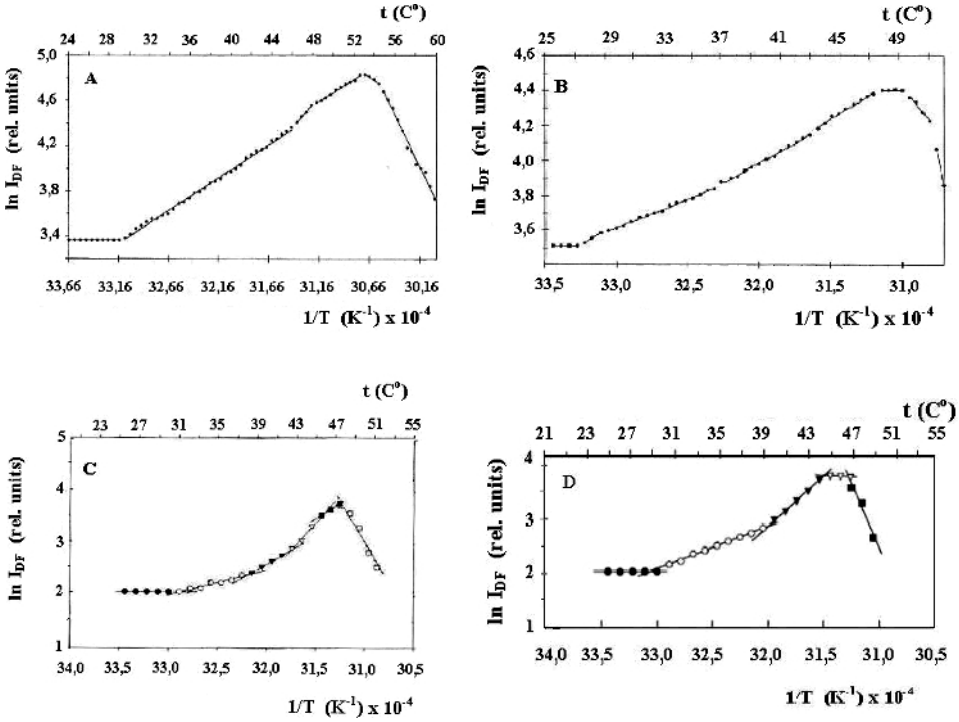

Fig. 5. — A, B, C and D The Arrhenius plot for the determination of critical temperatures and conformational changes in the thylakoid membrane of the above-ear leaf of maize inbred lines with significant breeding properties and erect top leaves: ZPPL 16(A), ZPPL 218(B), ZPPL 62(C) Z and ZPPL 233(D)

5. *Activation energy and critical temperatures in the thylakoid membrane of the observed maize inbred lines with erect top leaves*

Detailed studies on the thermal processes of DF, and especially on the analysis of thermal curve, encompassed not only the temperature dependence and the Arrhenius plot, but also the estimation of values of activation energies for critical temperatures (phase transition temperatures) in the thylakoid membranes of the observed maize inbreds with significant breeding properties and erect top leaves: ZPPL 16, ZPPL 218, ZPPL 62 and ZPPL 233. Obtained results are shown in Table II.

Tab. 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		ZPPL 233	
Ea, kJ/mol	t, °C	Ea, kJ/mol	t, °C	Ea, kJ/mol	t, °C	Ea, kJ/mol	t, °C
—	29.5	—	27.0	—	28.0	—	25
48.4	45.9	43.1	29.0	45.0	36.0	32	30
84.3	48.0	27.3	36.9	91.8	41.0	100.3	38
46.7	53.0	37.0	43.5	119.7	46.9	176.7	42
49.2	54.8	42.5	47.8	132.0	49.0	259.9	47
—	60.0	51.1	49.9	—	—	—	50

6. *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 important properties of these inbreds to which a great attention is paid in the processes of contemporary breeding and the production of high-quality hybrid maize seed. Obtained results are presented in Table III.

Tab. 3. — Water content (%) in initial and subsequent measurements

Inbred lines	I initial measure-ment	II measure-ment after 7 days	III measure-ment after 14 days	IV measure-ment after 21 days	V measure-ment after 28 days	VI measure-ment after 35 days	Daily dry down
ZPPL 16	31.40±3.22	28.11±3.11	24.82±3.05	21.53±2.98	18.24±2.81	14.95±2.41	0.47±0.06
ZPPL 218	29.44±3.06	26.29±2.91	23.14±2.77	19.99±2.51	16.84±2.31	14.20±1.76	0.45±0.08
ZPPL 62	28.09±3.28	25.29±3.09	22.49±2.88	19.69±2.56	16.89±2.04	14.09±1.94	0.40±0.07
ZPPL 233	27.44±3.80	24.36±3.51	21.28±3.33	18.20±3.07	15.12±2.81	12.04±2.24	0.44±0.09

7. *Chemical composition, physical properties and grain structure of maize hybrids with erect top leaves*

Results on studies of grain structure, physical properties and chemical composition of maize hybrids with erect top leaves are presented in Tables IV, V and VI.

Tab. 4. — 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

Tab. 5. — Physical properties of the grain of maize hybrids with erect top leaves*

Hybrid	TKW	TW	D	FI	MR	HEF	SEF	WAI
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

* TKW = 1000-kernel weight (g), TW = test weight (kg m^{-3}), D — density (g cm^{-3}), FI — floatation index (%), MR — milling response (s), HEF — hard endosperm fraction, (%), SEF — soft endosperm fraction (%), WAI — water absorption index

Tab. 6. — 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

DISCUSSION

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 fundamental and hybrid maize seed. The number of plants per area unit has been growing since 1978. This programme was referred to as a "plant density" programme and it further directly affected the yield increase of high quality fundamental and hybrid maize seed (R a d e n o v i ć et al., 1978). 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 inbreds with the erect top leaves were the closest to the proposed efficient photosynthetic model (R a d e n o v i ć et al., 1978, 2000, 2001a, 2003a, 2004a, R a d e n o v i ć and G r o d z i n s k i j, 1998). The complementary and mass implementation of these programmes led to very important re-

sults in both, maize breeding and the hybrid seed production (Ivanović et al., 1995, Trifunović, 1986, Trifunović et al., 2000, Dumanović, 1986, Kojič, 1993). New and numerous hybrids with high grain and silage yields were developed and grown on large areas due to their high yielding potential and the appropriate quality of the plant and the grain (Duvick, 1984, Russell, 1986, Dumanović, 1986, Hallauer, 1988, Kojić, 1993, Ivanović et al., 1995).

The special contemporary studies have been performed on top maize leaves. The ear leaves have been particularly observed, but also other top leaves up to the tassel. The most efficient and the longest photosynthetic processes necessary for the maize plant have been achieved by these leaves (Radenović and Grodzinskij, 1998). According to the stated, a new hypothesis that precisely top leaves (above-ear leaves) achieve the efficient photosynthesis 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 maize production can be achieved?, and (2) which traits should maize inbred lines have?

The gained results of experimental studies can offer at least a partial answer to asked questions. The first series of experiments included the measure of the angle and the leaf area of observed maize inbred lines with significant breeding properties and erect top leaves. The results obtained on these traits classify them into important seed breeding and seed production traits (Radenović et al., 2003a, 2004a, 2004b, 2007, 2008). The second series of experiments encompassed photosynthetic fluorescence studies on conformational and functional changes in the thylakoid membrane of the intact above-ear leaf of studied maize inbred lines with significant breeding traits. The temperature dependence of thermal processes of DF for the studied maize inbred lines is presented in a form of the empirical procedure (Figure 3). The presented results show that the temperature dependence of DF in each of the four maize inbred lines with erect top leaves is characterised with typical intersection points of two segments on the thermal curve (Figures 3 and 4). The first typical point occurred on the intersection of the segment **a** and the segment **b**, and it represented the lowest critical temperature 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 (Figure 3 and Figure 4 A, B, C and D) 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 (R a d e n o v i ć et al., 2003a, 2003b, 2004a, 2004b, 2007).

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 values of critical temperatures (°C), their frequency and intermediate distance characterise observed maize inbred lines with erect top leaves in relation to their tolerance, resistance, flexibility and adaptability not only to increased and high temperatures, but also to drought (R a d e n o v i ć et al., 2001a, 2001b, 2002, 2003a). 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 (R a d e n o v i ć, 1994, 1997, R a d e n o v i ć et al., 2003a, 2003b, 2004a, 2004b).

Presented photosynthetic fluorescence traits of studied maize inbred lines with erect top leaves can contribute to more exact, rational and expeditious proceedings of breeding processes and the production of high-quality hybrid maize 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 significant 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 (R a d e n o v i ć, 1998, R a d e n o v i ć et al., 2008, 2009). 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, which is prone to the external atmospheric pressure, as well as, to frequency and intensity of air currents and significant changes in relative air 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 affinity to bind 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.

Gained results presented in Tables IV, V and VI, 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 (Bekrić, 1997, Radosavljević et al., 2000, 2002).

CONCLUSION

According to the gained results it can be established that semi-non-invasive photosynthetic fluorescence method can be applied in breeding and the maize hybrid seed production and that the estimation of maize inbred lines with significant breeding traits for their tolerance, resistance, flexibility 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 the photosynthetic apparatus of observed maize inbred lines with significant breeding properties and erect top leaves:

— The temperature dependence was monitored within the range of 24—60°C,

— Different monotonies of the increasing part of the thermal curve, which points out to uneven tolerance, resistance, flexibility and adaptability of observed maize inbred lines to increased and high temperatures, as well as, to drought, were established,

— Values of critical temperatures at which smaller or greater structural and functional changes occurred in the thylakoid membranes of observed maize inbred lines with erect top leaves were determined,

— Values of activation energies (Ea, kJ mol^{-1}) were determined before and after the occurrence of critical temperatures in the thermal process of DF,

— It was shown that observed inbred lines had a trait of the erect position of top leaves and efficient photosynthesis model,

— A greater dry down rate in the grain maturation period was estimated and analysed in maize inbred lines with significant breeding properties and erect top leaves,

— Relevant physical and chemical traits of maize hybrids developed from the stated inbred lines with erect top leaves were analysed; these analyses point out to good quality of commercial maize and its diversified utilisation.

ACKNOWLEDGEMENT

These studies were mainly supported by the Maize Research Institute, Zemun Polje, and partially by the Ministry of Science and Technological Development of the Republic of Serbia (Projects: 03E211, 03E22, 142025, TR-20003, TR-20007, TR-20014).

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БИОФИЗИЧКА И ГЕНЕТИЧКА СВОЈСТВА ПРЕСТИЖНИХ ИНБРЕД ЛИНИЈА И ХИБРИДА КУКУРУЗА СА УСПРАВНИМ ПОЛОЖАЈЕМ ВРШНИХ ЛИСТОВА

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Резиме

Проучаване су четири престижне инбред линије кукуруза са усправним положајем вршних листова: ЗППЛ 16, ЗППЛ 218, ЗППЛ 62 и ЗППЛ 233. Ове линије су, као мајка или отац, укључене у стварање више од 50 хибрида кукуруза. У

текућем средњерочном периоду широку комерцијалну примену нашао је већи број хибрида кукуруза: ЗП 341, ЗП 360, ЗП 434, ЗП 578, ЗП 606, ЗП 677, ЗП 684 и други. У овом раду анализирани су само репрезентативни хибриди кукуруза: ЗП 341 (ФАО 300), ЗП 434 (ФАО 400), ЗП 578 (ФАО 500) и ЗП 684 (ФАО 600).

Овим радом потврђује се наша хипотеза да постоје елитне инбред линије и хибриди кукуруза са усправним положајем вршних листова, који поседују доминантно својство ефикасног фотосинтетично-флуоресцентног модела и успешно се користе у савременим програмима оплемењивања, производњи хибридног семена и меркантилног кукуруза. Овај закључак добијен је уз примену неинвазивног фотосинтетично-флуоресцентног метода погодног за оцену ефикасности фотомодела. Добијене фотосинтетичне карактеристике проучаваних престижних инбред линија кукуруза са усправним положајем вршних листова засноване су на ефектима и природи промена закаснеле флуоресценције хлорофила које се одигравају у њиховим тилакоидним мембранама, чији су показатељи температурна зависност интензитета закаснеле флуоресценције хлорофила, Аренијусов критеријум за утврђивање критичних температура (температуре фазних прелаза) у тилакоидним мембранама и енергије активације. Изложени резултати о величини угла између правца простирања првог листа изнад клипа и правца простирања стабљике, као и резултати о динамици ослобађања воде из зрна у периоду његовог сазревања додатно показују да су својства проучаваних инбред линија кукуруза са усправним положајем вршних листова погодни критеријуми за егзактнији, рационалнији и бржи процес оплемењивања.

Такође су анализирана и друга релевантна селекциона и семенарска својства проучаваних престижних инбред линија и хибрида кукуруза (квалитет меркантилног кукуруза преко структуре зрна, физичких и хемијских параметара).