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THE PRESTIGIOUS MAIZE INBRED LINES WITH ERECT TOP LEAVES. THE PRIORITY PERFORMANCE OF THE EFFICIENT PHOTOSYNTHETIC MODEL IN BREEDING

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This study conforms the hypothesis that there are elite maize inbred lines with erect top leaves that have a property of an efficient photosynthetic model and that as such are successfully used in the processes of breeding in which the number of plants is increased per area unit (plant density). This proof was established by the application of non-invasive photosynthetic-fluorescence method suitable for the evaluation of the efficiency of the photosynthetic model. The obtained photosynthetic and fluorescence properties of observed prestigious maize inbred lines with the erect top leaves are based on the effects and the nature of changes in chlorophyll fluorescence occurring in their thylakoid membranes. Their principal parameters are temperature dependence of the chlorophyll delayed fluorescence intensity, the Arrhenius plot for the

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determination of the phase transition in thylakoid membranes and the estimated activation energies.

The displayed results on the size of an angle between the direction of the propagation of the above-ear leaf and the direction of the stalk propagation, as well as, results on the dynamics of grain dry-down during the maturation period, additionally indicate that traits of observed maize inbred lines with erect top leaves are the prominent base for more exact, rational and faster proceeding of current processes of breeding.

Key words: adaptability, delayed chlorophyll fluorescence, erect top leaves, grain dry-down, inbred line, intact leaf, photosynthetic model, resistance,thylakoid membrane, thermal processes, transport processes

INTRODUCTION

Nowadays at the beginning of the 21st century the inevitability of connecting complex and interrelated processes of fundamental, multidisciplinary and applied sciences prevails. Such efforts to connect breeding, photosynthesis, fluorescence, biophysical chemistry and the seed production in elite maize inbred lines with the erect top leaves are encompassed by this study. The developmental paths of dominant processes for the stated scientific disciplines are briefly analysed in the present study and functional places of their efficiency and their interrelationship are revealed.

Maize breeding and the seed production have been intensively developing for the last 60 years. As a result of such an activity over 1200 grain and silage maize hybrids were derived. At the same time contemporary technical and technological prerequisites for performance of the modern maize hybrid seed production were provided (DUVICK 1977, 1984; SPRAGUE 1984; HALLAUER 1988; TRIFUNOVIĆ 1986; DUMANOVIĆ 1986; IVANOVIĆ *et al.*; 1995; RADENOVIĆ *et al*., 2000). Regardless of such a colossal success in maize breeding and the maize hybrid seed production, eagerness and enthusiasm of the overall research have not been slowed down, but on the contrary it has been searched for new methods and more exact approaches in order to complete and enrich breeding and the maize seed production.

Since 1980 the number of plants per area unit (plant density) has been significantly increasing, which the most directly affected the increase of yields of both, maize hybrid seed and mercantile maize (KOJIĆ and IVANOVIĆ 1986; KOJIČ 1993). Almost at the same time, another programme on breeding and the seed production of maize hybrids with erect leaves was performed (RADENOVIĆ *et al.,* 1978, 2003a, 2003b, 2004a, 2004b, 2007, 2008a, 2008b; FELNER *et al.,* 2006). It seems, according to our hypothesis, that these observed maize inbred lines with erect leaves are the closest to the assumptive photosynthetic fluorescence photosynthetic model (RADENOVIĆ and GRODZINSKIJ 1998).

The development of studies on photosynthesis of maize was quite different. Namely, although photosynthetic processes are very spread, highly

productive in their intensity, very complex in their nature, and vastly studied in their scientific actuality, their application in breeding and the maize hybrid seed production is still insignificant. It was almost not possible to provide a clear and direct interrelationships among photosynthesis, breeding and the hybrid maize seed production. Such a situation is probably a consequence of the existence of several functional interrelationships that encompass structural and dynamical changes within the chloroplasts and their thylakoid membranes, on the one hand, and effects of numerous environmental factors affecting these changes, on the other hand (RADENOVIĆ *et al.,* 2003a, 2004a, 2007, 2008a, 2008b). This state did not last long. Namely, during the last 35 years, new and significant studies within fields of bioluminescence and fluorescence phenomena of plant systems, including maize, were carried out (BARBER and NEUMANN 1974; BUKHOV *et al.,* 1989; DZHIBLADZE et al., 1988; GOVINDJEE and PAPAGEORGIOU, 1971; GOVINDJEE *et al.,* 1990; HAVEMAN and LAVOREL, 1979; HIPKINS and BARBER, 1974; HOLZAPFEL and HAUG, 1974; JURISNIĆ, 1989; JURISNIĆ and GOVINDJEE 1982; KRAUS and WEIS, 1991; LICHTENTHALERAND and RINDERLE, 1988; MCCAULEY and RUBY, 1981; PAPAGEORGIOU, 1975; VESELOVSKI and VESELOVA, 1990; MARKOVIĆ et al., 1987, 1993, 1999; RADENOVIĆ 1992, 1994, 1997, RADENOVIĆ *et al.,* 1994a, 1994b; RADENOVIĆ and JEREMIĆ, 1996). These studies cast a new light on complex photosynthetic and fluorescence processes. The direct dependence of delayed chlorophyll fluorescence (DF) with changes in photosynthetic processes in the thylakoid membranes of the intact leaves of maze was revealed (RADENOVIĆ 1994, 1997; RADENOVIĆ and JEREMIĆ 1996). Thus it was possible to monitor complex photosynthetic processes in the maize intact leaf with a photosynthetic-fluorescence response in a form of DF (RADENOVIĆ *et al* 2000, 2001a, 2001b). During the last 15 years, a team of researchers at the Maize Research Institute, Zemun Polje, developed a new, non-invasive photosynthetic-fluorescence method that functionally connected events of photosynthesis, fluorescence and maize breeding (RADENOVIĆ et al., 2002, 2003a, 2003b, 2004a, 2004b; MARKOVIĆ *et al*., 1996).

The methods of biophysical chemistry greatly contributed to a diverse connecting of studies of photosynthetic and transport processes in the thylakoid membrane and in different chemical structures of the kernel with the processes of fluorescence spectroscopy, chemical kinetics and the dynamics of grain dry-down in the period of the kernel maturation (RADENOVIĆ 1994, 1998; RADENOVIĆ *et al*., 2007, 2008a, 2008b; RUBIN *et al*., 1988).

The aim of this study was to show that the elite and prestigious maize inbred lines with erect top leaves can be an efficient photosynthetic model, i.e. that they can contribute to a functional connection of breeding, photosynthesis and fluorescence, whereby contemporary processes of breeding and the hybrid maize seed production can be improved.

MATERIAL AND METHOD

Plant material

The following three elite maize inbred lines with erect top leaves: ZPPL 16, ZPPL 218 and ZPPL 62 were observed in this study. Each of these inbreds belongs to the collection of the Maize Research Institute, Zemun Polje. Only the principal properties of these inbreds are presented.

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

The inbred line ZPPL 218 belongs to the Lancaster heterotic group population and to the FAO 650 maturity group. It is characterised with a dent kernel type and a red cob. This inbred was included into the development of more than 10 ZP maize hybrids, including the hybrid ZP 684. Recently released hybrids ZP 548, ZP 574, ZP 648, ZP 606 and ZP 805 especially stand out and it is expected that they will have a significant commercial and marketing value in the near future.

The inbred line ZPPL 62 belongs to the BSSS heterotic group and to the FAO 350 maturity group. It is characterised with a dent kernel type and a red cob. This inbred, as one of parental components, is included into more than 20 maize hybrids. However, out of all developed hybrids only hybrids ZP 260, ZP 341, ZP 360 and ZP 434 have a broad commercial application in this medium-term period.

These three lines are also characterised with the property of the efficient photosynthetic model, as all inbreds have erect top leaves. Furthermore, the observed maize inbred lines are characterised with a fast grain dry-down rate in the maturation period, as well as, with satisfactory tolerance to impacts of increased and high temperatures and drought.

Methods

The overall studies of the stated maize inbred lines encompassed three series of experiments that included three method procedures.

1. The measure of an angle and leaf area

The first series of experiments was related to studying of 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 stalk of maize inbred lines. The leaf area was measured using a 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 in the course of three years. These method procedures were described in previously published papers (RADENOVIĆ 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 energy. The test maize inbreds grown in the experimental field of the Maize Research Institute 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 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 Figure 1. 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 (RADENOVIĆ 1994, 1997; MARKOVIĆ *et al.,* 1996; RADENOVIĆ *et al.* 2001a, 2001b, 2002, 2004a, 2004b, 2007, 2008a, 2008b).

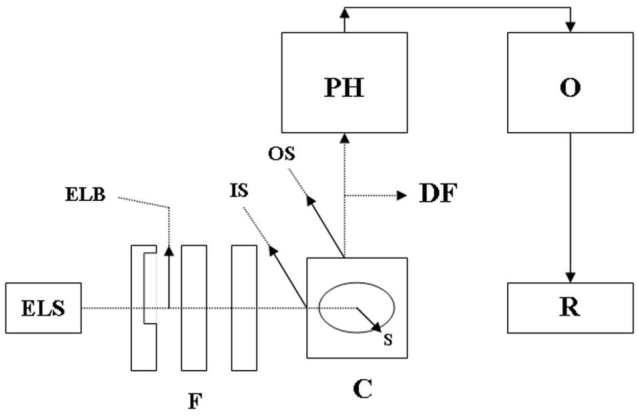

Figure 1. Experimental setup of the photosynthetic fluorescence method and the measuring equipment for delayed chlorophyll fluorescence: **ELS** - excitation light source; **F** - filters; **ELB** - excitation light beam, **IS** - input dark chamber slot, **C** - dark chamber with a sample stand; **s** - sample (intact leaf segment), **OS** - output dark chamber slot, **DF** - luminescent light (delayed fluorescence), **PH** - photo-multiplier; **O** - oscilloscope, **R** - printer

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 greater grain dry-down rate in the maturation period, which was observed by the application of the thermal method of oven-drying at 105 C^o 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) at the grain maturation was observed for not less than five years, because of a great instability of this trait in the majority of maize inbred lines (RADENOVIĆ *et al.,* 2008a, 2008b).

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

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 stalk of maize inbred lines. Results on the measures of angles between the above-ear leaf and the stalk, as well as, average leaf areas are presented in Table 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. However, the leaf area has no properties that would particularly characterise the studied maize inbred lines.

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)	
			$\overline{x}$	σ	$\overline{x}$	σ
ZPPL 16	700	Zemun Polje - BSSS	18,26º	1,120	3628,44	328,22
ZPPL 218	700	Zemun Polje - Lankaster	22,12º	1,361	3906,35	412,14
ZPPL 62	350	Zemun Polje - BSSS	20,30º	1,211	3330,21	318,43

*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.

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 establishing is most often analogous to segments in seconds designated with **a**, **b**, **c**, **d**, **e**, **f** and **g**, Figure 2.

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 or functional changes occur in the thylakoid membrane of the observed inbreds.

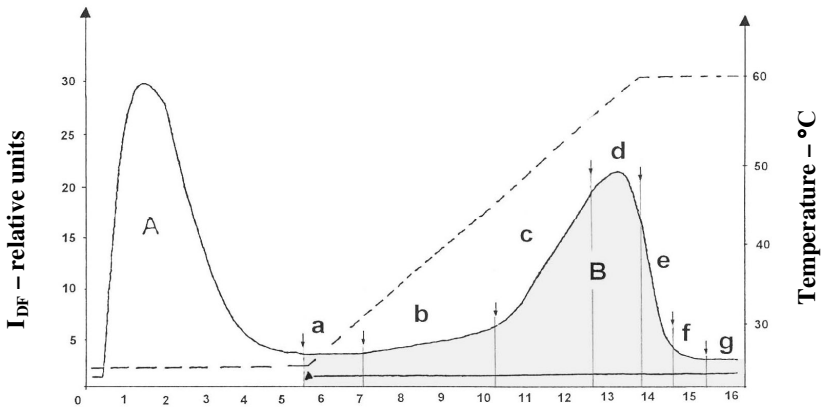

Figure 2. Schematic presentation of typical changes of DF intensities ($\mathbf{I_{df}}$) on the intact above-ear leaf of the observed prestigious maize inbred lines (solid line) and changes of temperatures (dashed line): curve **A** indicates induction processes of DF, while curve **B** encompasses 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.

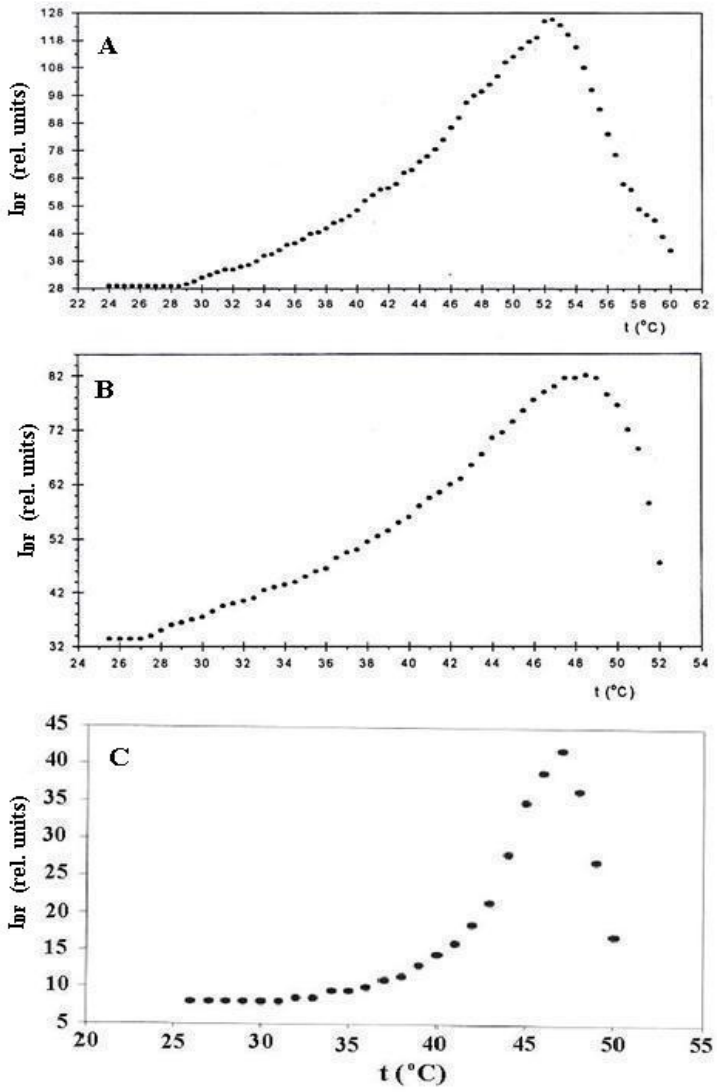

Figure 3 A, B, C. Changes of the intensity of the delayed chlorophyll fluorescence ($\mathbf{I_{DF}}$) of thermal processes in dependence on the effects of temperatures in the thylakoid membrane on the temperature dependence of the intact above-ear leaf of the prestigious maize inbred lines: ZPPL 16(A), ZPPL 218(B), ZPPL 62(C).

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, Figure 3 A, B, C. 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 Figure 4 A, B and C.

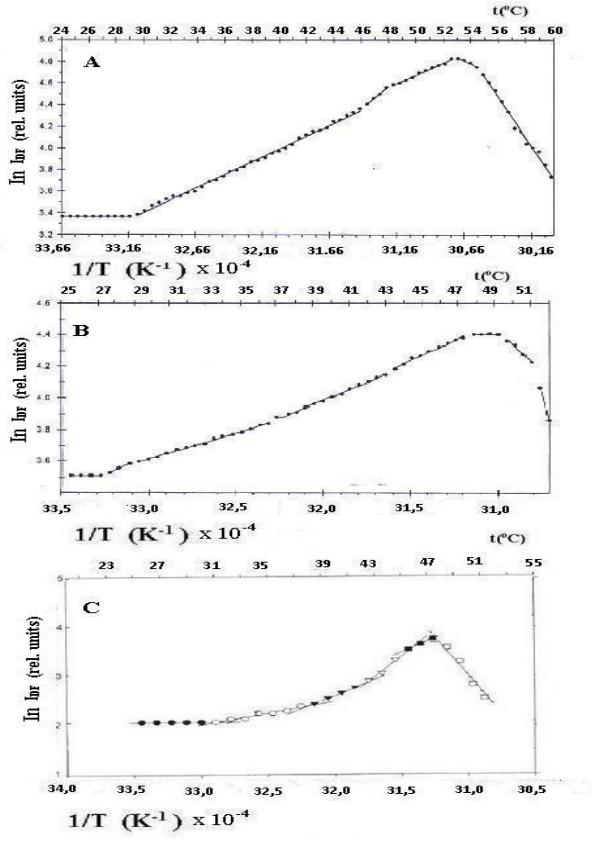

Figure 4 A, B, C**.** The Arrhenius plot for the determination of critical temperatures (intersection of two straight lines) and conformational changes in the thylakoid membrane of the above-ear leaf of observed prestigious maize inbred lines: ZPPL 16(A), ZPPL 218(B) and ZPPL 62(C).

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 Table 2.

Table 2. Changes in activation energies (Ea) and critical temperatures (tºC) in the course of thermal processes in the thylakoid membrane of the intact above-ear leaf of studied prestigious maize inbred lines

ZPPL 16		**ZPPL 218**		**ZPPL 62**	
Ea, kJ/mol	**t, ºC**	**Ea, kJ/mol**	**t, ºC**	**Ea, kJ/mol**	**t, ºC**
-	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	-	-

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 hybrid maize seed production. Obtained results are presented in Table 3.

Table 3. Dynamics of dry down during the grain maturation period of the maize inbred lines with erect top leaves

Inbred line	Water content (%) in initial and subsequent measurements						Daily dry down
	Initial measurement						
	I	II	III	IV	V	VI	
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

DISCUSSION

The second half of the 20th and the first decade of the 21st century, as already mentioned, will be remembered by a great success achieved in maize breeding and the hybrid seed production. This almost spontaneous and immense activity had a very broad and complex programme in maize breeding and the seed production. Its goal was clear and concrete - to provide the highest possible grain yield in the newly developed maize hybrids and to provide a sufficient amount of high-quality hybrid 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 most directly affected the further yield increase (RADENOVIĆ *et al*., 1978). In addition, a programme on the development of maize inbred lines with erect top leaves was established. In pursuance of our hypothesis it was considered that these inbreds were the closest to the proposed efficient photosynthetic model (RADENOVIĆ *et al*., 1978, 2000, 2001a, 2003a, 2004a; RADENOVIĆ and GRODZNISKIJ 1998). These two programmes in maize breeding and the seed production were not only complement, but they have also been expanded. Their implementation led to new results in both, maize breeding and the hybrid seed production (IVANOVIĆ *et al*., 1995; TRIFUNOVIĆ 1986; DUMANOVIĆ 1986; KOJIĆ 1993). In such a way, new and numerous hybrids with high grain and silage yields were developed (DUVICK 1984; RUSSELL 1986; HALLAUER 1988; DUMANOVIĆ 1986; KOJIĆ 1993; IVANOVIĆ *et al* 1995).

Considering the stated, it was quite expected that the Maize Research Institute, Zemun Polje, would take a role in the further development of the stated breeding programmes related to maize inbred lines with erect top leaves (RADENOVIĆ et al., 1978, 2001b, 2003a, 2003b, 2004a, 2004b, 2008a, 2008b; RADENOVIĆ and GRODZNISKIJ 1998). The initial studies on the erect leaves were performed on the leaves below the ear, and then they were performed on ear leaves at the Maize Research Institute, Zemun Polje (RADENOVIĆ *et al*., 2003a, 2004a, 2004b, 2007). In recent times top leaves of maize inbred lines have been studied. The above-ear leaves are especially observed, but also all other leaves up to tassels. The most efficient and the longest photosynthetic processes necessary for the maize plant are achieved in these leaves (RADENOVIĆ and GRODZNISKIJ 1998). According to the stated and our attempts a new hypothesis about top leaves having the efficient role of the photosynthetic model has been proposed.

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

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 three 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 (Table 1) classifies them into important seed breeding and seed production traits (RADENOVIĆ *et al* 2008a, 2008b). 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 establishing (Figure 2). However, the actual results of the temperature dependence of DF for each of the three tested prestigious maize inbred lines with erect top leaves are presented in Figure 3 A, B, C. The outcome is 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 (Figure 2). 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 and 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 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 segment. The typical points designated as **f** and **g** almost had no physiological role. The analysed typical intersection points (Figure 2 and Figure 3 A, B, C) can be considered the point characterising inbred lines with erect top leaves, as these points are precisely the points of conformational and functional changes in the thylakoid membrane (RADENOVIĆ 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 value of critical temperatures (^{o}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 (RADENOVIĆ 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 values of activation energies 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 (Table 3) (RADENOVIĆ 1994, 1997; RADENOVIĆ *et al.,* 2003a, 2003b, 2004a, 2004b).

Presented photosynthetic fluorescence traits of studied prestigious 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 a very important and prestigious property 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 (RADENOVIĆ 1998). 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, which is inclined to great changes (frequent air currents, changes in relative humidity and the like) that contribute to its uneven alterations; 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, 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.

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PRESTIŽNE INBRED LINIJE KUKURZA SA USPRAVNIM POLOŽAJEM VRŠNIH LISTOVA. PRIORITETNO SVOJSTVO EFIKASNOG FOTOSINTETIČNOG MODELA U OPLEMENJIVANJU

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I z v o d

Proučavane su tri prestižne inbred linije kukuruza sa uspravnim položajem vršnih listova: ZPPL 16, ZPPL 218, ZPPL 62. Ove linije su, bilo kao majka, bilo kao otac uključene u stvaranju više od 45 hibrida kukuruza. Međutim, u ovom srednjeročnom periodu, široku komercijalnu primenu ima više od deset hibrida kukuruza: ZP-341, ZP-360, ZP-434, ZP-578, ZP-606, ZP-677, ZP-684 i drugi.Ovim radom potvrđena je hipoteza da elitne inbred linije kukuruza sa uspravnim položajem vršnih listova imaju svojstvo efikasnog fotosintetičnog modela i da se, kao takve, u procesu oplemenjivanja uspešno koriste pri povećavanju broja biljaka na jedinici površine (gustina biljaka). Ovaj dokaz ostvaren je uz primenu neinvazivnog fotosintetično-fluorescentnog metoda pogodnog za ocenu efikasnosti foto modela. Dobijene fotosintetične karakteristike proučavanih prestižnih inbred linija kukuruza sa uspravnim položajem vršnih listova zasnovane su na efektima i prirodi promena zakasnele fluorescencije hlorofila koje se odigravaju u njihovim tilakoidnim membranama. Njihovi glavni pokazatelji su temperaturna zavisnost intenziteta zakasnele fluorescencije hlorofila, Arrhenijusov kriterijum za utvrđivanje faznih prelaza u tilakoidnim membranama i energije aktivacije. Izloženi rezultati o veličini ugla između pravca prostiranja prvog lista iznad klipa i pravca prostiranja stabljike, kao i rezultati o dinamici otpuštanja vode iz zrna u periodu njegovog sazrevanja dodatno pokazuju da su svojstva proučavanih inbred linija kukuruza sa uspravnim položajem vršnih listova prestižna osnova za egzaktija, racionalnija i brža odvijanja savremenih procesa oplemenjivanja.

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