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CHLOROPHYLL FLUORESCENCE CHARACTERISTICS AND SEED YIELD OF BULGARIAN COTTON CULTIVARS GROWN IN RAINFED CONDITIONS

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Abstract

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Changes of functional activity of photosynthetic apparatus of new Bulgarian cotton cultivars under water stress are studied. The genotypes were cultivated under field conditions during 2011 and 2012 at the Field Crops Institute in Chirpan. The chlorophyll fluorescence in dark adapted and light adapted leaves during flowering-boll formation stage was measured with a portable chlorophyll Fluorometer - MINI-PAM –WALZ-GmbH – Germany. The cotton plants from all used cultivars expressed relatively good photosynthetic performance judged by chlorophyll fluorescence parameters. Variety „**Avangard-264**" show better agronomic drought tolerance in severely dry 2012.

Keywords: Cotton - Chlorophyll fluorescence – Water stress

Резюме

Колева М., А. Василев, 2014. Характеристика на параметрите на хлорофилната флуоресценция и добива на български сортове памук, отглеждани при неполивни условия. FCS 9(2): 319-326

Проучвани са промените на функционалната активност на фотосинтетичния апарат на нови български сортове памук отглеждан при неполивни условия. Беше заложен полски опит в опитното поле на Института по полски култури – Чирпан през 2011 и 2012 година. Беше измерена хлорофилната флуоресценция в тъмнинно и светлинно адаптирани листа в периода на цъфтеж на памука с портативен хлорофилен флуориметър MINI-PAM-WALZ-GmbH – Германия. Стойностите на параметрите на хлорофилната флуоресценция за всички изследвани сортове памук са високи и са близки до стойностите типични за растения отглеждани при оптимален воден режим. Сорт „Авангард-264" показва по-добра агрономическа сухоустойчивост спрямо останалите сортове през изключително сухата 2012 г.

Ключови думи: Памук – Хлорофилна флуоресценция – Воден стрес

INTRODUCTION

Cotton (*Gossipium hirsutum* L.) is one of the most important fiber producing crops in the world. In Bulgaria cotton is traditionally cultivated in rainfed conditions and therefore it expresses good tolerance to drought (Bojinov et al., 2000). Nevertheless, the drought reduces significantly its potential yield. There is substantial evidence that soil water deficits during critical growing stages, such as reproductive stage, can significantly affect growth and yield (Kaur and Singh, 1992; Marur, 1991). We established that the boll productivity of pot-grown cotton plants exposed for 20 days at 35-40% of field water capacity was diminished by 23-35% (Koleva and Vasilev, 2010). The decrease of yield was accompanied by significantly depressed both net photosynthetic rate and photosynthetic pigments quantity of cotton plants (Vasilev and Koleva, 2011).

An opinion exists that several photosynthetic and leaf gas exchange parameters, namely photosynthetic rate, pigments content, transpiration intensity, stomata conductance, etc., may be used as indicators for tolerance of cotton genotypes to drought (Pettigrew, 2004; Ullah et al., 2008; Soomro et al., 2011). The results of other authors have not confirmed this statement (Massacci et al., 2009). Therefore, there is not general opinion and enough evidence concerning the usefulness of photosynthetic parameters for the screening studies for drought tolerance as well as selection criteria.

Chlorophyll fluorescence is widely accepted as suitable stress indicator for plants. At normal (physiological) temperatures it originates from photosystem II (PSII), which is susceptible to different stresses, including drought. Many *in vivo* studies have demonstrated that water deficit resulted in damages to the oxygen evolving complex of PSII and to the PSII reaction centers associated with the degradation of D1 protein (Lawlor, 1995; Yordanov et al., 2003; Zlatev and Yordanov, 2005). On the other hand, chlorophyll fluorescence measurements can be performed *in situ* and quickly with portable devices, which are very important for screening studies and breeding programs. Furthermore, parameters of chlorophyll fluorescence may also serve as physiological criteria for indirect selection for high yielding genotypes. For now there are limited and contradictory information about correlation between seed cotton yield and chlorophyll fluorescence inhibition in cotton (Dumka et al, 2004; Pettigrew, 2004).

Therefore, we have decided to study physiological performance of Bulgarian cotton cultivars grown in rainfed conditions using some chlorophyll fluorescence parameters in order to search for existence of correlations with the yield as a final goal.

MATERIALS AND METHODS

Experimental set-up

In the investigation are involved 13 cotton cultivars genotypes created in the Field Crops Institute – Chirpan, Bulgaria (Table 1). The genotypes were cultivated in field conditions during 2011 and 2012 in the experimental field station Field Crops Institute – Chirpan. The trial was conducted as a randomized block design in four replications, on leached smolnitza soil type, with harvesting plots of 20 m^2.

Chlorophyll fluorescence measurements

Physiological performance of cotton plants was studied using a pulse amplitude modulation chlorophyll fluorometer MINI-PAM (Walz, Effeltrich, Germany). The top fully developed attached leaves were used for the measurements. During the flowering-boll formation plant stage in 2011 and 2012 the fluorescence parameter – actual yield of photochemical energy conversion (Y) (Genty et al., 1989) were measured in several days - time scale. In addition, in 2012 several other basic fluorescence parameters were determined, namely F_0, F_m, F_v/F_m, qP and qN. Minimal fluorescence, F_0, was measured in 30 min dark-adapted leaves using weak modulated light of < 0.15 µmol m^{-2} s^{-1} and maximal fluorescence, F_m, was measured after 0.8 s saturating white light pulse (>5500 µmol m^{-2} s^{-1}). Maximal photochemical efficiency of PSII (F_v/F_m) for dark adapted leaves was calculated using equation $F_v=F_m–F_0$ for variable fluorescence. In light adapted leaves present fluorescence (F) before and maximal fluorescence (F_m`) after saturation pulse

(0.8 s white light pulse, > 5500 μmol m^{-2} s^{-1}) were determined. Photochemical (qP) and non-photochemical (qN) quenching parameters were calculated according following van Kooten and Snel (1990).

Table 1. Used Bulgarian cotton cultivars and their parentage
Таблица 1. Използвани български сортове памук и техния произход

Genotypes Сортове	Parentage Произход
Chirpan–539 / Чирпан	Beli izvor × Garant [G. hirsutum L.× G. hirsutum L.]
Avangard264/Авангард264	C – 460 × C – 6030 [G. hirsutum L.× G. barbadense L.]
Perla / Перла	Garant × Progres [G. hirsutum L.× (G. hirsutum L.× G. barbadense L.)]
Natalia / Наталия	№ 65 × T – 073 [(G. hirsutum L.× G. barbadense L.) × G. hirsutum L.]
Darmi / Дарми	№ 268 × C–9070 [(G. hirsutum L.×G. barbadense L.) × G.barbadense L.]
Kolorit / Колорит	№ 266 × Balkan [(G. hirsutum L.× G. barbadense L.) × G. hirsutum L.]
Vega / Вега	№ 266 × Ogosta [(G. hirsutum L.× G. barbadense L.) × G. hirsutum L].
Dorina / Дорина	T – 89/92
Nelina / Нелина	Perla – 267 × T – 073
Rumi / Руми	№ 268 × Deltapine 20
Helius /Хелиус	C – 6530 [irradiated with γ rays]
Boyana / Бояна	Chirpan – 603 × C – 9070 [G. hirsutum L.× G. barbadense L.]
Viki / Вики	C – 9070 [irradiated with γ rays]

Data analysis

The results obtained were processed by the dispersion analysis method using one-way and two-way ANOVA (for P < 0,05).

RESULTS AND DISCUSSION

Climatic conditions during the vegetation periods in 2011 and 2012 are characterized by different combinations of climatic factors. 2012 year is distinguished by extremely low amount of precipitation during the vegetation period of cotton – May – September compared with an average amount of precipitation for long period of time and can be described as severely dry (data not shown). The data for the quantity of available water content in different soil layers up to 1 meter is presented in Table 2. It is apparent that in the upper 20 cm the quantity of available water is too low and during the long periods (second decade July – first decade August 2011 and whole August 2012) is completely missing. It is due the absence of rain together with comparatively high temperatures leading to significant evapotranspiration and drying of upper soil layers. It is known that the major part of cotton roots is occupied in 50-cm layer and the central root is able to reach and even go further the 1-meter zone. Obviously, based on the presented data the water supply to cotton plants during the two vegetation periods has been ensured through the deeper soil zones.

Table 2. Available water content (mm) in different soil layers at flowering-boll formation stage of cotton plants grown in rainfed conditions during 2011 and 2012

Таблица 2. Продуктивна почвена влага (mm) в различните почвени слоеве по време на цъфтеж-плодообразуване през 2011 г. и 2012 г.

Soil layer, cm Почвен слой, cm	0 - 10		0 - 20		0 - 50		0 - 100	
Date / Дата	2011	2012	2011	2012	2011	2012	2011	2012
21-30 VI	0	4	3	17	36	64	109	154
1-10 VII	2	0	3	9	23	52	91	133
11-20 VII	0	0	0	6	20	34	86	109
21-31VII	0	0	0	2	11	20	73	89
1-10 VIII	0	0	0	0	8	15	63	74
11-20 VIII	7	0	17	0	42	6	93	55
21-31 VIII	2	0	6	0	25	9	75	47
Average productive moisture (1956-2007) Средна продуктивна влага (1956-2007)	89 mm				181 mm			

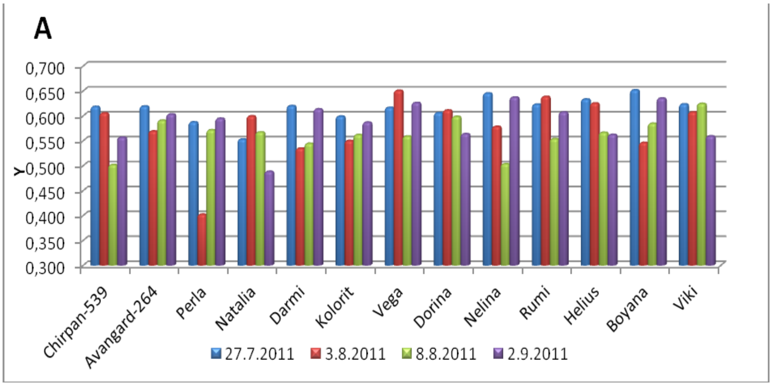
The data for actual yield of photochemical energy conversion (Y), presented in the Figure 1, gives evidence to what extent soil water availability has influenced the physiological performance of cotton plants. The data showed that values, with small exceptions (last measurement in 2012 and sporadic ones in 2011 in cultivars „**Perla**" and „**Natalia**") have exceeded 0.500. The lower values of Y from the last measurement during 2012 could be explained by leaf senescence as well as growth retardation in the end of vegetation, while the sporadic lower values in 2011 could be a result from technical error.

The conductance of fluorescence measurements on the selected cotton cultivars in dynamics (4-6 times per studied periods) were based on the hypothesis that, the eventual precipitation during the vegetation could allow differentiation of the used cultivars by their physiological response to the changes of soil water regime. Unfortunately, a stable moderate drought existed during the studied periods in both years, which did not give a possibility to check this hypothesis. Therefore, the data given in Figure 1 do not show significant variation in Y values of different cultivars during the studied periods in 2011 and 2012.

In our previous experiments with drought-exposed cotton plants we have obtained similar Y values and concluded that primary photochemical processes in these plants were not disturbed (Vasilev and Koleva, 2011). These results are in a good correspondence with the conclusions belonging to Genty et al. (1987) and Inamullah and Isoda (2005) who studied the photosynthetic performance of drought-stressed cotton plants.

To understand the reason for the relatively well saved photochemistry in rainfed cotton plants we performed quenching analysis of chlorophyll fluorescence in the first decade of September 2011. The data obtained are presented in Table 3.

The quenching analysis allows distinguishing two fundamentally different pathways of absorbed light energy conversion. qP reflects the fractions of open PS2 reactions centers and denotes the proportion of excitation energy trapped by them, while qN is a result of various processes that are responsible for thermal dissipation of excess energy in the photochemical apparatus - high-energy state, state transitions and photoinhibition (Bolhar-Nordenkampf and Oquist, 1993). qN has an important function in regulation of dissipation / utilization of excitation energy.



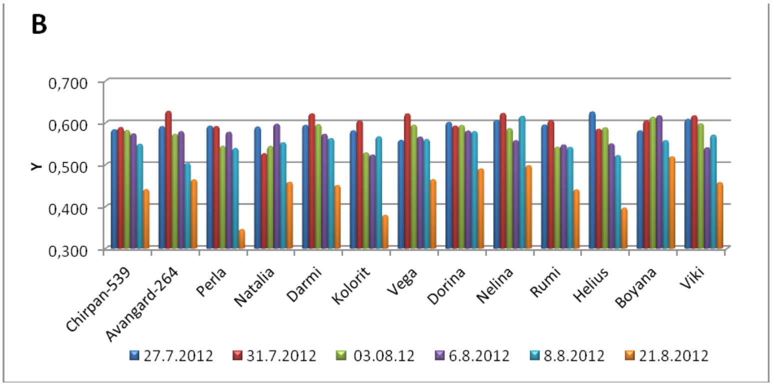


Figure 1. Actual yield of photochemical energy conversion (Y) in the leaves of Bulgarian cotton cultivars grown in rainfed conditions at flowering-boll formation stage during 2011 (A) and 2012 (B)

Фигура 1. Действителен квантов добив (Y) измерен в листата на памук отглеждан при неполивни условия в периода на цъфтеж – плодообразуване през 2011 (A) и 2012 (B)

The maximal photochemical efficiency of PSII (F_v/F_m) for dark-adapted cotton leaves varied from 0.77 to 0.84, which according to Bolhar-Nordenkampf and Oquist (1993) is in the norm for healthy leaves (Table 3). The values of qP were relatively high, giving an evidence for good use of the trapped excitation energy for photosynthetic processes. qN values were lower that qP ones.

The results regarding seed cotton yield from comparative varietals trial, conducted during two years are presented in fig. 2.

The applied analysis of variance reveals the presence of statistically significant difference in the amount of yield due to of both studied factors – genotype and year and the interaction between them. (Table 4). The variation of yield in our varietals trial is to the greatest extent, due to the year of cultivation with 60.7 % from the total variation. The influences of genotype – 8.4 % and interaction between year and genotypes – 12.8 % are vastly less, although the variances of both factors are statistically significant.

Table 3. Chlorophyll fluorescence parameters in leaves of Bulgarian cotton cultivars grown in rained conditions at flowering-boll formation stage during 2012

Таблица 3. Параметри на хлорофилната флуоресценция измерени в български сортове памук отглеждан при неполивни условия в периода цъфтеж-плодообразуване през 2012 г.

Cultivars / Сортове		F_v/F_m	Y	qP	qN
Chirpan-539 Чирпан-539		0.819 ± 0.030	0.590 ± 0.039	0.878 ± 0.105	0.526 ± 0.083
Avangard-264 /Авангард		0.843* ± 0.012	0.629 ± 0.039	0.897 ± 0.049	0.562 ± 0.035
Perla / Перла		0.832 ± 0.006	0.592 ± 0.094	0.867 ± 0.055	0.554 ± 0.104
Natalia / Наталия		0.831 ± 0.011	0.527 ± 0.069	0.837 ± 0.044	0.631 ± 0.129
Darmi / Дарми		0.772°° ±0.035	0.383 ± 0.182	0.911* ± 0.106	0.825 ± 0.094
Kolorit / Колорит		0.795 ± 0.026	0.528 ± 0.103	0.862 ± 0.156	0.508 ± 0.260
Vega / Вега		0.823 ± 0.016	0.493 ± 0.083	0.741 ± 0.114	0.501 ± 0.218
Dorina / Дорина		0.804 ± 0.014	0.551 ± 0.068	0.873 ± 0.051	0.548 ± 0.158
Nelina / Нелина		0.816 ± 0.017	0.519 ± 0.159	0.892 ± 0.060	0.626 ± 0.218
Rumi / Руми		0.804 ± 0.010	0.379 ± 0.181	0.704 ± 0.315	0.616 ± 0.219
Helius / Хелиус		0.810 ± 0.026	0.396 ± 0.143	0.638° ± 0.234	0.586 ± 0.147
Boyana / Бояна		0.813 ± 0.021	0.548 ± 0.046	0.841 ± 0.068	0.563 ± 0.093
Viki / Вики		0.817 ± 0.015	0.490 ± 0.082	0.976 ± 0.169	0.739 ± 0.118
GD	5 %	0.024	0.136	0.19	0.20
	1 %	0.033	0.181	0.26	0.27
	0.1 %	0.044	0.237	0.33	0.34

Based on the meteorological data and results of analyses of variance it can be concluded that both years of cultivation are vastly differ and the reduction in yield in the second year of cultivation is due to the severe drought. Under water stress conditions during 2012 the yield decreases at all studied varieties to varying degrees. The reduction in yield is highest in cultivars – „Chirpan-539" and „Boyana" and lowest in cultivars „Viki", „Darmi" and „Rumi". Furthermore at cultivar „Avangard-264" yield has increased by 4 % compared to 2011, probably this cultivar is characterized by better agronomical drought tolerance.

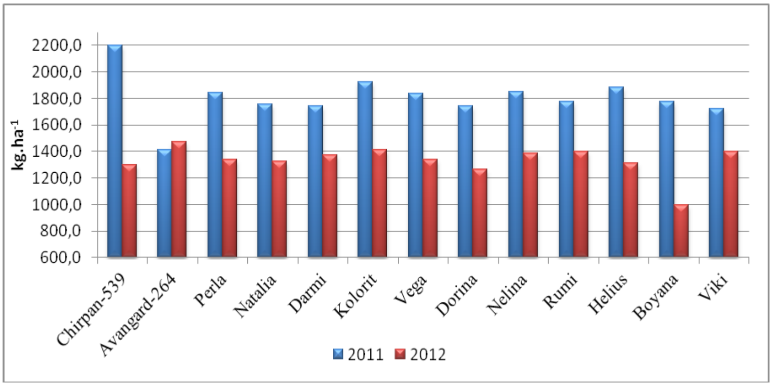


Figure 2. Seed cotton yield of Bulgarian cotton cultivars grown in rainfed conditions during 2011 and 2012

Фигура 2. Общ добив от памук отглеждан при неполивни условия през 2011 и 2012 г.

Table 4. Analysis of variance of yield
Таблица 4. Анализ на варианса на добива

Source of variation Източник на вариация	Df Степени на свобода	MS Средни квадрати	SS Сума от квадрати	η^2 Влияние на фактора, %
Total / Общо	103	3139	78476.8	100
Genotype /Сортове	12	670.8	8050	8.4
Environment /Години	1	58162	58162	60.7
Interactions/Взаимодействие	12	1022.1	12264.8	12.8
Error / Грешка	75	230.1	17262.8	18.0

CONCLUSION

Bulgarian cotton cultivars have relatively high tolerance to soil drought. At rainfed conditions leading to significant decrease of the productive soil moisture in the upper layer (till 50 cm), the cotton plants from all used cultivars expressed relatively good photosynthetic performance judged by chlorophyll fluorescence parameters. The maximal photochemical efficiency of PSII (F_v/F_m) in their leaves was in the norm typical for healthy leaves and the actual yield of photochemical energy conversion (Y) was high enough for plants grown in water-limited conditions. Seed yield of the used cotton cultivars at rainfed conditions were lower then the potential yield. In 2012 all varieties realize lower yield compared with the yield in 2011. Solely variety „Avangard-264" show better agronomic drought tolerance in severely dry 2012.

At the present stage of the study, we did not find significant differences in the physiological status of the used cotton cultivar, which could be attributed to their specific tolerance to drought.

REFERENCES

Bojinov, B., A. Vasilev, L. Dimitrova 2000. Comparative studies on the photosynthetic activity of two cotton varieties – Chirpan 603 (*G. hirsutum L.*) and C-6037 (*G. Barbadense L.*) under severe drought and temperature stress. Plant science 37: 452 – 458.

Bolhar-Nordenkampf, H. R., G. Oquist 1993. Chlorophyll fluorescence as a tool in photosynthesis research. In: Photosynthesis and Production in a changing environment: a field and laboratory manual. Hall, D. O., J. M. O. Scurlock, H. R. Bolhar-Nordenkampf, R. C. Leegood and S. P. Long, Eds., Chapman and Hall, London, 193-205.

Genty B., J. M. Briantais, N. R. Baker,1989. The relationship between the quantum yield of photosynthetic electron transport and quenching of chlorophyll fluorescence. Biochim. Biophys. Acta, 990: 87-92.

Dumka D, Bednarz CW, Maw BW 2004. Delayed initiation of fruiting as a mechanism of improved drought avoidance in cotton. Crop Sci 44: 528–534.

Inamullah, A. Isoda 2005. Adaptive responses of soybean and cotton to water stress. II. Changes in CO_2 assimilation rate, chlorophyll fluorescence and photochemical reflectance index in relation to leaf temperature. Plant Production Science, 8: 131-138.

Kaur R., Singh O.S. 1992 Response of growth stages of cotton varieties to moisture stress. Indian Journal of Plant Physiology 35: 182-185.

Koleva M., Vassilev A. 2010. Influence of soil drough during flowering-boll formation stage on the productivity of three cotton cultivars. Agricultural sciences vol. II, issue 4: 85-88.

Lawlor D.W. 1995. Effects of water deficit on photosynthesis. In: Environment and plant metabolism (N. Smirnoff, Ed.), Bios. Scientific Publishers Ltd., Oxford, 129-160.

Marur C.J. 1991 Comparison of net photosynthetic rate, stomatal resistance and yield of two cotton cultivars under water stress. Pesquisa Agropecuaria Brasileira 26:153-161.

Pettigrew, W. T. 2004. Physiological consequences of moisture deficit stress in cotton. Crop Sci., 44: 1265-1272.

Soomro, M. H., G. S. Markhand, B. A. Soomro, 2011. Screening Pakistan cotton for drought tolerance. Pac. J. Bot. 44 (1): 383-388.

Ullah, I., M. Rahman, M. Ashraf, Y. Zafar 2008. Genotypic variation for drought tolerance in cotton (*Gossypium hirsutum* L.): Leaf gas exchange and productivity. Flora, 203: 105-115.

Van Kooten O., J. F. H. Snel 1990. The use of chlorophyll fluorescence nomenclature in plant stress physiology. Photosynth. Res., 25: 147-150.

Vassilev A., Koleva M. 2010. Photosyntesis response of plants from three cotton cultivars to soil drought. Scientific works vol. LV, book 1: 195-202.

Yordanov I., V. Velikova, T. Tsonev 2003. Plant responses to drought and stress tolerance. Bulg. J. Plant Physiol., Special issue, 187-206.

Zlatev Z., I. Yordanov 2005. Effects of soil drought on photosynthesis and chlorophyll fluorescence in common bean plants. Bulg. J. Plant Physiol., 30 (3-4): 3-18.