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PHYSIOLOGCAL TRAITS ASSOCIATED WITH CANOPY TEMPERATURE DEPRESSION IN DROUGHT STRESSED BREAD WHEAT CULTIVARS

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Summary: The relationship between leaf infrared sensing characteristics (canopy temperature and canopy temperature depression), plant water status (transpiration and relative water content of leaves) and yield characteristics (seed yield, yield stability index, stress susceptibility index and stress intensity) in some modern winter wheat cultivars (Katya, Guinesses, Geya-1 and Nikki) grown under a rain-out shelter and subjected to transient 15-days soil drought stress during heading stage (Zadoks53-59) was studied in connection with drought tolerance. Based on the calculated correlation coefficients among the traits, the cultivars were classified as drought tolerant (cvrs. Katya and Guinness), less drought tolerant (cv. Geya-1) and sensitive (cv. Nikki) to drought stress.

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Keywords: Drought tolerance, wheat cultivars, canopy temperature depression, water status.

Abbreviations: CTD – canopy temperature depression (Tair- Tfoliage); SSI- stress susceptibility index; YSI-yield stability index; SI – stress intensity.

INTRODUCTION

The infrared thermometer provides a useful and reliable technique for the remote detection of different kinds of stress in all types of plants (Blum et al., 1982). Plant stress in terms of the energy balance method can be quantified by different approaches (Idso et al., 1969; Jackson et al., 1981). Comparison between air and foliage temperature (T_{air} – $T_{foliage}$) provides the basis of methodology and application of the parameter called canopy temperature depression (CTD). CTD has positive values in well irrigated plants whereas it is negative under high

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air vapor pressure deficit (Blum et al., 1989). CTD can be influenced by a number of biological and environmental factors like soil water status, wind, evapotranspiration, cloudiness, conduction systems, plant metabolism, air temperature, relative humidity, and continuous radiation (Bilge et al., 2008). The relationship between CTD of crops and their grain yield is used as a selection criterion for tolerance to drought and high temperature stress (Blum et al., 1989; McKinney et al., 1989; Bilge et al., 2008). The suitability of CTD as an indicator of yield and stress tolerance prediction, however, must be evaluated for every individual environment and, in particular, for every plant species (Blum, 1989). Cool plant canopy during the heading and grain filling period in wheat experiencing drought stress can be an important physiological principle for evaluation of plant temperature and drought stress tolerance (Bilge et al., 2008).

Based on these considerations we aimed to evaluate the relationship between CTD, leaf water status (transpiration rate and relative water content of leaves), plant drought stress indexes and grain yield in irrigated and deprived of irrigation for 15 days four wheat cultivars with different plant morphology. The study was performed during heading growth stage. The results could be used to develop a breeding strategy related to the indirect indicators for physiological assessment of drought stress tolerance or avoidance in winter bread wheat cultivars. Thus, it could be involved in a breeding program for higher wheat yield stress potential or in a national cereal cropping strategy in the southeastern region of Bulgaria.

MATERIALS AND METHODS

Rain exclusion shelter enclosing area of 12 x 5x 2.5 m covered with a plastic sheet was used for rainfall manipulation planted plot study. Planted plots were initially designed for the experiment by dividing them into 3 compartments - two controls (well irrigated up to 60 % full soil moisture capacity) situated apart from the middle part and one middle alley in the center for drought stress application (Figs. 1, 2). Soil in the shelter bed was cinnamon vertisols (pH 6.0) (pellic vertisol) (FAO). Soil in the experimental plots was fertilized before planting the seeds with the rate of 250 $kg.ha^{-1}$ triple superphosphate (45% P205) and at the start of active seedling growth with 350 $kg.ha^{-1}$ NH_4N0_3 (33% N). Conventionally prepared seed beds were used for planting the seeds (50 seeds per m^2) during October (planting dates: 15 and 20 of October). All planted plots were well watered to keep 60 % full soil moisture capacity from seed emergence to plant heading stage (Zadoks scale № 07- 53) (Zadocks et al., 1974). After this stage, the plots with plants in the middle alley were deprived of watering for 15 days during heading stage (Zadoks59). Each plot consisted of four rows. The control rows included an area of 0.8 x 0.25 m while the middle alley plots were 1.60 m long and 0.25 m wide. All treatments were performed in 3 replicates and randomly distributed in block design. Day/night temperatures were 28/15°C in the growth season, light intensity under the shelter cover was 750-900 $mmol.m^{-2}.s^{-1}$ PAR and relative air humidity varied between 40 and 60 RH%.

Figure 1. Photograph of the rain-out shelter with a view of the non-stressed irrigated wheat plants during heading growth stage.

Figure 2. Photograph of the rain-out shelter with a view of the stressed wheat plants subjected to drought caused by interruption of irrigation for 15 days during heading growth stage.

Plant material

Bread winter wheat (*Triticum aestivum* L.) plants from four cultivars Katya, Guinness, Geya-1 and Nikki differing in their yield performance in dry field conditions were used in the experiment (IRGR seed bank of Sadovo). Cv. Katya was recognized as a standard for drought tolerance (it was included in 1-st Facultative and Winter Wheat Elite Trial for Rain Fed Conditions, which was performed in SYMMIT-Ankara Turkey and ICARDA-Syria).

Fresh, dry and grain yield

Fresh, dry and grain yield per plant (g DW plant^{-1} of 25 replicates) from randomly chosen plots was determined by weighing after harvest and drying plant material to a constant weight at 80° C in an oven.

Transpiration rate

Transpiration rate of individual leaves was measured gravimetrically by water loss for a short time (min) according to the method described by Vulchev and Georgiev (1991). Leaf was cut, immediately enclosed in a glass vial, transferred to the lab and weighed. After exposure to the sun open air for 3 min the vials were weighed again. The loss of water for 1 min per unit leaf area was quantified as a transpiration rate (mg H_20. cm^{-2} flag leaf area. min^{-1}).

Relative water content

Relative water content of 15 individual flag leaves was measured according to Kocheva and Georgiev (2003). Relative water content in leaves was calculated using the formula:

RWC (%) = [(FW – DW)/(TW-FW)].100

where FW is the fresh weight of leaves, TW is the weight at full turgescence achieved after soaking the leaves in water for 24h and DW is the weight estimated after drying the leaves for 4 h at 80°C or until a constant weight is achieved.

Indexes of drought tolerance

Stress susceptibly index (Fischer and Maurer, 1978) was calculated according to the equation:

$$SSI = \frac{1-(Y_s / Y_p)}{SI}$$

where:

stress intensity - $SI = 1 - \left(\frac{\overline{Y_s}}{\overline{Y_p}} \right)$

Yield stability index (Bouslama and Schapaugh, 1984) was calculated according to the equation:

$$YSI = \frac{Y_s}{Y_p}$$

where:

Ys - yield of cultivar in stress conditions;
Yp – yield of cultivar in normal conditions;
$\overline{Ys}$ – total yield mean in stress conditions;
$\overline{Yp}$ – total yield mean in control conditions.

Hand-held digital IR thermometer

A hand-held digital IR thermometer (model CCM-200 manufactured by Opti-Sciences, Inc. 8 Winn Avenue Hudson, NH 03051, USA) was used to measure CTD =T°air – T°leaf according to Blum (1982). The distance from the leaf surface was 20 cm and the slope was 45°C.

All measurements were done in

15-25 replicates and statistical analysis of means was performed using the statistical programs SPSS 13.0 and Statistica-10.

RESULTS AND DISCUSSION

The mean air temperatures under the shelter measured above the well irrigated and drought stressed planted plots did not vary significantly (28.51°C - 28.97°C). Unlike air temperature, mean flag leaf temperatures of the plants differed between well irrigated controls (28.62°C) and drought stressed plants (31.22°C). The differences in the surface leaf temperatures of plants were related to the cultivar origin. These changes reflected the calculated CTD values for control and stressed plants (Fig. 3). The lowest values of CTD were found in cv. Katya while the highest were calculated in cv. Nikki. The difference between air and leaf temperature in the well irrigated plants was positive, while in the stressed plants CTD was negative in all cultivars. The reason for the observed differences in plant performance can be assigned to the altered water relations in the shoot under stress. Except for the morphological, some physiological factors can also affect these changes (Sanchez et al, 2001). First of all, the effect of inhibited shoot transpiration rate following stomatal closure is associated with the signaling processes of water shortage in the roots (Jones, 1999). Stomatal closure affects some physiological processes, among which photosynthetic activity plays a leading role. The inhibition of photosynthesis, mainly connected with a decrease of CO_2 concentration inside the stressed leaves, is regarded as the main factor altering the canopy emissive properties (Idso et al.,

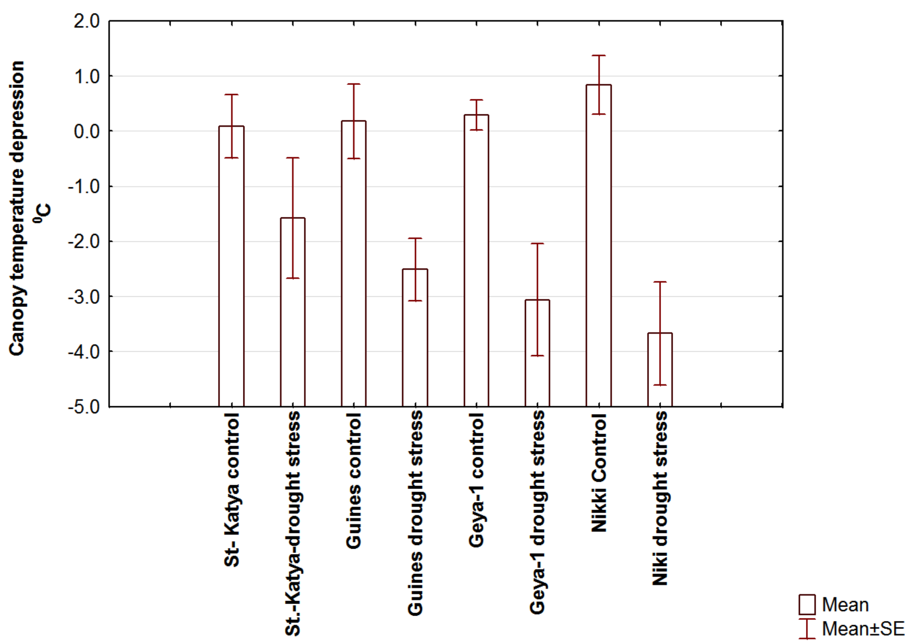

Figure 3. Canopy temperature depression (Tair – T leaf) of irrigated and non-irrigated (15 days during heading growth stage) wheat cultivars grown under a rain-out shelter.

1969; Jackson et al., 1981). The inhibition of leaf photosynthesis (including effects on dry matter accumulation or changes in pigments) and the lowered leaf water content have a profound effect on canopy IR thermometer readings (Reinolds et al., 1998; 2001).

Our results indicated that the interruption of irrigation for 15 days during heading stage led to a gradual decrease of leaf transpiration rate (Fig. 4). The transpiration rate of the flag leaf was obviously more inhibited in cvrs. Katya and Guinness than in cvrs. Geya-1 and Nikki. These changes were associated with a significant loss of bulk water more in the leaves of cv. Nikki and less in cvrs. Katya and Guinness (Fig. 5). The calculation of correlation coefficients between transpiration and relative water content (RWC) in leaves of drought-stressed plants confirmed the close dependence of these traits (Fig. 6). The correlation coefficient value was higher in cv. Katya than in cv. Nikki. Since bulk water content of leaves depends on the ratio between surface area and volume, these parameters can be related to the emissive properties of the leaves as well (Reinolds et al., 1998). The calculation of flag leaf area of irrigated and non–irrigated (for 15 days during heading stage) plants gave more information about the role of these traits (Fig. 7). Our results indicated that the flag leaf of cv. Katya had a lower leaf area, while the flag leaf of cv. Nikki which was wider than in cv. Katya showed the biggest leaf area among the studied cultivars. Regarding the relations between leaf transpiration rate and leaf area it could be speculated that the altered water relations of these cultivars were directly related to their leaf morphology. The regression coefficients between transpiration rate and RWC of the flag leaf were in compliance with the above suggestion (Fig. 6).

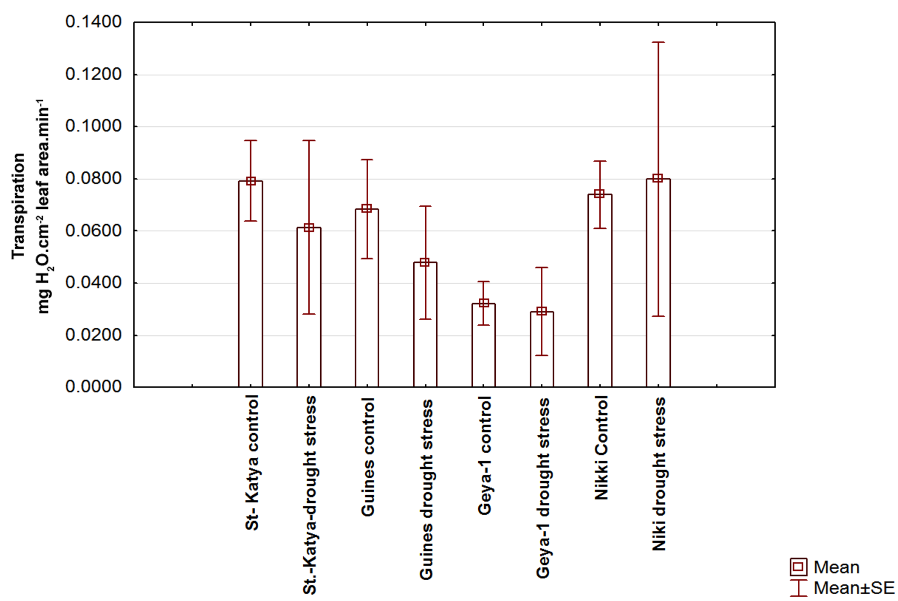

Figure 4. Transpiration rate (mg H_20. cm^{-2} leaf area .min^{-1}) of the flag leaf of irrigated and non-irrigated (15 days during heading stage) wheat cultivars grown under a rain-out shelter.

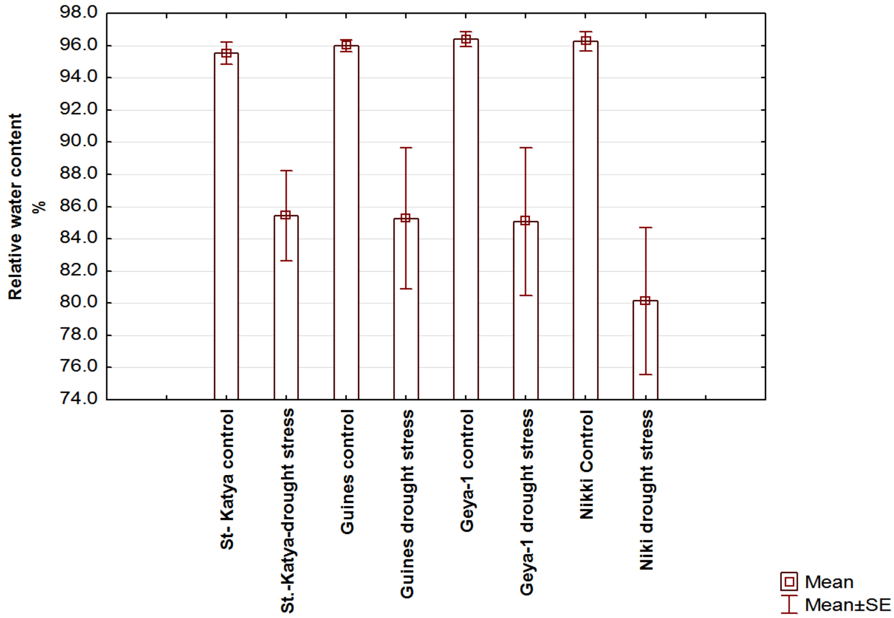

Figure 5. Relative water content (RWC %) of the flag leaf of irrigated and non-irrigated (15 days during heading stage) wheat cultivars grown under a rain-out shelter.

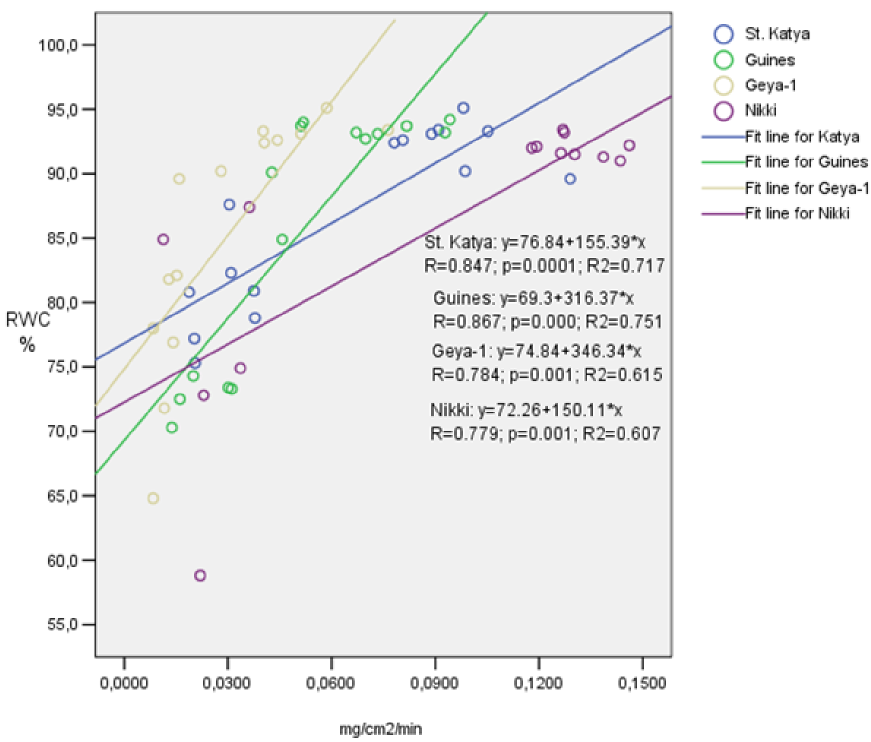

Figure 6. Correlation dependence between RWC and transpiration rate (mg.cm^{-2}.min^{-1}) measured on the flag leaf of irrigated and non-irrigated (15 days during heading stage) wheat cultivars grown under a rain-out shelter.

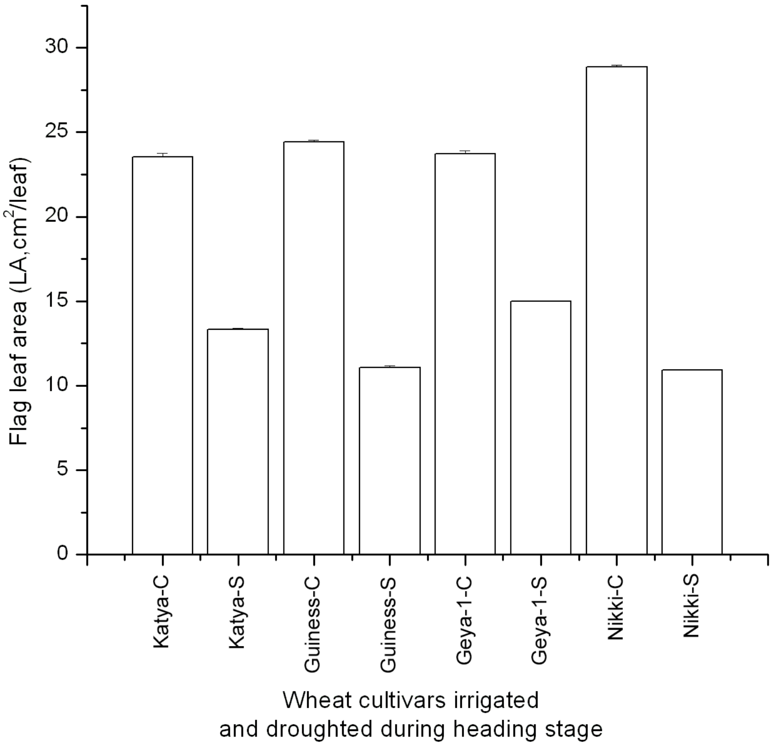

Figure 7. Flag leaf area measured during heading stage of wheat cultivars grown under a rain-out shelter. Control (C)– continuously irrigated plants; S – drought stress caused by interrupted irrigation for 15 days during heading stage.

Although the grain yield of well irrigated control plants did not differ significantly among the studied cultivars, the grain yield of drought stressed plants varied strongly and was negatively influenced by drought stress (Fig. 8). The least affected grain yield was those of cv. Katya in comparison with the control, while the grain yield of cv. Nikki showed the maximal reduction among the studied cultivars. This cultivar showed greater difference in the CTD, more negative water relations and different leaf morphology as well. The correlation coefficients between grain yield under drought and CTD readings give information about the connection between traits (Fig. 9). This correlation was higher in cvrs. Guinness and Katya and lower in cvrs. Nikki and Geya-1.

Well known mathematical models based on the correlation between grain yield of non-stressed and stressed plants are widely used for assessment of the effects of stress on plant yield performance as well as for stress tolerance qualification (Rosielle and Hamblin, 1981; Fischer and Maurer, 1978; Bouslama and Schapaugh, 1984). Among all commonly used parameters the so-called stress sensitivity index (SSI) and yield stability index (SYI) were found to be more relevant for assessment of the stress effect on wheat cultivar performance under conditions of the rain-out shelter experiment. Results based on the assessment of yield under normal and stress conditions indicated

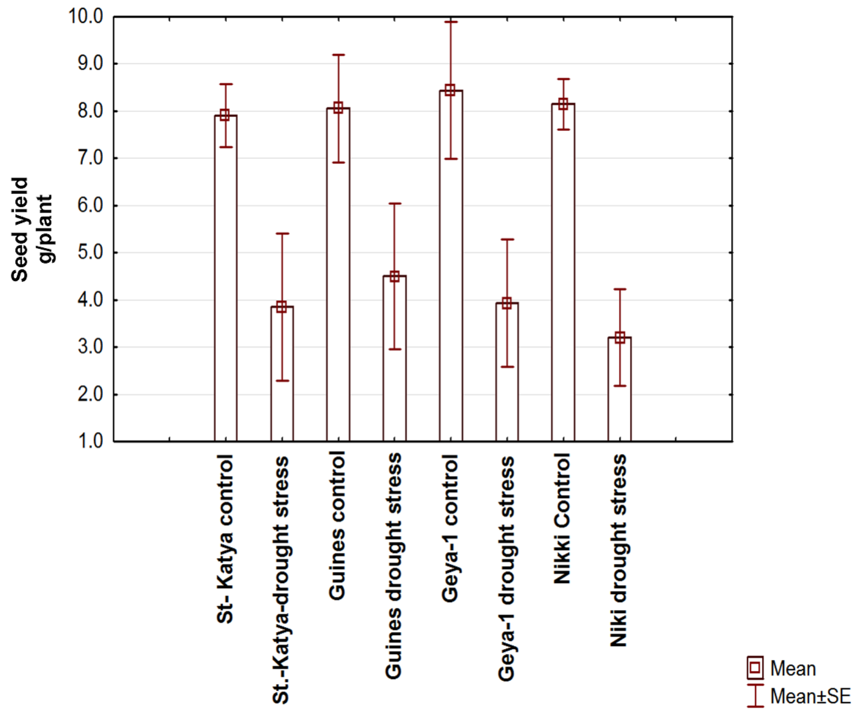

Figure 8. Seed yield of wheat cultivars grown under a rain-out shelter. Control (C) – continuously irrigated plants; S- drought stress caused by interrupted irrigation for 15 days during heading stage.

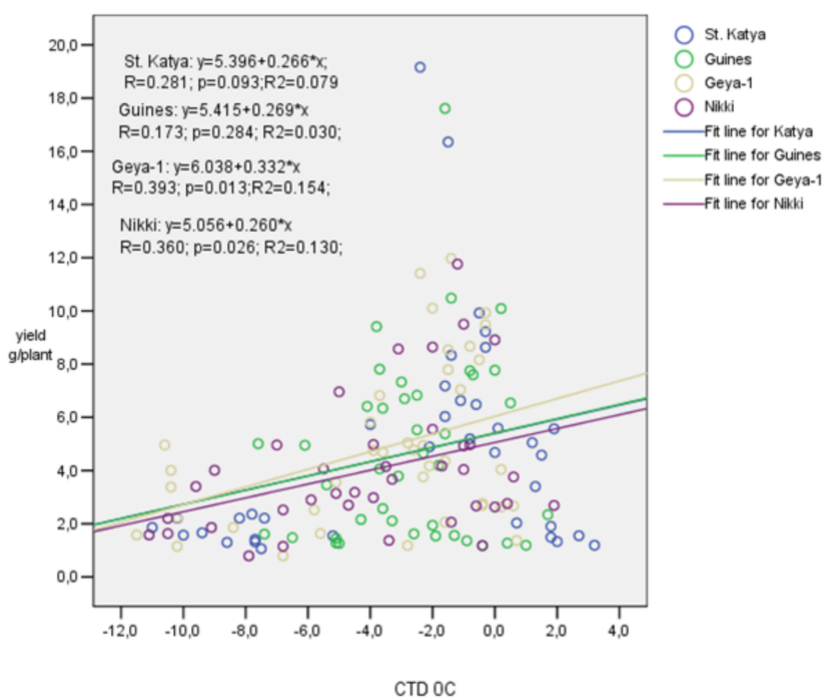

Figure 9. Correlation dependence between seed yield per plant and CTD of the flag leaf measured on irrigated and non-irrigated plots for 15 days during heading stage of wheat cultivars grown under a rain-out shelter.

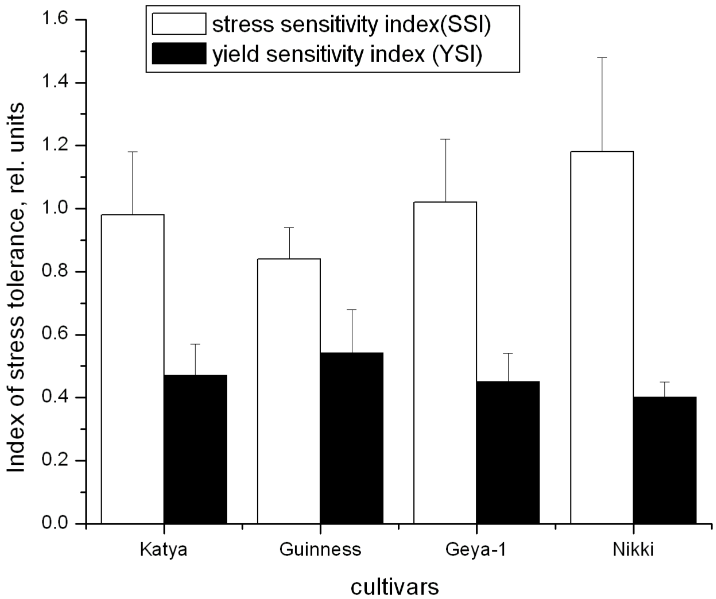

Figure 10. Yield stress indices in wheat cultivars grown under a rain-out shelter stressed by interruption of irrigation for 15 days during heading stage (for description of the formulae see Material and Methods).

that the stress level can be considered as mild according to the calculated value for the stress intensity index (SI). Based on the results calculated for SSI and SYI cv. Katya can be assessed as less sensitive to the imposed drought stress in comparison with cvs. Nikki and Geya-1 (Fig.10).

CONCLUSIONS

Based on the relationship between stress indexes and calculated correlation coefficients among the traits the studied winter bred wheat cultivars can be assessed according to their response to transient drought applied during heading growth stage. The studied cultivars showed distinct differences of the stress response and can be classified as drought tolerant (cvrs. Katya and Guinness), less tolerant (cv. Geya-1) and sensitive (cv. Nikki).

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