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STRESS RESISTANCE INDICATORS AS THE TOOL FOR SELECTING DROUGHT-TOLERANT WHEAT GENOTYPES

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Abstract

Climate change and the resulting increase in the frequency and severity of drought can have significant impacts on plant production. The use of drought-tolerant crop varieties can significantly improve plant production under drought conditions. Therefore, the goal of this research was to evaluate the drought tolerance of different wheat genotypes using stress resistance indicators. An experiment was conducted with sixteen wheat genotypes in Novi Bečej (Vojvodina) in different growing seasons. The spike weight was used as a phenotypic marker of the effect of drought stress on the plant. Selection based on resistance indicators such as stress tolerance index (STI), mean productivity (MP), and geometric mean productivity (GMP) favors the selection of genotypes Dunavka, Skopjanka, and Fundulea 4, which were characterized by the highest average values of spike weight, especially in favorable growing conditions. However, genotype Fundulea 4 is characterized by the highest stress susceptibility index (SSI) and the lowest yield stability index (YSI), which makes this genotype undesirable for growing under drought conditions. The parameters SSI and YSI favor the selection of the genotype Pitoma, which showed the highest value of spike weight in drought conditions as well as the least reduction in value caused by stress. Genotypes Pitoma, Dunavka, and Skopjanka, characterized by a high yield index (YI), are suitable for cultivation in drought conditions, where they achieved above-average trait values. The most suitable stress resistance indicators for selecting drought-tolerant wheat genotypes are SSI, YSI, and YI.

Key words: *drought stress, stress susceptibility index, stress tolerance index, wheat.*

Introduction

The greatest threats to the availability of food in the present and future are population growth and climate change. Drought is one of the most significant consequences of climate change and can which have a severe impact on agricultural production, especially in arid and semi-arid areas (Cheng et al., 2021). Wheat is the primary food source for around 40% of the world's population and a main source of daily protein and calories for about 2.5 billion people in developing countries (Braun et al., 2010). According to predictions made by Alexandratos et al. (2012), the demand for wheat in developing countries could rise by as much as 60% by 2050. Some of the causes influencing this projected rise in demand include urbanisation, rapid population expansion, and changes in dietary patterns.

According to Darvanto et al. (2016) drought conditions can reduce wheat productivity by 50 to 90% of the crop potential. Drought affects wheat at all growth stages, but it is more severe during the flowering and grain-filling stages, leading to significant yield losses (Sareen et al., 2023). A worldwide effort to reduce the severity of droughts involves the development of drought-tolerant cultivars. However, progress has been significantly delayed by the complex structure of the drought-tolerance characteristics, which is controlled by a number of genes and greatly influenced by the environment (Pandey et al., 2022). Accordingly, identifying genotypes with tolerant genes is a difficult process (Anwaar et al., 2020). One of the approaches in the identification of drought-tolerant genotypes is the calculation of stress resistance indicators, which compare the value of the yield achieved in drought conditions with the yield in normal conditions (Anwaar et al., 2020, Aksić et al., 2020).

The aim of this study is to identify the wheat genotypes that exhibit the highest drought tolerance in the agro-ecological conditions of the semi-arid climate. Also, the goal is to select the best drought resistance indicator.

Material and Methods

A field experiment was established in Novi Bečej (Banat, AP Vojvodina, Serbia), which includes 16 wheat genotypes (Dukat, Dunavka, Fundulea 4, Iskra, Jedina, Jugoslavija, Kavkaz, Mačvanka 1, Marija, NS 58-04, Pitoma, Poljana, Skopjanka, Tamiš, Vali PKA-7114, and Zvezda). The analysed genotypes were sown according to the randomized block system in three replications with an inter-row spacing of 12 cm, where the size of the basic plot was 2 m^2. The soil type was humogley, which is characterised by a high content of clay. The usual agrotechnics for wheat production were implemented, where monoammonium phosphate (MAP) was used as the basic fertilizer in the amount of 250 kg ha^{-1}, while urea was used in the amount of 250 kg ha^{-1} for crop feeding. In both vegetation seasons, the harvest was performed at the optimal time (the first week of July in 2015/2016 and the last week of June in 2016/2017), when the grain moisture was below 14%. The spike weight was measured in 30 plants for each analysed genotype.

The stress resistance indicators were calculated based on the value of the spike weight under stress conditions (Yd), which characterized the 2016/2017 growing season, and the value of the spike weight in conditions favorable for plant development (Yp), which characterized the 2015/2016 season. The following stress resistance indicators are expressed in this paper:

Stress susceptibility index – SSI (Fisher and Maurer, 1978):

$$SSI = 1-(Yd/Yp)/1-(\bar{Y}d/\bar{Y}p)$$

Mean productivity – MP (Rosielle and Hamblin, 1981)

$$MP = (Yd + Yp)/2$$

Stress tolerance index – STI (Fernandez, 1992)

$$STI = (Yd + Yp)/\bar{Y}^2p$$

Geometric mean productivity – GMP (Fernandez, 1992):

$$GMP = \sqrt{Yd \times Yp}$$

Yield stability index – YSI (Bouslama and Schapaugh Jr, 1984):

$$YSI = Yd/Yp$$

Yield index – YI (Gavuzzi et al., 1997):

$$YI = Yd/\bar{Y}d$$

A cluster analysis was applied according to Ward's method for grain yield per ear and indicators of stress tolerance using the programme IBM SPSS Statistics, Trial Version 22.0 (https://www.ibm.com/). Distances between clusters are expressed as squared Euclidean

distances, and the significance of distances was tested by the t-test. The number of cluster groups was identified using a dendrogram, after which a K-means analysis was performed with a predetermined number of cluster groups. After the analyses were carried out, the cluster groups were ranked according to the mean values of the analysed parameters.
During the experiment, large differences were noted regarding the amount of precipitation between the analysed growing seasons. Twice as much precipitation was recorded in the 2015/2016 growing season) compared to 2016/2017 (612 or 300 mm). Because of this, the 2016/2017 season is regarded as dry. In 2015/2016, during the growing season, average monthly temperatures were within the multi-year average, and the amount of precipitation was significantly higher than the multi-year average in almost all months. Heavy rainfall in June (164.0 mm) extended the grain filling period. On the other hand, 2016/2017 growing season was characterised by significantly higher temperatures than the multi-year average and a pronounced deficit of precipitation, especially in the grain-filling phenophase, which caused an earlier harvest of crops in the mentioned season (http://www.hidmet.gov.rs/).

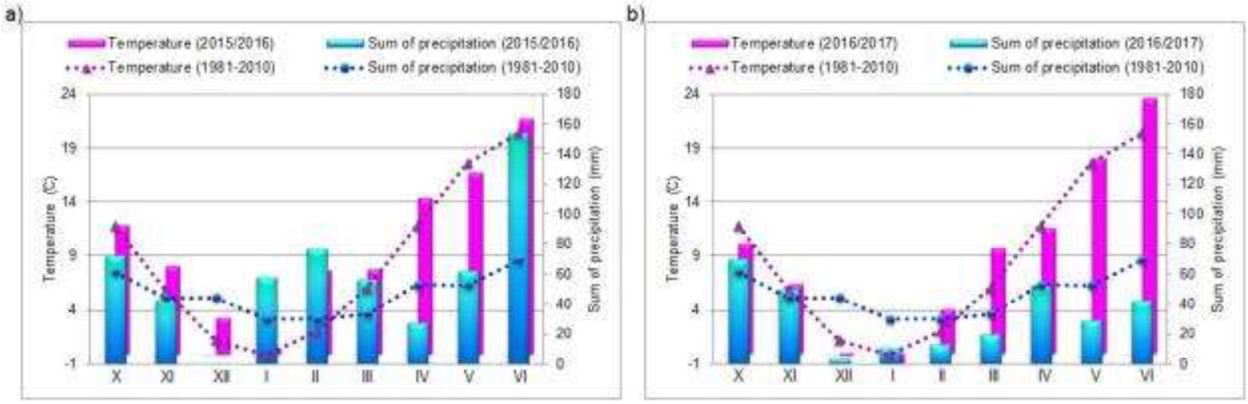

Figure 1. Mean monthly temperatures and sum of precipitation in Novi Bečej locality in 2015/2016 (a) and 2016/2017 (b) vegetation season

Results and Discussion

In this study, it was established that the drought stress conditions in the 2016/2017 vegetation season affected the reduction of the spike weight value in all analysed wheat genotypes, compared to the values achieved in the favourable 2015/2016 vegetation season (Figure 2, a).
The greatest decrease in the spike weight was recorded in the Fundulea 4 genotype (58.0%), while the smallest decrease was observed in the Pitoma genotype (20.2%) (Figure 2, 2). In accordance with the above, spike weight is considered a good phenotypic marker of the impact of drought stress on wheat. Wasaya et al. (2021) also found a decrease in the wheat spike weight under drought stress conditions, which they explained by a reduction in photosynthetic parameters.

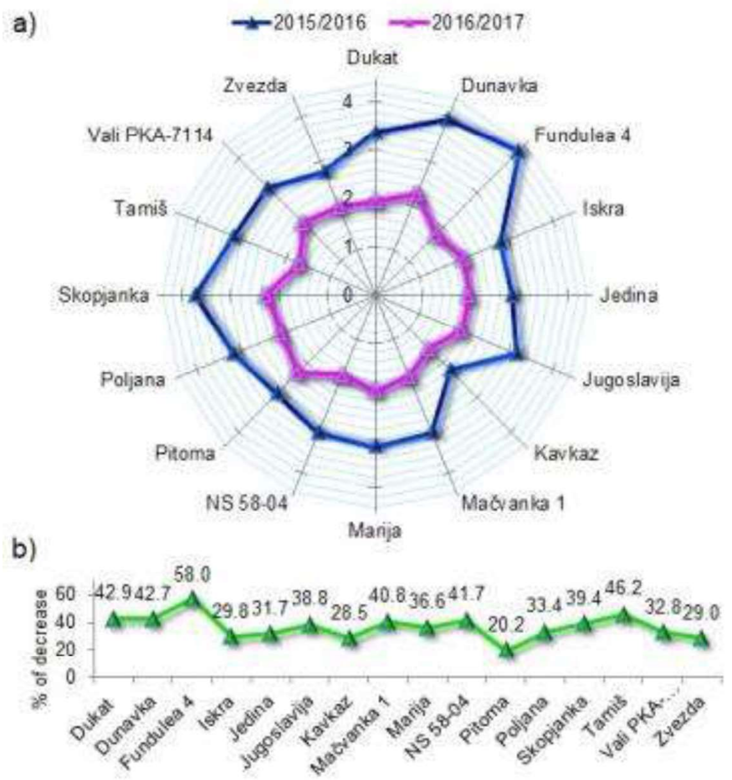

Figure 2. Radar graph of spike weight in examined wheat genotypes grown in drought stress and favorable conditions (a) and decrease (%) in spike weight due to drought stress (b)

The stress resistance indices were calculated, according to the values of spike weight of the analyzed wheat genotypes (Table 1). Indicators of resistance such as mean productivity (MP), stress tolerance index (STI) geometric mean productivity (GMP) take into account the spike weight achieved both in drought and in favorable environmental conditions. Golbashy et al. (2010) noted that STI and GMP are effective in identifying genotypes with high grain yield values in both, non-stress and stress conditions. According to the mentioned stress resistance indicators, the first-ranked cluster group includes the genotypes Dunavka, Skopjanka, and Fundulea 4, which were characterized by the highest average values of spike weight, especially in favorable growing conditions (Table 1, Figure 1,a). Similarly, Aksić et al. (2020) observed that STI, MP, and GMP indicators are positively correlated with grain yield achieved under irrigated conditions. Among the mentioned genotypes, Dunavka and Skopjanka are distinguished by the highest value of the yield index (YI) indicator (1.15), which relates the spike weight of certain genotypes in drought conditions to the average spike weight of all genotypes in drought stress conditions. Although genotype Fundulea 4 has a high value of MP (2.99), STI (0.59), and GMP (2.73), it is characterized by the highest stress susceptibility index (SSI) (1.53), the lowest yield stability index (YSI) (0.42), as well as a low value of the yield index (YI) (0.90). This genotype showed a very high value of spike weight in non-stress conditions, but a low value in drought stress conditions. According to Awnaar et al. (2020), such genotypes are not suitable for growing in wider areas, due to large yield losses under stress conditions. Stress resistance parameters SSI, YSI, and YI favor the selection of the genotype Pitoma, which showed the highest value of spike weight under drought stress conditions, as well as a smaller decrease in value under the influence of drought. Therefore, this genotype is considered the most drought-tolerant. Also, according to the SSI, YSI and YI parameters, the Kavkaz genotype is classified among drought-tolerant genotypes, exhibiting a small decrease in the spike weight under drought. However, according to the MP, STI, GMP and YI indicators, it is classified in the lowest ranked cluster group (4 and 5), characterized by lowest value of spike weight, which makes it an undesirable genotype in breeding programs and for cultivation in semi-arid climate conditions.

Table 1. AMMI analysis of variance for spike weight in 27 wheat genotypes grown in different agro-ecological conditions

Genotypes	SSI	MP	STI	GMP	YSI	YI
Dukat	1.13 (2)	2.66 (2)	0.53 (2)	2.55 (3)	0.57 (4)	0.98 (3)
Dunavka	1.12 (2)	3.12 (1)	0.62 (1)	3.00 (1)	0.57 (4)	1.15 (1)
Fundulea 4	1.53 (1)	2.99 (1)	0.59 (1)	2.73 (2)	0.42 (5)	0.90 (4)
Iskra	0.78 (4)	2.40 (3)	0.48 (3)	2.36 (4)	0.70 (2)	1.01 (3)
Jedina	0.83 (4)	2.39 (3)	0.47 (3)	2.35 (4)	0.68 (2)	0.99 (3)
Jugoslavija	1.02 (3)	2.56 (2)	0.51 (2)	2.48 (3)	0.61 (3)	0.99 (3)
Kavkaz	0.75 (4)	1.90 (4)	0.38 (4)	1.87 (5)	0.71 (2)	0.80 (5)
Mačvanka 1	1.07 (2)	2.48 (3)	0.49 (3)	2.39 (4)	0.59 (3)	0.94 (4)
Marija	0.96 (3)	2.57 (2)	0.51 (2)	2.50 (3)	0.63 (3)	1.01 (3)
NS 58-04	1.10 (2)	2.45 (3)	0.49 (3)	2.36 (4)	0.58 (4)	0.92 (4)
Pitoma	0.53 (5)	2.58 (2)	0.51 (2)	2.56 (3)	0.80 (1)	1.16 (1)
Poljana	0.88 (4)	2.64 (2)	0.52 (2)	2.59 (3)	0.67 (2)	1.07 (2)
Skopjanka	1.04 (3)	3.00 (1)	0.60 (1)	2.90 (1)	0.61 (3)	1.15 (1)
Tamiš	1.22 (2)	2.43 (3)	0.48 (3)	2.32 (4)	0.54 (4)	0.86 (4)
Vali PKA-7114	0.86 (4)	2.63 (2)	0.52 (2)	2.57 (3)	0.67 (2)	1.07 (2)
Zvezda	0.76 (4)	2.36 (3)	0.47 (3)	2.33 (4)	0.71 (2)	1.00 (3)

Note: The numbers in parentheses represent the rank of the cluster group for each resistance indicator, where number 1 is the cluster group with the highest, and number 5 with the lowest mean value of the resistance indicator.

Conclusion

Drought stress affected the reduction of spike weight in all analyzed wheat genotypes, which makes this trait a good phenotypic marker of the impact of drought stress on wheat. Therefore, stress resistance indicators were calculated based on the value of this trait. High values of the MP, STI, and GMP resistance indicators favor the selection of genotypes Dunavka, Fundulea 4, and Skopjanka, characterized by a high average spike weight, especially in non-stressful environmental conditions. Genotype Pitoma characterized by high values of MP, STI, GMP, YSI, YI and low value of SSI is rated as highly drought-tolerant genotype. Also, Dunavka, and Skopjanka are characterised by high YI values and are considered drought-tolerant genotypes. Genotype Fundulea 4, characterised by high values of MP, STI, and GMP and low values of SSI, YSI, and YI, are preferred for cultivation in non-stressful, but not in stressful environmental conditions. The most suitable stress resistance indicators for selecting drought-tolerant wheat genotypes are SSI, YSI, and YI.

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