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THE RELATIONSHIP BETWEEN PLANT HEIGHT AND RESISTANCE TO LODGING OF PROMISING WHEAT GENOTYPES

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ABSTRACT

In two growing seasons (2018/19 and 2019/20) on the experimental field of the Center for Small Grains and Village Development in Kragujevac, plant height, lodging resistance and grain yield of ten prospective wheat genotypes were analyzed with one of two standards. During the growing seasons, the average annual temperature and amount of precipitation were above the long-term average, which affected the increased values of the analyzed properties. In the first growing season, the season with a more significant amount and favourable distribution of precipitation, the plant height was about 3 cm higher than in the second season. All allied genotypes generally had a satisfactory resistance to lodging, with the fact that genotypes with a taller plant height had lodging of less than 20% of lodging plants in both years. Three genotypes achieved a significantly higher yield than the standard varieties, six were up to the standard, while only one genotype had a significantly lower yield than the standard.

Keywords: *grain yield, lodging, plant height, wheat.*

INTRODUCTION

The main goal of breeding is the creation of new varieties of plants with high genetic potential for yield that would best suit specific regions, which are heterogeneous in terms of climate and soil conditions. However, yield formation is highly dependent on numerous characteristics during the plant's life cycle. Dormancy in cereal crops is a significant agronomic problem that greatly affects production efficiency (Singh et al., 2019) and can cause yield losses of up to 40% if they occur shortly after flowering (Kelbert et al., 2004). Yield losses due to lodging depend on the intensity of lodging and the developmental stage of the plant. Crop yield is reduced by more than 1% per day of dormancy (Stapper and Fischer, 1990). It has also been estimated that lodging can lead to grain yield losses of up to 80%, 80% and 66% in wheat, rice and barley, respectively (Zuber and

Kang, 1978; Berri et al., 2015, Yu et al., 2021), depending on the intensity of settlement and the developmental stage of its origin.The main causes of lodging are excessive crop density, increased levels of mineral nitrogen, soil compaction, disease and natural disasters such as storms, sowing date and seed type are fundamental factors contributing to lodging in cereals (Rawson and Macpherson, 2000; Shah et al., 2019).

Zuo et al. (2017) state that lodging can refer to the breaking or bending of the stem (stem prostrate) or root prostrate (firmness i.e. its attachment to the soil). Plant height is one of the main factors influencing lodging resistance (Berry et al., 2004). Plant height is determined by internode elongation, regulated by genes involved in gibberellin (GA) and brassinosteroid (BR) biosynthesis (Niu et al., 2021). Semi-dwarf is a valuable and widely used trait for intensive agriculture. The high yield potential of semi-dwarf varieties is attributed primarily to their improved harvest index, their resistance to lodging and more efficient use of the environment (Milach and Federizzi, 2001). The Green Revolution, led by semi-dwarf varieties in wheat, was due to the introduction of the *Rht* gene, which encodes a mutant form of the DELLA protein, a repressor of gibberellin signaling (Peng et al., 1999). Biochemical characteristics of stems, such as cellulose, hemicellulose, lignin, silica, and soluble sugar content, contribute significantly to the physical strength of stems against lodging stress. Low lignin or cellulose content in the stem leads to brittleness of plant leaves (Jones et al. 2001), and lodging-resistant cultivars show more lignin accumulation than lodging-susceptible ones (Xia et al., 2013; Peng et al. 2014). The strength of basal internodes is one of the key factors that determines the degree of resistance to lodging, with longer basal internodes contributing to increased susceptibility to lodging (Sarker et al., 2007). The length of the second basal internode is determined by additive and dominant gene effects, with the non-additive effect being the most influential (Madić et al., 2009). The genetic basis of lodging resistance revealed by mapping QTLs for this trait, as well as for related traits, has recently been the subject of numerous investigations (Ookawa et al., 2016; Verma et al., 2005; Hai et al., 2005; Ellis et al., 2005). , although their application in breeding is still quite limited (Shagh et al., 2019). In addition to the already widely used stem height reducer genes (*Rht* genes), the use of newly discovered *Rht* genes is also an integral part of wheat breeding programs for lodging resistance.

MATERIALS AND METHODS

On the experimental field of the Center for Small Grains and Village Development in Kragujevac in the growing season 2018/19 (GS1) and 2019/20. (GS2) plant height, lodging resistance and grain yield of 10 promising winter wheat genotypes were analyzed: G-2/6, G-5/98, G-5/7, G-6/7, G-4/4, G-2/24, G-2/2, G-1/5-9, G-19/5-4 and G-3-2. The standard varieties with which the lines were compared were: for winter common late wheat - Pobeda, and for winter common early wheat - Renaissance. The experiment was set up according to a completely randomized block system design in four replications, with a basic plot area of 5 m^2, number of rows of 10, distance between rows of 12.5 cm and plant spacing in a row of 3 cm. Pre-course in both years was maize. Sowing in both years was done with a micro-seeder, at the optimal time in the second half of October. In the experimental field, 400 kg ha^{-1} of NPK 8:16:24 fertilizer was added to the soil in autumn, while 300 kg ha^{-1} of KAN was added in the spring feeding. The height of the Plant is measured from the base of the stable to the top of the class. The resistance of the genotypes to lodging was evaluated with an appropriate score based on monitoring the lodging of plants up to the classes and at the milky maturity of the grain.

Meteorological conditions

Table 1. Average monthly temperature and precipitation amount

Vegetation season / month	*Average monthly temperature*(°C)			*Precipitation amount* (mm)		
	GS1	GS2	1981- 2010	GS1	GS2	1981-2010
X	13.9	13.6	11.9	9.4	196	48.9
XI	7.6	11.7	6.4	41.8	68.1	49.5
XII	2.6	4.9	2.1	51.8	57.6	45.8
I	0.1	1.3	0.9	85.3	23.3	37.9
II	4.2	6.2	2.3	2.2	47.6	37.0
III	9.1	7.8	6.6	10	55.7	42.3
IV	13.2	11.8	11.7	35.2	17.8	53.9
V	14.5	15.7	16.7	125.3	7.9	58.7
VI	22.4	19.9	20.0	143	192.9	76.4
VII	22.3	22.0	21.9	83.2	61.6	57.7
Average/Sum	10.9	11.49	10.5	627.2	728.5	508.1

The mean annual air temperature in both growing seasons (10.97 and 11.49°C) was higher than the thirty-year average (10.5°C). According to the average air temperature (11.7 °C), the year 2020 was the seventh warmest since 1951 until today. The average temperatures during the growing season (March-July) were generally higher or at the level of the multi-year average. Amount of precipitation in the growing season 2018/19. it was 627.2 mm, while 2020 was an average rainy year, and in certain central parts of Serbia, it was very rainy and extremely rainy. Amount of precipitation for the city of Kragujevac in the vegetation period 2019/20. it was 728.5 mm. The highest amount of precipitation in 2019 and 2020 was in June and amounted to 143 mm in 2019 and 192.9 mm in 2020. The mean annual temperature and amount of precipitation in both growing seasons were above the long-term average (Table 1).

RESULTS AND DISCUSSION

The height of the plant is one of the most important initial selection criteria and is the main factor affecting resistance to lodging and depends on the genetic constitution of the variety, climatic conditions and applied production technology measures. Crop height not only determines the resistance of plants to lodging but also affects crop architecture, biomass and mechanical harvesting. The morphology of the stem, as well as the chemical characteristics of the basal internodes, are the basic determinants of the strength and elasticity of the stem (Berri et al., 2003, Tripathi et al., 2005, Kong et al., 2013, Madić et al. 2016), while the strength of the connection between the roots and the soil is related to development and depth of penetration of the root system and mechanical characteristics of the soil itself (Foulkes et al., 2011). The height of the tree showed a discrepancy by age. Wheat genotypes differed in plant height, so the highest value for this trait in both growing seasons was genotype G-2/24, and the lowest was G-2/6 (Table 2). In the first growing season, a slightly higher height of the plants was recorded and on average it was about 3 cm higher than in the second year. All analyzed genotypes generally had satisfactory resistance to lodging, with only two genotypes, the genotype with the highest tree height, having lodging of less than 20% in both years (Table 2). Plant height in grain is associated with lodging resistance in all developmental stages (Berry et al., 2015). Genotypes with longer stalks are sensitive to lodging, which is in accordance with the obtained results, in contrast to lower genotypes that do not lay under conditions that cause lodging.

Table 2. Plant height, lodging,heading date and grain yield of wheat genotype

Genotype	*Plant height (cm)*			*Lodging (score1-9)*		*Heading date*		*Grain yield (kg ha^{-1})*		
	GS1	GS2	*Average*	GS1	GS2	GS1	GS2	GS1	GS2	*Average*
G-2/6	75.50	70.38	72.94	1*	1	23.5.	21.5.	6360	5808	6084b
G-5/98	85.20	82.50	83.85	1	1	22.5.	19.5.	6530	6200	6365a
G-5/7	91.50	87.25	89.38	3	3	19.5.	18.5.	6000	6462	6231b
G-6/7	74.42	75.13	74.77	1	1	18.5.	15.5.	5715	5978	5846c
G-4/4	84.00	85.25	84.66	1	1	12.5.	10.5.	6090	5960	6025b
G-2/24	97.50	90.00	93.75	3	3	23.5.	21.5.	6580	5833	6206b
G-2/2	90.45	87.00	88.73	1	1	18.5.	18.5.	6710	6120	6415a
G-1/5-9	86.70	86.88	86.79	1	1	17.5.	18.5.	6320	6650	6485a
G-19/5-4	84.50	85.25	84.87	1	3	20.5.	20.5.	5870	6540	6205b
G-3-2/3	81.00	78.53	79.77	1	1	17.5.	16.5.	5705	6420	6062b
Renesansa	90.00	84.13	87.65	1	1	14.5.	11.5.	6330	6092	6211b
Pobeda	84.00	83.50	84.04	1	1	20.5.	18.5.	6025	6320	6172b
Average	85.08	82.71						6186	6416	

*1-*no lodging;* 3- do 20% to the *20% lodged plants*

Analyzing the genetic variability for lodging resistance in a divergent population of wheat (140 genotypes) in a group of genotypes formed on the basis of stem height (low, medium and tall genotypes) Navabi et al. (2006) came to the conclusion that grain yield is negatively correlated with lodging, that is, sensitivity to lodging is positively correlated with plant height. As plant height appeared to be the main component of lodging resistance, some variation was also observed in taller plants. This suggests that genetic gain in lodging tolerance may exist, to some extent, independently of plant height (Nawabi et al., 2006). Acrechen and Slafer, (2011) indicated that lodging affected the reduction of number of grains per m^2 and average grain weight (AGW). The decrease of the number of grains per m^2 was associated withreductions in the crop growth, while the AGW loss seemed related to both a reduction of the availabilityof assimilates to fill grains and a direct effect on grain size potential.

Prospective wheat genotypes differed in grain yield and showed disagreement by year (Table 2). Three genotypes had a significantly higher yield than the standard varieties, six were up to the standard, while only one genotype had a significantly lower yield than the standard. Wheat is one of the most important agricultural crops that is produced in the world in areas that vary from 209 to 232 million hectares, with a grain yield of 560 to 750 million tons (Knežević et al., 2022). In the Republic of Serbia, compared to the ten-year average (2011–2020), the areas under wheat increased by 9.4%, and the average wheat yields range from 4.5 - 8 t ha^{-1} (Republički zavod za statistiku 2023). To increase the yield, producers can use the variety as a biological tool and cultivation technology as a technological solution that enables a different level of expression of the genetic potential of the fertility of the variety (Denčić et al. 2009, Knežević et al, 2020). This variation in yield shows us that to a large extent grain yield depends on climatic conditions.

CONCLUSION

During the growing seasons, the average annual temperature and amount of precipitation were above the long-term average, which affected the increased values of the analyzed properties. In the first growing season, the season with a larger amount and favorable distribution of precipitation, the plant height was about 3 cm higher than in the second season. All analyzed genotypes mostly had satisfactory resistance to lodging, with the fact that the genotypes with higher tree height had lodging of less than 20% of fallen plants in both years. Three genotypes achieved a significantly higher yield than the standard varieties, six were up to the standard, while only one genotype had a significantly lower yield than the standard.

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