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WHEAT BREEDING IN ABIOTIC STRESS CONDITIONS OF SOLONETZ

Miodrag DIMITRIJEVIĆ, Sofija PETROVIĆ, Borislav BANJAC

Department of Field and Vegetable Crops, Faculty of Agriculture,
University of Novi Sad, Serbia

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The complex stress environment at locality Kumane (Banat) primarily is caused by alkaline soil of solonetz type, but includes the other sources of wheat variability, water-logging and occasional extreme temperatures, as well. In order to obtain wheat varieties that could fulfill the requirement of enhanced tolerance to abiotic stress conditions of alkaline soil a set of wheat varieties was examined in parallel trials in Kumane (solonetz), and at Rimski Šančevi on chernzem (black soil). The multiyear results helped to select usable wheat genetic material among the existing varietal genetic variability. That variability was used as parents in *in situ* established crosses. The results in segregating F_2 offspring surpassed the average parental values for examined traits – plant height, grain number and grain weight per spike. Hence, selecting desirable genetic variability in

Corresponding author: Miodrag Dimitrijević, Faculty of Agriculture, sq. D. Obradovića 8, 21000 Novi Sad, Serbia. Phone: +381 21 485 3211, e-mail mishad@polj.uns.ac.rs

novel variability through years could lead to wheat plant ideotype capable to bring forth a economically justified yield.

Key words: abiotic stress, breeding, solonetz, wheat

INTRODUCTION

Global climate change has and will have, according to expert estimates, the multiple consequences. A significant change in the global and regional climate conditions is going to lead to major changes to the distribution of plant and animal species (The Geological Society of America, 2006). A thoughtful multidisciplinary science policy that would respond to changes resulting in appropriate strategies in food production is required (RAJARAM, 2001; HEISEY, 2002). Moreover, the intensive agricultural production during the XX century influenced the erosion of the human environment. The consequences are complex and manifold stress conditions in plant production: air and soil drought, low temperature, soil degradation caused rinsing, salinization, etc. The success of food production and future directions of agricultural development will largely depend on the effectiveness of responses to these challenges at various levels (FORSTER *et al.* 2000; TRETHOWAN, 2001; WITCOMB *et al.*, 2008).

Abiotic stress conditions are often a critical point in obtaining a stable and high yield of bread wheat in Vojvodina, and beyond. Stressful conditions are caused by poor distribution and amount of precipitation, temperature variations and extremes, and sometimes soil conditions. Alkaline soils occur as a result of irrigation, but could appear naturaly formed as solonetz or solonchak soil type in arid regions of lowland steppe climate. About 0.5% of Europe is covered with solonetz soil, known as alkaline, clay and sodium reach land mainly in Russia, Ukraine, Hungary, Bulgaria, Romania, and Kazakhstan (IUSS WORKING GROUP WRB, 2006). In Vojvodina, there is approximately 80,000 hectares of this type of soil, mostly in the Banat (BELIĆ *et al.*, 2006). Solonetz is commonly utilized for extensive pasture, but some crops and remedial measures can raise the productive value of land.

Most crops are adversely affected by salinity. In general, cereals are more tolerant than legumes (REYNOLDS *et al.* 2005). Small grains including bread wheat are generally regarded as moderately tolerant to alkaline soil (MUNNS *et al.*, 2006, WITCOMBE *et al.*, 2005, LIN *et al*., 2012). As such, they do not require too much investment in production and are suitable for cultivation on solonetz (ROYO and PITTSBURGH TRIBUNE REVIEW, 2003, SABIR, and ASHRAF, 2008, ZENG *et al.*, 2008). Solonits is oftenly subjected to chemical remedial measures. Drainage combined with application of calcium materials (gypsum, calcium chloride, calcium nitrate, phosphogypsum) or acid - H_2SO_4, HCl, HNO_3, coul be used (HELGASON, 2000, OAD *et al.*, 2002, SADIQ *et al.* 2003). GHAFOOR *et al.* (2001) suggest that repair of phosphogypsum to growing rice or wheat has proven to be most economical to alkaline soils in the Punjab. In addition, the assessment of practical value of varieties, within the existing genetic variability of wheat, for tolerance to alkaline abiotic stress could be conducted, as well as, the creation of new genetic variability in *in situ* breeding programs (CSEUZ *et al.*, 2002, ARAUS *et al.*, 2008).

Plant adaptations to most abiotic stresses involve a range of traits that interact and jointly contribute to plant tolerance (ROY *et al.*, 2011). Salinity is one of the most complex stress tolerances to breed for. The effect of combination of sodality and salinity, timing regarding the plant growth stage and intensity of stress could vary considerably. Moreover, salt tolerance is multigenic trait (FLOWERS 2004). ISLA *et al.* (2003) reported that in higher salinity, breeding for yield and salinity tolerance together was important. Simultaneous screening for salinity and water-logging tolerance is recommended as well. The selection method should depend upon the stresses faced in the target environment. Marker-assisted selection for component traits of salinity tolerance in wheat has produced some results and the pyramiding of stable quantitative trait loci controlling component traits may provide a solution (WITCOMBE *et al.*, 2008).

Selection criteria for the early offspring of crosses are often formed based on components of grain yield (DASHTI *et al.*, 2010). This is particularly true for those components that are significantly positively correlated to yield. Plant height influences the efficient translocation of nutrition from vegetative to generative part of the plant. Number of grains per spike has a significant contribution to the formation of grain yield, especially under conditions of abiotic stress (GARCÍA DEL MORAL *et al.*, 2003). Similarly, the grain weight per spike, has no or small positive correlation with grain yield of wheat under normal conditions, but under stress, there is a stronger positive correlation between these two properties (DENČIĆ *et al.*, 2000).

The aim of this paper is to estimate the possibilities of obtaining usable genetic variability of plant height and grain weight per spike in progenies of the wheat crosses made and grown *in situ* on solonetz soil.

MATERIALS AND METHODS

Plant Material

The experiment included eleven varieties of *Triticum aestivum ssp. vulgare* L, of the Institute of Field and Vegetable Crops in Novi Sad: Renesansa, Pobeda, Pesma, Sara, Partizanka, Rapsodija, Dragana, Cipovka, NSR 5, Evropa 90 (winter types) and Nevesinjka (facultative). All the varieties are resistant to low temperatures, while the varieties Renesansa and Rapsodija are particularly resistant to drought conditions. Varieties chosen for the experiment are grown in Serbia and neighboring countries, while variety Rapsodija is grown beyond the region, in the EU and Ukraine. Varieties Renesansa, Rapsodija, Pobeda, NSR-5 and Evropa 90 are selected as particularly adaptable genotypes. Varieties Nevesinjka and NSR-5 can grow on poor soil fertility. The results for varieties were aggregated from three years (2005, 2007 and 2009). F_2 progenies of nine cross combinations of five varieties (Pobeda, Renesansa, Sara, Partizanka, and Pesma) out 11 are studied: Pobeda x Renesansa, Pobeda x Sara, Pobeda x Pesma, Renesansa x Sara, Renesansa x Partizanka, Renesansa x Pesma, Sara x Partizanka, Sara x Pesma i Partizanka x Pesma. The progeny results, as well as, the results of corresponding parental varieties, are obtained from F_2 in two years 2010, and 2011.

Locations and Soil Conditions

Sites of the experiment are in Pannonian Plain-Banat region–Kumane village (latitude: 45.521994^{0}N, longitude: 20.194919^{0}E) with solonetz soil type (pH = 9.86) and Test field of the Institute of Field and Vegetable Crops - near Novi Sad (latitude: 45.324936^{0}N, longitude: 19.842883^{0}E) on the chernozem soil type (pH = 6.86). The solonetz soil type is characterized by unfavorable chemical and physical properties, caused by the high content of clay and the presence of adsorbed Na in the B_t horizon. Sodium causes highly alkaline reaction. The trial was set on non-ameliorated solonetz (control variation). Chernozem (black soil) is classified as automorphic soil, with favorable air and thermal regime. Texture is predominantly loamy and crumbly structure with stable aggregates. Chemical properties were favorable: the content of humus and plant nutrients is high, with a neutral to slightly alkaline reaction.

Vegetation Periods

The results of a experiments in two vegetation seasons 2004/2005 and 2008/2009, are given. Because the period from October 2004 to September 2005 was characterized by unusually large amounts of precipitation for the climate of Serbia, the crops were perfectly secured humidity, almost all the time. During that vegetation period no large and long-term variation in air temperature values from multi-year average was observed. Vegetation period 2008/2009 was characterized by deficit of rainfall and the occurrence of drought in April that extended to May. In the third decade of June, there was an abundance of rainfall, which significantly disrupted the harvest in the first part of July.

The experiment setting

The part of the experiment where wheat varieties were studied was set up by Randomized Complete Block Design in three replications. Each variety was sawn in eight 12.5cm spaced rows, 155m of length. Fifty kilograms of NPK 15:15:15 fertilizer was applied with sowing. Plant height (cm), number of grains per spike, grain weith per spike (g) and grain yield (t/ha) were followed. Analyzed grain yield was measured in representative samples of 4x5m^2 (solonetz) and 6m^2 (chernozem) and calculated per hectare. The progenies were examined on solonetz with the same fertilization applied. The rows were one meter long with 20cm between space, and spike per row was sown.

RESULTS AND DISCUSSION

The trial on solonetz soil at the locality of Kumane (Banat) was started in fall 1999. The first step was to examine the behavior of the existing genetic wheat variability. The genotype by environment interaction, quantitative traits and the grain yield were followed. According to the results a set of varieties was favored for further investigations. Some of them exhibited good behavior in harsh conditions of solonetz (Pobeda, Renesansa). Variety Rapsodija well reacted to ameliorative measures, while Evropa 90 showed both. Old variety Partizanka, as well as facultative Nevesinjka, was bred for good stress conditions handling and behaved accordingly (PETROVIĆ *et al.*, 2006; DIMITRIJEVIĆ *et al.*, 2009; PETROVIĆ *et al.*, 2009; DIMITRIJEVIĆ *et al.*, 2010; PETROVIĆ *et al.*, 2010; PETROVIĆ *et al.*, 2010a; DIMITRIJEVIĆ *et al.*, 2011; DIMITRIJEVIĆ *et al.*, 2011a). The aggregated experimental results for three years illustrate a pattern that was generally observed. A soil abiotic stress conditions in Kumane, predominantly caused by alkaline solonetz soil, but oftenly combined with water-logging, extreme temperatures, strong wind, cause the decrement of the yield components, as well as, grain yield *per se*. The multiyear results of the given wheat varieties sample compared with the results of parallel trial conducted on the black soil (chernozem) at the experimental field in Rimski Šančevi of the Institute of Field and Vegetable Crops from Novi Sad illustrate and quantify that generally observed pattern. The plant height appeared to be 20 to 40% shorter (Cipovka and Pobeda, respectively) in Kumane than in Rimski Šančevi, and that affected the lessening of photosynthetic area. Overall difference (*d*=Ku-RS) mean value ($\bar{X}$=65.9cm) showed that stress environment of Kumane predominantly caused by alkaline solonetz soil influenced shortage of vegetative plant part for about 34% comparing to the plant height of the same varieties grown on chernozem, and in general environmental conditions of Rimski Šančevi. Smaller photosynthetic area led to less productive generative plant part – the spike. The number of grains per spike in Kumane trial was almost halved comparing to that number in parallel trial in Rimski Šančevi (*d*=55%). Though, the trait expressed more uniformity in Kumane (V=9.05%), the differences of varietal mean values between locality Kumane and locality Rimski Šančevi varied 28% (Nevesinjka), to 58% (Renesansa), meaning that variety Nevesinjka achieved to produce only 42% of grains per spike in Kumane comparing to Rimski Šančevi and that variety Renesansa was the most productive for that trait in Kumane with about 72% of its Rimski Šančevi production. Corresponding spike mass productivity relations were denoted, as well. Overall grain weight per spike in Kumane trial was 48.3% of that weight in Rimski Šančevi. The smaller differences between varieties for that trait in Kumane than in Rimski Šančevi (V=9.19 and V=18.39%, respectively) was observed, too. Variety Nevesinjka reacted well to good growing conditions in Rimski Šančevi trial developing $\bar{X}$=2.29g of grain weight per spike. In Kumane 33.2% of that weight was obtained. Renesansa showed the smallest genotype by environment interaction, again, achieving $\bar{X}$=0.99g or about 1g of grains per spike. That was 63.5% of $\bar{X}$=1.56g that was average spike yield for that variety in Rimski Šančevi trial. The grain yield was almost halved in abiotic stress conditions of locality Kumane. Actually, the varieties in the sample presented in this article reached d=58.9% in Kumane ($\bar{X}$=3.91t/ha) of the grain yield level in Rimski Šančevi ($\bar{X}$=6.64t/ha). Variety Nevesinjka differed in grain yield on two localities about 7%, only, with $\bar{X}$=4.54t/ha in Kumane, and $\bar{X}$=4.86t/ha in Rimski Šančevi. The grain yield of Nevesinjka was the highest in Kumane, but the lowest in Rimski Šančevi, proving that variety durable in final result of grain yield. That durability and ability to survive in stress conditions provide more plants per growing area resulting in the highest yield. In Rimski Šančevi that advantage was of no avail (tab. 1).

Table 1. Mean values of four quantitative traits examined at localities Kumane (Ku) and Rimski Šančevi (RS) for eight wheat varieties. Overall means ($\bar{X}$), standard deviation (σ), coefficient of variation (V), standard error ($s_{\bar{x}}$), and minimum, as well as, maximum values were calculated

Varieties	Plant height (cm)			Number of grains per spike			Grain weight per spike (g)			Grain Yield (t/ha)		
	Ku	RS	*d** (%)	Ku	RS	*d* (%)	Ku	RS	*d* (%)	Ku	RS	*d* (%)
Renesansa	54,9	82,9	66,2	23	32	71.9	0,99	1,56	63,5	3,90	6,89	56,6
Pobeda	55,2	91,1	60,6	22	39	56.4	0,84	1,95	43,1	3,50	6,53	53,6
Rapsodija	56,3	79,3	71,0	22	45	48.9	0,86	2,01	42,8	3,48	6,86	50,7
Dragana	60,3	94,8	63,6	17	37	45.9	0,74	1,31	56,5	3,64	7,11	51,2
Cipovka	69,6	88,2	78,9	23	39	59.0	0,88	1,71	51,5	3,70	5,58	66,3
Nevesinjka	56,0	91,4	61,3	21	50	42.0	0,76	2,29	33,2	4,54	4,86	93,4
NSR 5	53,9	85,6	62,9	22	40	55.0	0,85	2,03	41,9	2,36	5,83	40,5
Evropa 90	57,2	90,6	63,1	22	38	57.9	0,81	1,49	54,9	3,91	6,64	58,9
Mean ($\bar{X}$)	57,9	88,0	65,9	22	40	55.0	0,84	1,79	48,3	3,63	6,23	58,9
σ	5,09	5,10		1,96	5,40		0,07	0,33		0,62	0,78	
V(%)	8,79	5,79		9,05	13,50		9,19	18,39		16,91	12,46	
$s_{\bar{x}}$	1,80	1,80		0,69	1,91		0,03	0,12		0,22	0,27	
Min	53,86	79,34		17	32		0,74	1,31		2,36	4,86	
Max	69,58	94,84		23	50		0,99	2,29		4,54	7,11	

* *d*- represents the difference between Kumane and Rimski Šančevi, where the value measured at R. Šančevi represents 100%

Summarizing the testing results of wheat varieties samople, we are facing the fact, that there is a number of yield components to be improved to get a chance to narrow the gap between the grain yield in Kumane (solonetz), and in Rimski Šančevi (charnozem). First of all, the plant height readjustment is required. In order to enhance the grain yield, plants for solonetz soil condition should be about 30-40% taller, in general. The plant height of about 80cm provides enough photosynthetic active area for productive generative part. Number of grains, and grain weight per spike represented generative part individual productivity in the trial. According to previous experience based on Kumane trial observations, individual plant performance gains importance in abiotic stress environmental growing conditions, alkaline solonetz soil and water logging in this case. The observed is in accordance to the results of DENČIĆ *et al.,* (2000), and GARCÍA DEL MORAL *et al.*, (2003). In that sense, individual spike productivity represents an important trait that contributes to grain yield formation per area unit. The number and the grain weight per spike should be about 50-60% improved in Kumane to meet the satisfactory level that gives a chance to reach about 40% higher grain yield achieved at Rimski Šančevi. A formal inducing of desirable genetic variability has started three four years ago at the locality of Kumane. In the *in situ* wheat crosses, the parents selected according to previous trial results were crossed. In F_2 progenies of the crosses, the mode of inheritance was studied. The results showed that mean values for the traits examined in this trial in F_2 progenies surpassed the parental averages. Hence, the genetic variability obtained in segregating offspring gives an opportunity to select desirable genetic variability that could give a satisfactory result through further selection process.

Table 2. Average values of three quantitative traits for parents and progenies, harvested in 2010, and 2011, at locality Kumane on solonetz soil

Genotypes		Plant height (cm) 2010	Plant height (cm) 2011	Number of grains per spike 2010	Number of grains per spike 2011	Grain weight per spike (g) 2010	Grain weight per spike (g) 2011
Parents	Renesansa	59,0	61,8	32	31	1,37	1,31
	Pobeda	55,6	61,0	29	30	1,22	1,31
	Pesma	54,4	58,1	39	36	1,32	1,43
	Sara	51,3	61,3	35	36	1,13	1,49
	Partizanka	62,9	64,1	34	34	1,33	1,31
Mean parents ($\bar{X}$)		56,6	61,3	34	33	1,27	1,37
F_2 Progenies	Pobeda X Sara	81,6	91,2	52	46	2,08	1,97
	Pobeda X Pesma	81,1	85,1	46	48	1,94	1,93
	Renesansa X Sara	86,3	76,4	42	46	1,69	1,85
	Renesansa X Pesma	73,7	80,7	44	37	1,71	1,53
	Sara X Partizanka	70,9	91,5	45	41	1,75	1,58
	Sara X Pesma	74,3	88,6	38	40	1,59	1,57
	Partizanka X Pesma	82,9	88,3	37	48	1,47	1,90
Mean progenies ($\bar{X}$)		78,7	86,0	43	44	1,75	1,76

CONCLUSION

In order to obtain wheat varieties having the higher tolerance to abiotic soil stress conditions a set of wheat varieties was examined in multiyear trials. According to the wheat trial results, the abiotic stress conditions of alkaline solonetz soil reduced plant height, the number and weight of grain per spike, as well as, grain yield 35-50%. The F_2 offspring of crossed parents chosen because of, in some aspects, superior behavior in alkaline soil growing conditions, was obtained. The mean values for the traits examined in F_2 progenies at locality Kumane (solonetz soil) appeared to be superior comparing to the parental averages. That gives a possibility to select desirable genotypes through further selection process that could lead to wheat varieties capable to enhance economic utilization of alkaline soil.

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OPLEMENJIVANJE PŠENICE U USLOVIMA ABIOTIČKOG STRESA SOLONJECA

Miodrag DIMITRIJEVIĆ, Sofija PETROVIĆ, Borislav BANJAC

Poljoprivredni fakultet, Departman za ratarstvo i povrtarstvo, Novi Sad

I z v o d

Složeni stresni uslovi gajenja na lokalitetu Kumane (Banat), pored alkalnog zemljišta tipa solonjec, uključuju I druge izvore varijacije osobina pšenice – vodoleže i povremene temperaturne ekstreme. Da bi se dobile sorte pšenice tolerantnije na uslove abiotičkog stresa prevashodno izazvanog alkalizovanim zemljištem, postavljeni su višegodišnji paralelni ogledi na lokalitetu Kumane (solonjec) i Rimski Šančevi (černozem). Ovi ogledi su pomogli da se izdvoje one sorte pšenice u postojećem sortimentu, koje su iskazivale pojedine osobine, ili grupe osobina koje sui m davale prednost u gajewu u uslovima alkalnog zemljišta. Izabrane sorte su poslužile kao roditelji u ukrštanjima na samom lokalitetu Kumane. Rezultati dobijeni u F_2 generaciji ovih *in situ* ukrštanja pokazuju das u prosečne vrednosti potomsva prevazilazile proseke roditelja za sve tri ispitivane komponente prinosa – visinu biljke, kao i broj i masu zrna po klasu. Ovo pruža mogućnost da se kreiranjem nove genetičke varijabilnosti, rekombinacijom postojećeg genskog fonda, kao da dobije ideotip biljke sposobna da iznese ekonomski opravdan prinos u uslovima abiotičkog stresa alkalizovanih zemljišta.

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