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TRAITS OF 25 WINTER WHEAT VARIETIES GROWN IN CROATIA IN THE LAST 100 YEARS

SVOJSTVA 25 SORTI OZIME PŠENICE SIJANIH U POSLJEDNJIH 100 GODINA U HRVATSKOJ

Valentina Španić, G. Drezner, K. Dvojković, Daniela Horvat

ABSTRACT

Experiments with 25 wheat varieties which were developed in the last 100 years in Croatia, Italy, Romania, France and Russia were set up in Osijek (eastern Croatia) during three years. Grain yield, plant height, heading date, 1000 kernel weight, test weight, protein content, sedimentation value, wet gluten, gluten index and falling number were analyzed. Varieties 'Katarina', 'Alka' and 'Renata' had the highest grain yield. 'Alka' and 'Katarina' had yields in average 15% higher in average 15% higher yields compared with 'Slavonija', 18% higher than 'Dropia' and 'Flamura 85', 30% higher than 'Bezostaja 1' and about 54% higher than 'Sirban Prolifik' and 'U1'. The lowest grain yield in all three years of research had varieties 'U1' (introduced in the production in 1936), 'Sirban Prolifik' (introduced in the production in 1905) and 'Dubrava' (recognized in1968).

SAŽETAK

U Osijeku (istočna Hrvatska) tijekom tri godine postavljeni su pokusi s 25 sorti pšenice nastalih u Hrvatskoj, Italiji, Rumunjskoj, Francuskoj i Rusiji. Analizirani su prinos zrna, visina biljke, datum klasanja, masa 1000 zrna, hektolitarska masa, sadržaj proteina, sedimentacijska vrijednost, vlažni gluten, gluten indeks i broj padanja. Najveći prinos ostvarile su sorte 'Katarina', 'Alka' i 'Renata'. 'Alka i 'Katarina' imale su u prosjeku veće prinose za 15% u odnosu na 'Slavoniju', za 18% u odnosu na 'Drpopiu' i 'Flamuru 85', za 30% u odnosu na 'Bezostaju 1' i oko 54% u odnosu na 'Sirban Prolifik' i 'U1'. Najniže prinose u tri godine istraživanja imale su sorte 'U1' (uvedena u proizvodnju 1936.), 'Sirban Prolifik' (uvedena u proizvodnju 1905.) i 'Dubrava' (priznata 1968.).

INTRODUCTION

Economically, winter wheat (*Triticum aestivum* L.) is an important crop grown in Croatia. Wheat production is approximately 4.6 t ha^{-1} on average with the harvested area of 169 583 ha from 2000 to 2012 (Croatian Bureau of Statistics, 2013). The winter breeding program has existed in Croatia since the beginning of the 20th century (Martinčić et al., 1996). The conservation and use of wheat genetic resources is essential to support future genetic progress in Croatia, and is an insurance against unexpected threats to crop productivity such as diseases or abiotic stresses (Gepts, 2006). It is also important to assure high and stable grain yield, a polygenic trait influenced by a number of environmental factors including temperature at emergence, vegetative stage, grain filling period and grain formation (Ahmad et al., 2011). It is not uncommon for some years to have sufficient rainfall adequate for good plant growth while in others there is a decrease in yield or quality because of water stress from insufficient soil moisture which is consequence of climate changes (Pepó et al., 2007; Spanic et al., 2008). The effects of water stress depend on timing, duration and magnitude of water deficiency (Rad and Abbasian, 2011).

Wheat end-use depends on the variety, environment and their interaction. The wheat flour quality and grain yield are strongly controlled by genetic factors but the environmental conditions during grain filling considerably affect their expression (Souza et al., 2004). There is the need to increase the yield potential and improve nutritive quality of wheat varieties in view of climate change, rising demand for healthy wheat products, and the increasing loss of its wild germplasm. In the last few decades in Croatia and the surrounding countries, new wheat varieties have been made and they differ from older wheat varieties in their genetic potential, stem height, quality properties and disease resistance. Modern wheat is dwarf/semidwarf wheat, a variety developed in the ’60s in order to massively increase yield. Increased yield can lead to the reduction in wheat mineral content, because modern wheat has shorter root systems than older wheat varieties. Another negative property of modern wheat is the one that it contains gluten peptide known as glia-α9, which is almost absent in older wheat and is the most reactive celiac disease epitope (van den Broeck et al., 2010). The objectives of this research were to examine some agronomic and quality traits of 25 bread winter wheat varieties developed in the last 100 years and to determine differences in selected traits.

MATERIALS AND METHODS

Experiments with 25 wheat varieties which were developed in the last 100 years in Croatia, Italy ,Romania, France and Russia were set up in Osijek (eastern Croatia), 45°32′N, 18°44′E, during three years (Table 1). Soil type was Eutric Cambisol (pHKCl – 6.25, humus – 2.20%, K_2O 37.70 mg 100 g^{-1}, P_2O_5 39.70 mg 100 g^{-1}). The experiments were set up as completely randomized block design with four replications. Genotypes were sown in eight row plots of 7 m length and 1.08 m wide in October. The climate conditions during growing season significantly differed in the amount of rainfall. The sums of precipitation in growing seasons during 2008–2011 were 368.6, 846.6 and 500.4 mm, respectively. The average annual temperatures during growing period were 10.8, 10.3 and 9.9 ºC, respectvely. To control seedborne diseases the seed was treated with Vitavax 200 FF (thiram+carboxin) at a rate of 200 g 100 kg^{-1}. The standard agricultural management practices were applied as in the commercial production of wheat (disease protection was excluded). Fertilization differed during the study (N:P:K 120-140:80-100:120-150 kg*ha^{-1}).

Grain yield (dt*ha^{-1}), plant height (cm), heading date, 1000 kernel weight (g), test weight (kg*hl^{-1}), protein content (%), sedimantation value (ml), wet gluten (%), gluten index and falling number (s) were analyzed. Plant height of each plant was measured from the ground level to the apex of the spike excluding awns. The quality traits considered were: protein content (Infratec 1241, Foss Tecator), wet gluten content and gluten Index (ICC method No 155), Zeleny sedimentation volume (ICC method No 116/1) and falling number (ICC method No 107/1). Statistical analyses were done using software Cropstat 6.1. (Cropstat for Windows, 1998–2007, International Research Institute).

RESULTS

Analysis of variance revealed highly significant differences between genotypes and years for all traits, and for the genotype-by-year interaction except for grain yield and plant height. The effect of the weather conditions in a year was the greatest on the grain yield (Table 2). Highly significant differences between years indicated their influences on protein content, sedimentation value, wet gluten content and falling number (Table 3).

Table 1. Origin and pedigree of the examined varieties

Tablica 1. Podrijetlo i pedigre ispitivanih sorti

No.	Genotype	Origin	Pedigree
1	Olimpija	Croatia, PIO, 2009	Slavonija/Divana
2	Srpanjka	Croatia, PIO, 1989	Osk.4.50-1/Zg.2696
3	Zitarka	Croatia, PIO, 1985	Osk.6.30-2/Slavonka// Osk.6.78-1-73/Kavkaz
4	Golubica	Croatia, PIO, 1998	Slavonija/Gemini
5	Super Zitarka	Croatia, PIO, 1997	GO3135/Zitarka
6	Lucija	Croatia, PIO, 2001	Srpanjka/Kutjevcanka
7	Alka	Croatia, PIO, 2003	Osk.5.140-22-91/Sana
8	Demetra	Croatia, PIO,1991	Osk.4.216-2-76/Zg 2877-74
9	Dropia	Romania, 1993	Colotana/F-2120-W-1
10	Flamura 85	Romania, 1989	Rannyaya-12/Nadadores-63//Lovrin-12
11	Katarina	Croatia, PIO, 2006	Osk.5B.4-1-94/Osk.5.140-22-91
12	Renata	Croatia, PIO, 2006	Zitarka/Osk.7.5-4-82/ Kom.Bg.160/86//Srpanjka
13	Soissons	France, 1987	Iena/HN-35
14	San Pastore	Italy, 1940	Balilla/Villa gloria
15	Slavonija	Croatia, PIO,1984	Osječka 20/Osk.4.216-2-76
16	Osječka Crvenka	Croatia, PIO,1976	Libellula/Bezostaja
17	Osječka 20	Croatia, PIO, 1978	Osk.6.9-1-64/V-188-M
18	Sirban Prolifik	Hungary, 1905	Unknown pedigree
19	U1	Croatia, PIO, 1936	Marquis/Carlotta Strampelli
20	Libellula	Italy, 1965	San Pastore//Tevere/Guiliani
21	Bezostaja 1	Former USSR, 1955	Skorospelka 2/Lutenscens 17
22	Zlatna Dolina	Croatia, Bc, 1971	Leonardo/ZG 414-57
23	Tena	Croatia, PIO, 1973	Libellula/Bezostaja 1
24	Osjecanka	Croatia, PIO, 1980	Tena (EMS1.5%)

PIO – Agricultural Institute Osijek, Croatia; Bc – Bc Institute, Croatia

Table 2. Analysis of variance for the grain yield, test weight, 1000 kernel weight and plant height

Tablica 2. Analiza varijance za urod zrna, hektolitarsku masu, masu 1000 zrna i visinu biljaka

Source of variability	Mean square				
	Degree of freedom	Grain yield	Test weight	1000 kernel weight	Plant height
Genotype (G)	24	939.26***	24.61***	219.73***	3753.67***
Replication	3	276.96*	2.49 ns	6.26*	30.44 ns
Year (Y)	2	13422.76***	1655.40***	4367.73***	366.01***
G × Y	48	96.89 ns	8.59***	17.72***	37.79 ns
Error	222	82.61	1.45	2.36	29.13

***, * – significant at P < 0.001 and 00.5, respectively; ns – not significant (P > 0.05)

Table 3. Analysis of variance for the protein content, sedimentation value, wet gluten, gluten index and falling number

Tablica 3. Analiza varijance za sadržaj proteina, sedimentacijsku vrijednost, vlažni gluten, gluteni indeks i broj padanja

Source of variability	Mean square					
	Df	Protein content	Sedimentation value	Wet gluten	Gluten index	Falling number
Genotype	24	4.98***	397.34***	86.11***	542.99***	11109.60***
Year	2	68.32***	591.41***	539.54***	236.21**	21344.17***
Error	48	0.27	49.83	5.20	42.13	2449.55

***, * – significant at P < 0.001 and 00.5, respectively; ns – not significant (P > 0.05)

Mean grain yield of the first year (84.79 dt*ha^{-1}) was higher than the second (63.98 dt*ha^{-1}) and third (83.85 dt*ha^{-1}) year. Average grain yield over three years varied from 56.96 dt*ha^{-1} ('U1') to 91.65 dt*ha^{-1} (‘Katarina’). Average test weight in over three years varied from 77.49 kg*hl^{-1} (‘Sirban Prolifik’) to 84.09 kg*hl^{-1} (‘Super Zitarka’). Large variability, on average, over three years was also found among wheat varieties for 1000 kernel weight, which varied from 35.27 g (‘Soissons’) to 51.65 g (‘Dropia’) (Table 4).

Table 4. Examined winter wheat traits on average in years 2009, 2010 and 2011 at location Osijek, Croatia

Tablica 4. Ispitivana svojstva u prosjeku u 2009., 2010. i 2011. godini na lokaciji Osijek, Hrvatska

Genotype	Grain yield $dt*ha^{-1}$	Test weight $kg*hl^{-1}$	1000 kernel weight g	Plant height cm
Katarina	91.65	80.45	37.85	77
Alka	91.27	79.85	40.70	83
Renata	88.29	80.43	41.32	75
Lucija	86.70	79.86	37.04	83
Demetra	86.12	79.58	38.45	80
Srpanjka	82.26	80.06	35.53	69
Zitarka	82.26	82.59	42.38	85
San Pastore	81.78	79.79	46.20	105
Golubica	81.71	81.71	39.94	88
Soissons	81.27	77.93	35.27	87
Slavonija	79.40	80.03	36.83	82
Dropia	78.28	82.29	51.65	91
Super Zitarka	77.12	84.09	44.85	87
Flamura 85	76.84	81.10	48.35	94
Osjecka Crvenka	76.73	81.13	42.61	93
Zlatna Dolina	76.69	78.98	37.19	87
Libellula	75.20	81.10	39.59	102
Osjecanka	74.97	81.40	42.69	95
Osjecka 20	73.11	80.99	36.48	83
Tena	72.53	80.78	45.48	106
Bezostaja 1	70.54	80.73	45.32	110
Olimpija	69.31	81.98	43.95	91
Sirban Prolifik	61.76	77.49	43.22	131
Dubrava	61.02	80.02	41.52	128
U1	56.96	79.08	46.48	140

Mean values of protein content over the years were 13.81, 15.88 and 12.61%, respectively. 'U1' showed the highest wet gluten content (45.63%), while ‘Alka’, ‘Soissons’, ‘Demetra’, ‘Srpanjka’, ‘Dropia’ and ‘Lucija’ were varieties with the highest gluten index (99). In three years sedimentation value varied from 23.67 ml (‘Libellula’) to 66.67 ml (‘Dropia’). ‘Renata’ (398 s) had the highest falling number and ‘San Pastore’ (143 s) the smallest (Table 5). In this study, grain yield was significantly negatively correlated with 1000 kernel weight and plant height, but a close positive correlation was observed between grain yield and year of origin of variety (Table 6).

In Table 7 the year of origin correlated negatively with protein content and wet gluten, but positively with sedimentation value and gluten index.

DISCUSSION

The effect of the weather conditions in a year was the greatest on the grain yield which was in accordance with the results of previous research of Mladenov et al. (2012). The results of our study show a large variability in yielding ability, which is the normal picture for nursery containing old and modern wheat varieties. Grain yield varied from year to year (data not shown). Over 100 years ago, in Croatia, introduction or breeding for higher yields, adaptation to climate changes, better bread-making characteristics, and improved disease resistance had started. The variation in grain yield is normal for a wheat nursery which contains both older and newly created varieties. Similar variations considering grain yield and other traits were also obtained by other researchers as well (Ágoston T., 2006, Sanchez-Garcia et al., 2013, Beche et al. 2014). Increased grain yield from the early sixties is the result of the adoption of the Green Revolution (del Pozo et al., 2014). The highest grain yield had varieties ‘Katarina’, ‘Alka’ and ‘Renata’. ‘Alka’ and ‘Katarina’ in average 15% higher yields compared with ‘Slavonija’ (‘Saray Bosna’, ‘Brasilia’), 18% higher than ‘Dropia’ and ‘Flamura 85’, 30% higher than ‘Bezostaja 1’ and about 54% higher than ‘Sirban Prolifik’ and 'U1'. As reported for hexaploid wheat and for durum wheat, old varieties were later and taller than modern varieties and their harvest indices were lower (Koc et al., 2003). The introduction of semi-dwarfing genes allowed a reduction in plant size that increased grain yield (Shearman et al., 2005). In both dry years, varieties ‘Alka’, ‘Katarina’, ‘Renata’ and ‘Lucija’ had the highest grain yield. The higher grain yield of the modern varieties was accompanied by higher test weight

Table 5. Examined winter wheat traits for quality on average in years 2009, 2010 and 2011 at location Osijek, Croatia

Tablica 5. Ispitivana svojstva kvalitete u prosjeku u 2009., 2010. i 2011. godini na lokaciji Osijek, Hrvatska

Genotype	Protein content %	Sedimentation value ml	Wet gluten %	Gluten index	Falling number s
Katarina	12.8	46	27.9	98	266
Alka	12.5	43	25.2	99	341
Renata	14.3	59	29.7	97	398
Lucija	12.9	45	26.4	99	315
Demetra	12.8	54	26.3	99	246
Srpanjka	12.9	45	26.5	99	381
Zitarka	13.9	46	33.2	82	337
San Pastore	14.0	37	36.9	71	143
Golubica	14.1	63	33.9	97	317
Soissons	12.0	38	22.9	99	339
Slavonija	13.3	46	31.6	83	339
Dropia	14.4	67	29.4	99	206
Super Zitarka	13.2	45	30.9	92	331
Flamura 85	14.1	57	28.4	98	201
Osjecka Crvenka	15.1	49	35.9	92	378
Zlatna Dolina	13.3	27	29.8	82	289
Libellula	14.3	24	33.9	69	312
Osjecanka	14.4	40	34.6	74	326
Osjecka 20	13.9	30	33.6	72	359
Tena	15.2	51	34.9	82	322
Bezostaja 1	13.9	50	32.5	88	249
Olimpija	16.0	63	34.9	92	364
Sirban Prolifik	16.9	34	44.3	60	314
Dubrava	15.4	49	34.5	84	345
U1	17.0	29	45.6	53	308

Table 6. Correlation coefficient between different traits and investigated year of origin

Tablica 6. Korelacijski koeficijent između različitih svojstava i istraživanih godina priznanja sorte

Trait	Test weight	1000 kernel weight	Plant height	Year of origin
Grain yield	−0.036	−0.415*	−0.797**	0.651**
Test weight		0.327	−0.019	0.344
1000 kernel weight			0.680**	−0.234
Plant height				−0.712**

** – $p \leq 0.01$, * – $p \leq 0.05$

Table 7. Correlation coefficient between different quality traits

Tablica 7. Korelacijski koeficijent između različitih svojstava kvalitete

Trait	Sedimentation value	Wet gluten	Gluten index	Falling number	Year of origin
Protein content	0.147	0.837**	−0.581**	0.033	−0.419*
Sedimentation value		0.148	0.529**	0.049	0.538**
Wet gluten			−0.826**	0.010	−0.612**
Gluten index				0.101	0.761**
Falling number					0.272

** – $p \leq 0.01$, * – $p \leq 0.05$

and 1000 kernel weight, similar to the research of Fang et al. (2011). In a rainy year, all varieties had significantly lower grain yields, lower 1000 kernel weight and test weight, but higher protein content, while varieties ‘Demetra’, ‘Katarina’, ‘Dropia’, ‘Zitarka’ and ‘Alka’ had the highest grain yield. Varieties 'U1' (introduced in the production in 1936), ‘Sirban Prolifik’ (introduced in the production in 1905) and ‘Dubrava’ (recognized in 1968) had the lowest grain yield in all three years of research. In contrast, varieties 'U1' and ‘Sirban Prolifik’ had the lowest grain yield, but the highest protein content. It is shown that none of the varieties had higher yield than the modern ones. Croatian modern varieties had higher yield than foreign varieties which was expected,

because these varieties were adapted to Croatian environment. It was also observed that older varieties were later and taller in comparison to modern varieties, and the distribution of dry matter before anthesis which is not effective can lead to lower grain yield in old varieties. The decrease of yield in all varieties was mainly affected by low level of resistance on fungal pathogens responsible for leaf diseases such as powdery mildew and leaf rust or fusarium head blight.

Big wheat kernels usually have a higher ratio of endosperm than nonendosperm components and can be criteria for predicting flour yield. The oldest varieties 'Sirban Prolifik' and 'U1' were 130–140 cm high, 7–14 days later in heading date with significantly higher protein content (but poor technological quality of gluten) than varieties developed in the last twenty years. Some highest yielding varieties from Croatia were accompanied by higher plant height during three years of research, which can be important with respect to obtaining more biomass for feeding animals and/or biogass. The results of the conducted experiment led to the conclusion that newly developed varieties had considerably higher grain yield compared with the old ones. Wheat grains contain 8–20% proteins which are closely related to wheat nutritional and bread-making quality.

Unfortunately, higher grain yields are usually associated with lower protein concentration, which is in accordance with other authors (Jablonskyte Raščė et al., 2013). Wheat breeding efforts during the past decades have had not only a great impact on grain yield but also on the grain quality in different countries (Trethowan et al., 2007).

In general higher protein content of genotypes is accompanied by higher wet gluten content and sedimentation value. From that, it can be concluded that high crude protein content in grain is a clear advantage of the old wheat varieties when compared to modern wheat varieties. The unique dough elasticity and viscosity of wheat flour is mainly influenced by gluten proteins (Horvat et al., 2013), because gluten is prepared as a by-product of the starch isolation from wheat flour and the storage (Pasha et al. 2007).

Gluten index as a valuable indicator of gluten strength varied over the years from weak (53) to very strong (99) indicating significant differences between varieties. Gluten is a protein composite, which means it is composed of several different proteins. The primary proteins giving gluten its utility in baking and its adverse effect on health are glutenin and gliadin. The oldest varieties 'Sirban

Prolifik' and 'U1' in spite of the highest protein content (16.9 and 17.0%, respectively) were accompanied by the lowest gluten index (60 and 53, respectively) suggesting a very poor quality of gluten. Wheat proteins contribute to dough properties, bread loaf volume, and crumb structure (Magdić et al., 2006), as well as to pasta production, in which gluten proteins generate the desired cooking quality. The oldest varieties 'Sirban Prolifik' and 'U1' with falling number 314 s and 308 s showed optimum α-amylase activity in contrast to varieties 'San Pastore', 'Dropia' and 'Flamura 85' (falling number lower than 220 s). Millers do not accept wheat with low falling number, because it produces lower flour yield and sticky dough that cannot withstand intense mixing. Previous reports indicate a global trend towards lower grain quality in highly yielding modern varieties (Triboi et al., 2006). In this study, grain yield was significantly negatively correlated with 1000 kernel weight and plant height, but a close positive correlation was observed between grain yield and year of origin of the variety. The negative correlation between these traits could be attributed to genetic selection over years.

Today's commercial wheat is a semi-dwarf and high-yield type, so it is expected that grain yield is positively correlated with year of origin while plant height negatively correlated with the same. Shorter wheat means that it is more resistant to "lodging" and more mineral elements are put into seed production. So it is understandable that in the course of the last 100 years the development from old to modern wheat varieties has led to a drastic shift in agronomical, morphological and quality traits.

The results, based on the data of the 25 varieties during 2009–2011 indicated that 'Katarina', 'Alka' and 'Renata' had a high yield potential. 'Dropia' had bigger kernels in Croatian conditions. In comparison with modern varieties, older ones have a higher protein content characterized by significantly lower quality (lower sedimentation value, gluten index and falling number). Some other researchers provided similar studies and concluded that the new biotechnological tools can help wheat breeding to become more efficient (Riede et al., 2001). However, success in breeding depends on heritability of these traits, i.e., from the ratio of genetic variance within the total phenotypic variance as well as the ratio of the components of genetic variance (Knezevic et al., 2012). The information derived from our study further suggest that the wheat varieties from Croatia have high yield accompanied by good quality and other desired traits what which may be important to growers in Croatia and abroad.

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Author's address – Adresa autora:
Dr. sc. Valentina Španić,
Dr.sc. Georg Drezner
Dr. sc. Krešimir Dvojković
Dr.sc. Daniela Horvat
Poljoprivredni institut Osijek
Odjel za oplemenjivanje i genetiku strnih žitarica
Južno predrađe 17, 31 103 Osijek
e-mail: valentina.spanic@poljinos.hr

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