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The performance of the genetic gain and breeding progress of historical winter wheat cultivars set in the period from 1930 to 2013 in South-eastern Europe

Sonja ILIN, Bojan JOCKOVIĆ, Milan MIROSAVLJEVIĆ, Vojislava MOMČILOVIĆ, Vladimir AĆIN, Dragan ŽIVANČEV, Sanja MIKIĆ, Ljiljana BRBAKLIĆ

National Institute of the Republic of Serbia, Institute of Field and Vegetable Crops
Maksima Gorkog 30, 21000 Novi Sad, Serbia
E-mail: sonja.ilin@ifvcns.ns.ac.rs

Abstract

The aim of this study was to analyse the changes in winter wheat (*Triticum aestivum* L.) grain yield and stability during the last century and to identify meteorological variables related to the cultivar performance in many-years research. A historical set of 47 winter wheat cultivars widely grown in the Pannonian Plain region during the period between 1930 and 2013 was studied. Field experiments with 47 winter wheat cultivars were conducted during ten growing seasons. Grain yield, main agronomic traits, protein content, and Zeleny sedimentation test were studied. The selected cultivars were widely grown and/or extensively used in breeding activities in Serbia and surrounding countries. The obtained results varied significantly across the growing seasons and breeding periods. The grain yield was closely related to winter wheat genetic gain. The genetic progress of grain yield was 48 kg ha^{-1} per year of cultivar release. Precipitation during winter, stem elongation, and mid and late grain filling stages were highly associated with the grain yield and genetic gain. Differences among the breeding periods were significant for the plant height. The cultivars of the 1st breeding period were the highest with an average plant height of 109 cm. The lowest plant height was recorded in the cultivars of the 5th and 6th breeding periods: 78.5 and 80.5 cm, respectively. Among the growing seasons, the average plant height ranged from 69.5 to 98.6 cm. The hectolitre weight varied from 77.6 to 79.6 kg hl^{-1}. The thousand grain weight showed a small variation and ranged from 40.1 to 41.9 g. The protein content significantly varied among the breeding periods and growing seasons. Modern cultivars of the 6th (12.4%) and the 4th (12.5%) breeding periods had the lowest protein content, while the highest protein content (14.0%) was recorded in the initial cultivars of the 1st breeding period. The modern winter wheat cultivars showed a higher grain yield potential and stability than older ones. Therefore, the improvement of cultivars stability across different environmental conditions should represent a notable strategy for further increase of the winter wheat grain yield potential.

Keywords: breeding progress, grain yield, Pannonian plain, stability, *Triticum aestivum*.

Introduction

Wheat (*Triticum aestivum* L.) is one of the most important crops in Serbia as well as in other surrounding Central and South-eastern European countries. Wheat occupies a central place in human nutrition providing 20% of the daily protein and food calories (Živančev et al., 2021). Constantly growing needs of human population for bread wheat justify research for more economical cultivation and production of this crop. The wheat grain yield has increased continually from 1.4 t ha^{-1} in 1948 to 4.5 t ha^{-1} in 2019 due to the introduction of new cultivars and advances in the management practices in Serbia (Statistical Office of the Republic of Serbia, https://data.stat.gov.rs/). Although the grain yield continues to increase in many areas, Ray et al. (2012) found that the yield of 24–39% maize-, rice-, wheat- and soybean-growing areas either never improve, stagnate, or collapse. In the present moment and the nearest future, grain yield stagnation could possibly be avoided with new investments as well as strategies to continue increasing yield in the high-performing areas are required to achieve a challenge of meeting increasing global agricultural demands. In some countries, large gains can still be achieved by improvements in agronomy, but in many others the yield gain will only be achieved by further genetic improvement (Hawkesford et al., 2013). In order to understand the future global food security situation, Tian et al. (2021) predicted the global demand for food crops, yield trends of food crops, and global crop production, and they found that the food demand would maintain a steady growth rate in the next 30 years. To resolve this global food production could be increased by increasing the irrigated area, appropriately increasing the

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amount of fertilisation and improving the efficiency of water and fertiliser use.

Considering different cereal crops, grain yield (GY) is more related to an increase of the grain number (GN) per unit area. Furthermore, the genetic progress in winter wheat GY has been related mostly to an increase in GN, while the effects of grain weight were less reported (Beche et al., 2014; Kitonyo et al., 2017). The main determinants of GN and GY in the conditions of the Pannonian Plain are the grain number per spike and the spike number per unit area (Mirosavljević et al., 2018). Also, in the last century, breeding activities have had a significant influence on the grain quality (Hristov et al., 2010a) altering the grain protein and wet gluten content. Modern winter wheat cultivars have a high-quality level due to the improvement of protein quality, the value of sedimentation, and the increase of gluten index (Mirosavljević et al., 2020).

Crop performance is the result of a genotype, environment, and different genotypic response to different environments (genotype by environment interaction, GEI). The GY related traits are mostly under a significant environmental control (Mladenov et al., 2012a). In Southern Europe and the Pannonian Plain, winter wheat is produced under rain-fed conditions, and GY is restricted due to unfavourable environmental conditions during the stem elongation and grain filling stage. As a result of climate change, higher air temperature, and water scarcity in the mid and late grain filling stages, the year-to-year variability has been constantly rising during the past decades and will further increase in this century (Trnka et al., 2014). Therefore, environmental conditions have the highest influence on winter wheat productivity resulting in a high GY instability between growing seasons.

In addition to the environmental influence, winter wheat GY and other agronomic and quality traits are under strong genotypic effects (Mladenov et al., 2012b; Kaya, Akcura, 2014; Ayranci, 2020). Development of cultivars characterised by a high and stable GY represents one of the main goals in winter wheat breeding programs. Moreover, different winter wheat cultivars showed a contrasting performance across different environments due to a significant GEI (Hristov et al., 2010b; Tatar et al., 2020). Knowledge about GEI is important for crop breeders, since GEI complicates the selection of superior genotypes affecting breeding strategies, multi-environmental testing, time, and the allocation of resources (de Leon et al., 2016). To understand GEI, a number of statistical approaches have been used (Zobel et al., 1988). Application of these methods could enable an appropriate selection of stable cultivars in order to respond to the high year-to-year variable climate of the Pannonian Plain and South-eastern Europe. To determine a genetic gain achieved through breeding activities, experiments with historical cultivar sets were conducted (Yadav et al., 2021). Research like this has so far been done on a significantly smaller number of genotypes in a shorter time under the environments of South-eastern Europe.

Therefore, the aims of this study were (1) to determine the changes in winter wheat grain yield and its stability during the last century, and (2) to identify meteorological variables related to the cultivar performance in different environments.

Material and methods

An experiment with a historical cultivar set has been conducted to determine a genetic gain (GG) achieved through breeding activities in the Pannonian Plain. During the experiment, the historical set of 47 winter wheat (*Triticum aestivum* L.) cultivars released in Serbia and surrounding countries between 1930 and 2013 was used. The selected cultivars were widely grown and/or extensively used in the breeding activities in the Pannonian Plain. The breeding periods, cultivar names, years of cultivar release, countries of origin, and pedigrees are shown in Table 1. Although the division of continuous breeding activities in different periods is not strict, the cultivars were grouped in six breeding periods according to the year of cultivar release, breeding methodology, and material used in the breeding programs.

In 2009–2019, field experiments were performed in the experimental field (45°20′ N, 19°51′ E) of the Institute of Field and Vegetable Crops, Novi Sad, Serbia, a typical Pannonian environment. The soil was characterised as a Haplic Chernozem Aric according to WRB (2015) with soybean as previous crop in each season. Basic soil properties were determined from the soil samples taken each growing season from the topsoil (0–30 cm) layer before ploughing, and a combination of nitrogen (N), phosphorus (P), and potassium (K) fertilisers was applied according to the results of soil analyses (Table 2).

The selected winter wheat cultivars were sown between 10 and 20 of October (recommended sowing date in the Pannonian Plain), while the harvest took place in late June. The plots were sown mechanically with a self-propelled row seeder HEGE 76/80 (HEGE GmbH, Germany) to reach the plant density of 550 plants per m^2 in three replications. The plots were 5 m long and 1 m wide with 10 rows per plot. In late February, before the stem elongation stage, an additional N fertiliser (ammonium nitrate, 34% N) was top dressed to avoid N deficiency during the intensive plant growth according to the results of mineral N analysis and amount of readily available N in the 0–90 cm soil layer (Wehrmann, Scharpf, 1979). To control the weeds, pathogens, and insects during the experimental period, herbicides (tribenuron-methyl, fluroxypyr, and iodosulfuron-methyl Na + amidosulfuron), fungicides (tebuconazole, epoxiconazole, metconazole, and propiconazole), and insecticides (deltamethrin, lambda-cyhalothrin, and gamma-cyhalothrin) were used. No additional irrigation was applied.

The plots were mechanically harvested with a small plot combine harvester Wintersteiger Delta (Wintersteiger AG, Austria), and the grain yield (GY) was adjusted to 14% moisture. The days of heading (DH) (after 1 January) were recorded for each plot when 50% of the spikes emerged (BBCH 55). The plant height (PH) was measured manually from the soil surface to the spike end of ten randomly chosen plants per cultivar per plot. The hectolitre weight (HW) was determined by GAC 2100 Agri (DICKEY-john, USA). The thousand grain weight (TGW) was calculated as the mean of three sets of 1 000 grains from each replication. The grain N content was determined by a Kejltec 2300 Analyzer Unit (Foss, Denmark) according to the AACC (2000) method 46-10, and the protein content (PC) percent was calculated after multiplying Kjeldahl N by 5.7, expressed on a grain dry weight basis. The sedimentation value (SV) of winter wheat samples was determined by the AACC (2000) method 56-62.01.

Daily meteorological data were recorded in all growing seasons from the meteorological station (Republic Hydrometeorological Service of Serbia) located near the experimental site in Rimski Šančevi. To characterise the climate, 20 meteorological variables were considered in October to February (O–F), March (MR), April (AP), May (MY) and June (JN): the sum of precipitation (pp): O-F.pp, MR.pp, AP.pp, MY.pp, and JN.pp; the average daily air temperature (tav): O-F.tav, MR.tav, AP.tav, MY.tav, and JN.tav; average maximal air temperature (tmax): O-F.tmax, MR.tmax, AP.tmax, MY.tmax, and JN.tmax, and minimal daily air temperature (tmin): O-F.tmin, MR. tmin, AP.tmin, MY.tmin, and JN.tmin.

Table 1. The breeding periods, analysed winter wheat cultivars, countries of origin, years of release (YOR), and pedigrees

Breeding period	No.	Cultivar	Origin	YOR	Pedigree
1st Before 1960	1.	Banatka	SRB	1930	Lv.-Banat
	2.	Bankut 1205	HUN	1931	Marquis/Bankut 5
	3.	San Pastore	ITA	1940	Ballila/Villa Glori
	4.	Bezostaja 1	RUS	1959	Selection from Bezostaja 4
2nd 1960–1970	5.	Mironovska 808	UKR	1963	Selection from spring cultivar Artemovkayspring
	6.	Libelula	ITA	1965	Tevere/Giuliari//1482-54-3/San Pastore
	7.	Dunav	SRB	1968	Haine VII/129genus
	8.	Odesskaya-51	UKR	1969	Odesskaja-16/Bezostaja 1
3rd 1970–1979	9.	Sava	SRB	1970	Fortunato/2/Red Coat
	10.	Zlatna dolina	HRV	1971	Zg 414-58/Leonardo
	11.	Partizanka	SRB	1973	Bezostaja 1/NS116
	12.	Sremica	SRB	1974	Argelato/Bolonjska 5//Bez-1
	13.	KG 56	SRB	1975	(Bez-1 × Halle Stamm) × Bez-1
	14.	NS rana 2	SRB	1975	Bez-1/NS262// Mir.808/NS435
	15.	Balkan	SRB	1979	Bačka/Bezostaja 1//Mir.808/3/NS435/4/Skorospelka 35
4th 1980–1989	16.	Jugoslavija	SRB	1980	NS646/Bez-1//Aurora
	17.	Skopljanka	MKD	1982	Argelato/Kavkaz
	18.	Sana	HRV	1983	Zlatna Dolina/TP.114-1965A//Sanja
	19.	Partizanka niska	SRB	1984	//(SP2 × Purdue5369-A-12-3) × B-1/ × Aa/ × Pz
	20.	Lasta	SRB	1987	Step.30/Sava/3/Bez.1/Sava//Lut32/Sava/4/Aueora
	21.	Soissons	FRA	1987	Jena/HN35
	22.	Rodna	SRB	1988	NS646/Bez-1//Aurora/3/Partiz.
	23.	Zadruga	SRB	1989	Jugoslavija/Balkan
5th 1990–1999	24.	Evropa 90	SRB	1990	Talent/Novosadska rana 2
	25.	Pobeda	SRB	1990	Sremica/Balkan
	26.	Rana niska	SRB	1990	[(Tobari-66 × Kavkaz) × Bačvanka-1] × NS rana 1
	27.	NS rana 5	SRB	1991	[(NS rana 1 × Tisa) × Partizanka] × Mačvanka 1
	28.	GK Zugoly	HUN	1993	GK Kincso/GK Istvan
	29.	Renesansa	SRB	1994	Jugoslavija/NS 55-25
	30.	Prima	SRB	1995	{[(Tobary66 × Kavkaz) × Nova Banatka]
	31.	MV Magdalena	HUN	1996	Yubileinaya 50/Fundulea-29//MV-MA
	32.	Sofija	SRB	1998	GKGRA 965-2/Panonija
6th After 2000	33.	Ljiljana	SRB	2000	NS 3287-3/Rodna
	34.	Dragana	SRB	2002	Ns63-26/Francuska
	35.	Rapsodija	SRB	2003	Agri/Nacozari F76//Nizija
	36.	Simonida	SRB	2003	NS 63-25/Rodna//NS-3288
	37.	Zvezdana	SRB	2005	NS 63-27/Stamena//NS rana 5
	38.	Janja	SRB	2005	Rodna/Pobeda//Milica
	39.	Viktorija	SRB	2005	NS 845/Bezostaja 1
	40.	Arlequin (LG)	FRA	2005	
	41.	NS 40S	SRB	2006	NS.694/ISA 88-3141
	42.	Srma	SRB	2006	Rodna/Pobeda//Milica
	43.	Balaton	HUN	2007	
	44.	Apache (LG)	FRA	2007	Axial/NRPB-84-4233
	45.	Andino (LG)	FRA	2009	
	46.	NS Ilina	SRB	2010	Tiha/ NS 74-96
	47.	NS Pudarka/NS3 7222	SRB	2013	NS 40S/NMNH-07//Simonida

Table 2. Basic soil properties and amounts of applied nutrients

Year	Soil properties						Fertilisation			
	pH KCl	$CaCO_3$ %	P_2O_5 mg 100 g^{-1}	K_2O mg 100 g^{-1}	Humus %	Available N (0–90 cm)	P_2O_5 kg ha^{-1}	K_2O kg ha^{-1}	N kg ha^{-1} prior to sowing	N kg ha^{-1} topdressing
2009–2010	7.35	9.03	30.6	21.8	2.45	60	45	40	50	80
2010–2011	7.58	6.36	67.1	26.8	2.54	50	–	30	40	90
2011–2012	6.30	1,27	9.3	23.6	2.55	75	100	40	45	70
2012–2013	7.33	4.17	34.9	25.9	2.05	110	40	30	60	40
2013–2014	5.93	0.16	16.5	35.0	3.44	95	60	20	45	60
2014–2015	6.05	0.77	8.5	25.1	2.32	90	100	40	50	60
2015–2016	7.38	8.63	71.4	31.4	3.45	85	–	30	50	70
2016–2017	7.31	4.17	40.2	40.9	2.57	90	30	20	45	70
2017–2018	6.40	1.00	10.9	25.1	2.17	70	100	40	50	80
2018–2019	7.30	2.53	15.9	32.0	2.59	75	60	30	45	80

P_2O_5 and K_2O – A-L method; humus – Tyurin method; available N – N-min method

Principal component analysis (PCA) was performed on a set of meteorological variables, GY and a PCA biplot was constructed to show an association between the investigated traits. The data were standardised prior to PCA. In order to determine the total variation, a combined analysis of variance (ANOVA) was conducted, where the genotype effect was partitioned into a breeding period considered as a fixed factor, and a genotype within a breeding period considered as a random factor. Grain yield stability was determined by the regression coefficient (bi) according to the Finlay-Wilkinson model (1963).

As a measure of GY stability, Lin and Binns (1988) defined the superiority index (Pi) as the genotype general superiority measure Si and as the distance mean square between the genotype's response and the maximum response over locations:

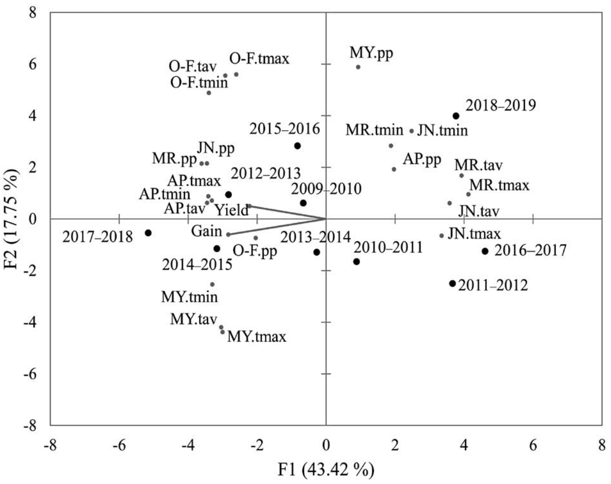
$$Si = \sum (R_{ij} - M_j)^2/2e.$$

This is the sum of the squares of the differences between its GY response (Rij) in each environment (j) and the GY response (Mj) of the best entry in that environment divided by twice the number of environments. Entries with smaller Si values are "superior", e.g., have greater GY superiority. Thus, a superior entry in this sense is one with a performance nearest to the maximum performance in multiple test environments (Döring et al., 2015).

Means were compared using the Tukey test ($p < 0.05$). In order to establish a change of the studied traits and the GY stability coefficient for each cultivar and its year of release, values of all measured traits were analysed as a function of the year of release with *SigmaPlot*, version 13.0 (Systat Software, USA).

Results

The PCA of the GY, GG, and 20 meteorological variables of the studied historical set of winter wheat grown during ten growing seasons is presented as PCA biplot with the first two principal axes (Figure 1). The first principal axis accounted for 43.42%, while the second one accounted for 17.75% of the total variation. In 2009–2010 and 2012–2013, warm April with a higher amount of precipitation in March and June were recorded. The weather conditions characterised by mild air temperature and an average precipitation level were recorded during 2010–2011 and 2013–2014. The growing season 2018–2019 was characterised by the highest average of minimal air temperature in March and June, a high amount of precipitation in April and May, cold temperature in May, and a less amount of precipitation during October–February. The 2011–2012 growing season was placed on the biplot near the 2016–2017 one indicating similar meteorological conditions with an increased maximal temperature in June and a low amount of precipitation during the whole growing season. The warm temperature



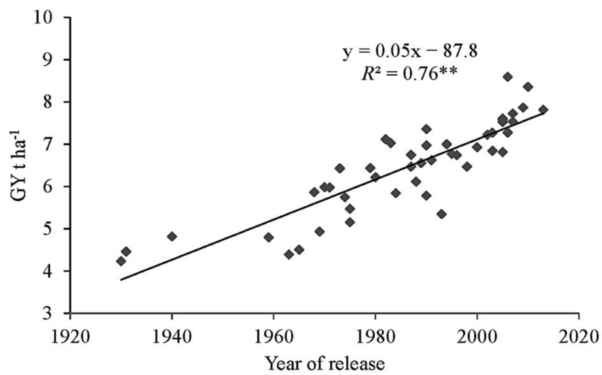
pp – the sum of precipitation in winter from October to February (O–F), March (MR), April (AP), May (MY), and June (JN); average air temperature: tav – average daily, tmax – maximal, and tmin – minimal in O–F, MR, AP, MY, and JN

Figure 1. Principal component analysis (PCA) of winter wheat grain yield (GY), genetic gain (GG), and 20 meteorological variables during ten growing seasons (2009–2019)

in April and May and the cold one in March, and a low amount of precipitation in April were recorded in the 2014–2015 and 2017–2018 growing seasons. The 2015–2016 growing season was characterised by mild winter and mild temperature in March, and an increased amount of precipitation in May.

The results of Table 3 show that DH varied between 124.3 (2nd breeding period) and 132.7 (1st breeding period). The longest pre-heading stage was recorded in 2010–2011, while 2017–2018 was characterised by the earliest heading date. Differences among the breeding periods were significant for PH. The cultivars of the 1st breeding period were the highest with an average PH of 109 cm. The lowest PH was recorded in the cultivars of the 5th and 6th breeding periods: 78.5 and 80.5 cm, respectively. Among the growing seasons, the average PH ranged from 69.5 to 98.6 cm. The HW varied from 77.6 to 79.6 kg hl^{-1}. The highest HW was recorded in the cultivars of the 3rd breeding period, while the most recent cultivars had the lowest HW. There was a significant influence of the growing seasons on HW showing a variation between 73.8 and 83.8 kg hl^{-1}. TGW showed a small variation and ranged from 40.1 to 41.9 g without a clear trend in the TGW changes during the breeding periods. PC significantly varied among the breeding periods and growing seasons. The lowest PC had the modern cultivars of the 6th (12.4%) and the cultivars of the 4th (12.5%) breeding periods. On the other hand, the highest PC (14.0%) was recorded in the initial cultivars of the 1st breeding period. The SV was the lowest in the initial cultivars (32.7 ml), while the highest SV was observed in the cultivars of the 5th breeding period (39.5 ml).

The GY significantly varied between the breeding periods and growing seasons. Winter wheat achieved the highest GY in 2013–2014 and the lowest one in 2016–2017. The initial cultivars released and introduced into production before 1960s had the lowest GY potential, about 4.58 t ha^{-1}. The GY steadily increased, and the modern cultivars had almost 3 t ha^{-1} higher yield potential than the cultivars of the 1st breeding period. Moreover, GY varied across the studied cultivars (Figure 2). The lowest GY of 4.23 t ha^{-1} was recorded in the cultivar 'Banatka' (released in 1930). On the other hand, the average GY of 8.59 t ha^{-1} of cultivar NS 40S was more than twice higher than that of 'Banatka'. According to Figure 2, which demonstrates the determination coefficient (r^2), a significant positive relationship was determined between the year of cultivars release and GY. The genetic progress in terms of GY was 48 kg ha^{-1} per year of cultivar release.



** – $P < 0.01$

Figure 2. Relationship between the winter wheat grain yield (GY) and the year of cultivar release

Table 3. Mean values of days of heading (DH), plant height (PH), hectolitre weight (HW), thousand grain weight (TGW), protein content (PC), sedimentation value (SV), and grain yield (GY) across six winter wheat breeding periods and growing seasons

Breeding period	DH, days	PH cm	HW kg hl^{-1}	TGW g	PC %	SV ml	GY kg ha^{-1}
1st	132.7 a	109.0 a	79.4 a	40.3 bc	14.0 a	32.7 d	4.58 e
2nd	124.3 c	100.3 b	77.9 b	41.9 a	13.5 b	38.0 ab	4.92 d
3rd	127.0 bc	84.0 c	79.6 a	41.4 ab	13.3 b	38.9 ab	5.88 c
4th	128.0 b	81.4 d	78.9 ab	40.9 abc	12.5 d	35.8 c	6.51 b
5th	126.4 bc	78.5 e	78.5 ab	40.5 bc	12.9 c	39.5 a	6.56 b
6th	127.3 bc	80.5 de	77.6 b	40.1 c	12.4 d	37.3 bc	7.53 a
Growing season							
2009–2010	127.1 bcd	84.3 c	75.6 gh	35.5 f	13.5 bc	47.6 a	5.97 e
2010–2011	132.2 a	83.1 c	81.2 bc	39.2 d	11.3 f	33.5 f	5.01 h
2011–2012	129.2 bc	69.5 e	83.8 a	43.9 b	13.5 bc	39.7 c	5.36 g
2012–2013	125.4 de	89.5 b	79.1 de	42.4 c	12.1 e	35.8 e	9.25 b
2013–2014	128.6 bc	89.4 b	82.4 ab	45.9 a	12.8 d	40.6 c	9.69 a
2014–2015	126.4 cd	90.2 b	77.5 ef	42.2 c	12.7 d	43.5 b	7.85 c
2015–2016	125.3 de	98.6 a	76.9 fg	40.1 d	11.1 f	28.5 g	6.57 d
2016–2017	129.7 ab	78.1 d	79.7 cd	43.9 b	14.7 a	38.2 d	3.97 i
2017–2018	123.0 e	76.2 d	73.8 h	38.1 e	13.4 c	33.1 f	5.25 g
2018–2019	127.3 bcd	90.1 b	74.5 h	35.6 f	13.7 b	33.0 f	5.62 f
Average	127.4	84.9	78.5	40.7	12.9	37.4	6.45

Note. Different letters represent significant difference between breeding periods and growing seasons ($p < 0.05$; Tukey test).

There was a significant linear relationship between the studied GY stability parameters and the year of cultivar release (Figure 3). The regression coefficient (bi) tends to increase in the modern cultivars with the rate of 4.6×10^{-3} yr^{-1} – it varied between 0.67 in ‘Bankut 1205’ and 1.31 in ‘Janja’. On the other hand, changes in the superiority measure index (Pi) had a negative relationship with the year of cultivar release showing a decrease of 0.16. The highest value of this parameter (13.67) was recorded in the cultivar ‘Banatka’, while the Pi value of modern cultivar NS 40S was 0.66. Furthermore, the GY relationship with the regression coefficient (bi) and the superiority measure index (Pi) is shown in Figure 3c and 3d, respectively.

The results of Figure 3c showed that the older cultivars released in the 1st breeding period had a lower GY and regression coefficient, while the modern ones tend to have higher GY and regression coefficient. Figure 3d shows similar results.

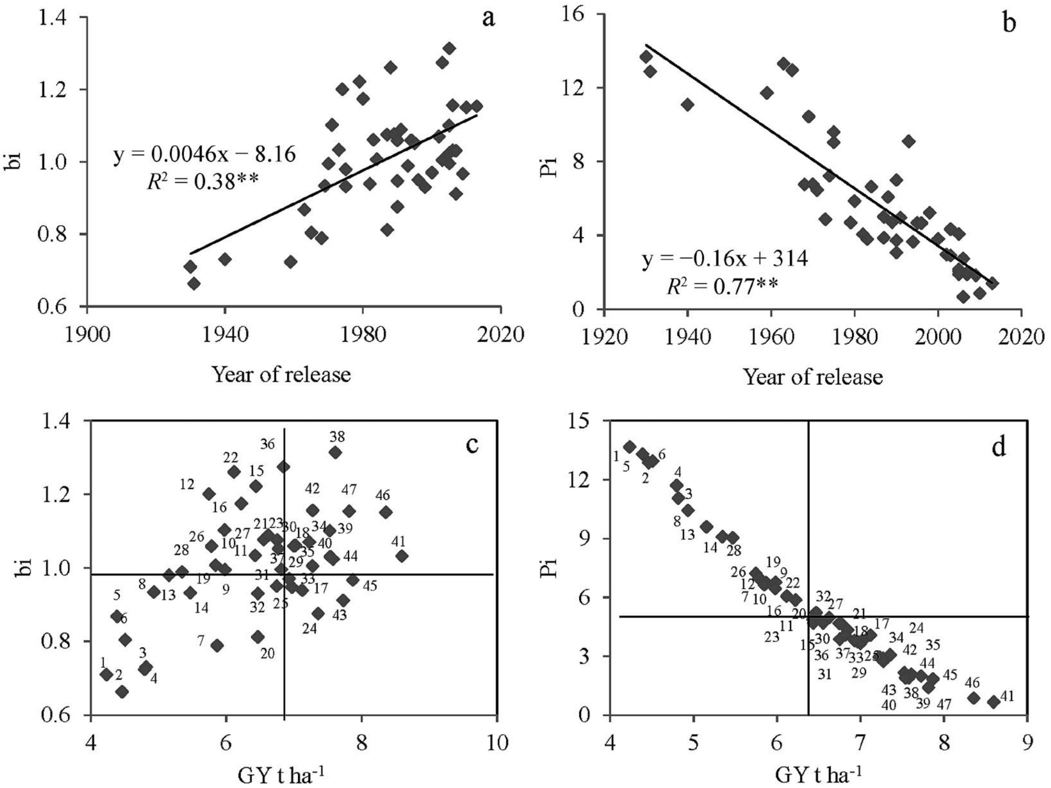


Figure 3. Relationship of the year of winter wheat cultivars release with the regression coefficient (bi) (a) and the superiority measure index (Pi) (b), the grain yield (GY) of winter wheat cultivars with the regression coefficient (bi) (c) and the superiority measure index (Pi) (d)

Discussion

In the conditions of the Pannonian Plain and South-eastern Europe, winter wheat is sown in mid-October. On average, wheat begins tillering in late November or early December and finishes it in mid-March. The tillering stage is followed by the stem elongation one, which lasts between mid/late March and early May, while the grain filling stage starts at mid-May and lasts until the middle or end of June. According to the PCA (Figure 1), GY and GG were closely associated indicating that GG was higher in the growing seasons that are favourable for winter wheat productivity. This association is expected since winter wheat breeding is usually conducted under the optimal production conditions. Therefore, the modern cultivars are characterised by higher N utilization efficiency than older cultivars developed before the Green Revolution (Ortiz-Monasterio et al., 1997).

GY and GG were mostly related to the precipitation in winter, March, and June, while the precipitation in May had less effect on these two traits. The drought period during the recommended dates of winter wheat sowing and field inaccessibility tends to increase as a result of climate change (Trnka et al., 2015) and will further represent a significant problem for winter wheat production in the Southern Europe and Pannonian Plain. Increased early precipitation promotes seed germination and crop establishment influencing winter wheat GY determination (Mladenov, Pržulj, 1999; He et al., 2013).

The stem elongation stage is critical for the formation of potential fertile florets and grain number determination (Slafer et al., 2014). Therefore, a higher amount of precipitation during this stage is closely related with the higher GY of winter wheat. Drought and heat stress during the grain filling stage, especially during the second half of the grain filling one, limits crop photosynthetic activity restricting assimilate synthesis and grain weight formation and decreases the final GY (Mirosavljević et al., 2021). GY was positively related with warmer April and May indicating that a prolonged cold period during the stem elongation and anthesis stages had a negative effect on GY and GN determination, as previously reported by Martino and Abbate (2019). On the other hand, years with the increased air temperature in March and June had a negative effect on the GY and GG of winter wheat due to a negative relationship between the monthly temperature and precipitation level and a negative effect of high temperature on crop performance.

Reduction in PH is associated with the introduction of dwarfing genes and the photoperiod-insensitive gene related to the increase in lodging tolerance, spike fertility, and GY (Borojević, Borojević, 2005). The winter wheat cultivars of the 1st and 2nd breeding periods were significantly higher than the ones of other breeding periods. The greatest PH reduction (16 cm) was recorded between the 2nd and 3rd breeding periods. Therefore, the 3rd breeding period represents the decade when *Rht* and photoperiod insensitivity genes were completely incorporated into local wheat cultivars and farmers excluded old high cultivars from production.

A low variability in TGW is similar to the results of most breeding progress studies of winter wheat and indicates the absence of improvement trend (Sanchez-Garcia et al., 2013; Lo Valvo et al., 2018). The highest TGW was recorded in cultivars of the 2nd breeding period, and from this period, the TGW substantially declined over time. This indicates that improving the TGW in winter wheat production and breeding in South-eastern Europe will require the introduction of cultivars of different genopoles (i.e., Eastern Europe) that are generally characterised by higher TGW.

Old cultivars of the 1st breeding period were characterised by the highest PC, while the lowest PC was recorded in the modern ones. In general, PC decreased significantly over time, although there was a slight increase in PC (0.5%) between the 4th and 5th breeding periods. Although a significant reduction in PC was determined, as previously reported by Laidig et al. (2017), the modern cultivars had maintained and increased the sedimentation value compared to that of the oldest ones indicating that they have retained protein and bread-making quality.

Comparisons of GY progress between the breeding periods showed that the difference in GY was the smallest between the 4th (6.51 t ha^{-1}) and 5th (6.56 t ha^{-1}) breeding periods – 50 kg. On the other hand, the highest gain was in the 6th breeding period, and the modern cultivars tend to have almost 1 t ha^{-1} higher GY compared to that of the cultivars of the 5th breeding period.

During the last breeding periods, Western Europe high-yielding cultivars have been widely introduced into production and breeding programs resulting in a significant increase in GY in South-eastern Europe. Genetic gain (GG) was similar as in the study of Mladenov et al. (2011) reported GG of 35 and 46 kg ha^{-1} yr^{-1} under a low and high N input, respectively. Also, Mirosavljević et al. (2020) gave an increase of 46 kg ha^{-1} with the year of cultivar release under the conditions of the Pannonian Plain. Moreover, GG notably varied among different climate areas. Morgounov et al. (2010) reported GG of only 15 kg ha^{-1} yr^{-1} of the Western Siberian winter wheat, while Balota et al. (2017) stated that the estimated annual GY gain ranged from 24.8 to 46.7 kg ha^{-1} yr^{-1} in Eastern USA. Different rates of GG in winter wheat should not be related only to breeding activities and methodology but also to differences in agro-ecological conditions and production management.

Although the regression coefficient (bi) tends to increase in modern cultivars, Eberhart and Russell (1966) stated that a stable cultivar should have a regression coefficient close to the environmental mean 1.0, whereas genotypes with the regression coefficient higher than 1.0 are adapted to favourable or high-yielding environments. Older cultivars were created for more extensive production conditions, and that is why they have regression coefficient below 1.0, which indicates adaptation to less favourable conditions. The explanation why the modern cultivars tended to have a higher regression coefficient is that new cultivars are created to be high yielding for certain regions that are favourable for a given cultivar and, therefore, their regression coefficient is over 1.0. Because of GY values and the regression coefficient, 'Mironovska 808', 'Odesskaya-51', and KG 56 could be distinguished as stable and low yielding, while NS 40S, 'Balaton', 'Apache', and 'Andino' could be considered as stable and high-yielding cultivars. Furthermore, the relationship between the year of release and the superiority measure index (Pi) confirmed that NS 40S, 'Balaton', 'Apache', and 'Andino' could be marked as the best cultivars.

Subira et al. (2015) reported that the modern durum wheat cultivars had a higher GY potential and lower values of superiority measure index than the cultivars of the previous periods indicating a lower GY stability and GY of old ones. These results and the similar ones obtained by Morgounov et al. (2010) show the reported increase of GY and stability of GY in the modern cultivars.

Conclusions

1. The results of this research have shown different relationships between 20 meteorological variables, genetic gain (GG), and grain yield (GY). The GG was closely related to the GY. The genetic progress of GY was 48 kg ha^{-1} per year of cultivar release. The GY was highly related to the precipitation level during the winter, early stem elongation, mid and late grain filling stages, and lower air temperatures in March and June. The GY and other studied agronomic and quality traits varied across the breeding periods and growing seasons. Changes in winter wheat GY and GG may be related to significant changes in main agronomic and quality traits.

2. Differences among the breeding periods were significant for the plant height (PH). The cultivars of the 1st breeding period were the highest with an average PH of 109 cm. The lowest PH was recorded in the cultivars of the 5th and 6th breeding periods, 78.5 and 80.5 cm, respectively. Among the growing seasons, the average PH ranged from 69.5 to 98.6 cm.

3. The hectolitre weight (HW) varied from 77.6 to 79.6 kg hl^{-1}.

4. The thousand grain weight (TGW) showed a small variation and ranged from 40.1 to 41.9 g.

5. Protein content (PC) significantly varied among breeding periods and growing seasons. The modern cultivars of the 6th breeding period (12.4%) and the cultivars of the 4th breeding period (12.5%) had the lowest PC, while the highest PC (14.0%) was recorded in the initial cultivars of the 1st breeding period.

6. These results indicated that winter wheat breeding in the Pannonian Plain resulted in a GY increase in the modern cultivars, which was also followed by stability improvement. Therefore, the analysis of genotypic stability should further represent an important task in winter wheat improvement programs.

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Žieminių kviečių selekcijos pasiekimai ir progresas Pietryčių Europoje nuo 1930 m. iki 2013 m.

S. Ilin, B. Jocković, M. Mirosavljević, V. Momčilović, V. Aćin, D. Živančev, S. Mikić, L. Brbaklić

Serbijos Respublikos nacionalinis laukininkystės ir daržininkystės institutas

Santrauka

Tyrimo tikslas – išanalizuoti žieminių kviečių grūdų derliaus ir stabilumo pakitimus per pastarąjį šimtmetį ir nustatyti kintamuosius dydžius, susijusius su veislių savybėmis ilgalaikėje perspektyvoje. Tirtos 47 žieminių kviečių veislės, augintos Panonijos lygumos regione nuo 1930 m. iki 2013 m. Lauko eksperimentai su 47 žieminių kviečių veislėmis vykdyti 10 auginimo sezonų. Atlikti grūdų derliaus, pagrindinių agronominių savybių, baltymų kiekio ir Zeleny sedimentacijos testo tyrimai. Atrinktos veislės buvo plačiai auginamos ir/ar naudojamos auginant kviečius Serbijoje ir aplinkinėse šalyse. Eksperimento rezultatai labai skyrėsi įvairiais augimo sezonais ir selekcijos laikotarpiais. Nustatytas ryšys tarp grūdų derliaus ir žieminių kviečių genetinio progreso. Grūdų derliaus genetinis progresas buvo 48 kg ha^{-1} per veislių kūrimo metus. Taip pat nustatytas stiprus ryšys tarp žiemos meto kritulių, stiebo pailgėjimo, vidurinės ir paskutinės grūdų pildymosi stadijų ir grūdų derliaus bei genetinio progreso. Veislių kūrimo laikotarpiai turėjo didelės reikšmės augalų aukščiui. Pirmojo laikotarpio kviečiai buvo aukščiausi – augalų vidutinis aukštis buvo 109 cm. Žemiausios buvo penktojo ir šeštojo laikotarpių augalai: atitinkamai 78,5 ir 80,5 cm. Įvairiais selekcijos laikotarpiais augalų vidutinis aukštis siekė nuo 69,5 iki 98,6 cm. Hektolitro svoris kito nuo 77,6 iki 79,6 kg hl^{-1}. Tūkstančio grūdų svoris skyrėsi nedaug – nuo 40,1 iki 41,9 g. Baltymų kiekis labai skyrėsi įvairiais selekcijos laikotarpiais ir augimo sezonais. Šiuolaikinių šeštojo (12,4 %) ir ketvirtojo (12,5 %) laikotarpių veislių baltymų kiekis buvo mažiausias, o didžiausią kiekį baltymų (14,0 %) turėjo pirmojo laikotarpio veislės. Žieminių kviečių naujų veislių grūdų derliaus potencialas ir stabilumas buvo didesnis už senesnių veislių.
Taigi, veislių stabilumo didinimas įvairiomis aplinkos sąlygomis turėtų būti neabejotina tolesnio žieminių kviečių grūdų derliaus potencialo didinimo strategija.

Reikšminiai žodžiai: auginimo (veisimo) progresas, grūdų derlius, Panonijos lyguma, stabilumas, *Triticum aestivum*.