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Development of selection criteria for improving grain yield in wheat grown in different agro-ecological environments

Mirela Matković Stojšin[1*], Sofija Petrović[2], Borislav Banjac[2], Svetlana Roljević Nikolić[1], Veselinka Zečević[3], Jasmina Bačić[1], Radiša Đorđević[3], Desimir Knežević[4]

[1] Institute "Tamiš", Novoseljanski put 33, 26000 Pančevo, Serbia
[2] Department of Field and Vegetable Crops, Faculty of Agriculture, University of Novi Sad, Sq. Dositeja Obradovića 8, 21000 Novi Sad, Serbia
[3] Institute for Vegetable Crops, Karađorđeva 71, 11420 Smederevska Palanka, Serbia
[4] Faculty of Agriculture, University of Priština, Kopaonička bb, 38219 Lešak, Serbia

**Corresponding author: matkovic.stojsin@institut-tamis.rs*

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A B S T R A C T

Various statistical methods were applied in this research: analysis of genetic parameters, Pearson's correlation, genotypic and phenotypic correlations, and Path analysis, with the aim of creating a selection criterion for increasing wheat grain yield. A two-year experimental study was conducted with twenty-seven wheat genotypes, grown on two localities: Rimski Šančevi (Bačka, Vojvodina), on Chernozem soil type; and Kumane (Banat, Vojvodina), on Solonjec soil type. The highest values of phenotypic coefficient of variation (CV_p) had the grain weight per plant (17.44% on Chernozem and 13.81% on Solonetz), while the lowest value of CV_p had the thousand grain weight (8.12% on Chernozem and 5.47% on Solonetz). On Chernozem, the value of the genotypic coefficient of variation (CV_g) ranged from 1.51%, in the number of grains per spike, to 9.17% in the spike length, while on Solonetz, grain weight per plant had the lowest value of CV_g (0.36%) and plant height the highest one (11.15%). At both localities, grain yield was in highly significant and positive correlations with all analyzed traits, except with plant height and spike length. In favorable environmental conditions (Chernozem), Path analysis revealed that grain yield directly depends on grain weight per spike (0.317**), number of grains per spike (0.232**) and spike weight (0.209**), and other analyzed traits have a positive indirect effect on grain yield over mentioned traits. Under salinity stress conditions, the grain weight per plant had the highest direct effect on grain yield (0.891**), which makes this trait a good selection criterion in breeding for salinity stress tolerance.

***Keywords**: variability, correlations, Path analysis, wheat, Solonetz, Chernozem.*

И З В О Д

У овом истраживању су примењене различите статистичке методе: анализа генетичких параметара, Пирсонове корелације, генотипске и фенотипске корелације и Path анализа, са циљем да се креира селекциони критеријум за повећање приноса зрна пшенице. Спроведено је двогодишње експериментално истраживање са двадесет седам генотипова пшенице, гајених на два локалитета: Римски Шанчеви (Бачка, Војводина), на земљишту типа чернозем; и Кумане (Банат, Војводина), на земљишту типа солоњец. Највеће вредности фенотипског коефицијента варијације (CV_p) има маса зрна по биљци (17,44% на чернозему и 13,81% на солоњецу), док је најмања вредност CV_p установљена код масе 1000 зрна (8,12% на чернозему и 5,47% на солоњецу). Вредност генотипског коефицијента варијације (CV_g) се, на чернозему, кретала од 1,51%, код броја зрна по класу, до 9,17%, код дужине класа, док је на солоњецу маса зрна по биљци имала најмању вредност CV_g (0,36%), а висина биљке највећу (11,15%). На оба локалитета принос зрна је у високозначајним и позитивним генотипским и фенотипским корелацијама са свим особинама, осим са висином биљке и дужином класа. У повољним условима средине (чернозем), Path анализа показује да принос зрна директно зависи од масе зрна по класу (0,317**), броја зрна по класу (0,232**) и масе класа (0,209**), док остале особине имају позитиван индиректни ефекат на принос преко наведених особина. У условима стреса заслањености, највећи директни ефекат на принос зрна има маса зрна по биљци (0,891**), што чини ову особину добрим селекционим критеријумом за повећање приноса зрна у условима стреса.

Кључне речи: варијабилност, корелације, Path анализа, пшеница, солоњец, чернозем.

1. Introduction

Wheat is considered the most important cereal because it presents the main source of nutrients for around 40% of the human population (Giraldo et al., 2019; Iqbal et al., 2021). According to FAOSTAT (2021), global wheat production in 2021 reached a record of 780 million tonnes, where it ranks first in area coverage. Thus, the use of wheat in the diet is growing globally, including in countries with unfavorable climatic conditions for wheat production (Shewry and

Hey, 2015; Schewry, 2018). Accordingly, there is a need to increase the production of this crop, even in the ecosystems that are unfavorable for agricultural production (Matković Stojšin et al., 2022; Grčak et al., 2019). However, the creation of genotypes with increased tolerance to abiotic stress is a slow process that depends on the available genetic variability (Crouch et al., 2009; Petrović et al., 2020; Marković et al., 2021). Thus, effective selection requires knowledge of genetic systems that control inheritance of traits, the nature and extent of population variation, the relationship between traits and grain yield, as well as the effect of the environment on the phenotypic expression of traits (Yagdi and Sozen, 2009; Madić et al., 2009; Knežević et al., 2020; Roljević Nikolić et al., 2021). Grain yield is formed during the ontogenetic development of the plant in interaction with environmental factors and it is the resultant value of the various traits – yield components. Therefore, knowledge of the relationship between grain yield and its components is of particular practical importance for the implementation of breeding programs (Knežević, et al., 2015; 2018; Rohani and Marker, 2016a; Khan et al., 2017; Baye, 2020). The study of yield components is of special importance in stress conditions, as well as in the early generational stages of plant breeding (Dimitrijević et al., 2013; Madić et al. 2019). Genotypic and phenotypic correlations provide information on the degree of association of yield components with economic productivity, i.e. grain yield (Zečević et al., 2010; Nukasani et al., 2013 and Rohani and Marker, 2016a).

Yield components such as grain weight per spike and number of grains per spike are considered indirect indicators of grain yield (Petrović et al., 2009; Nukasani et al., 2013). Also, Ebrahimnejad and Rameeh (2016) noticed a positive association between spike weight, number of grains per spike, grain weight per spike, and grain yield. However, knowing the correlations between yield components is often not enough, because two components can be correlated just because both are correlated with a third trait (El-Mohsen et al., 2012). Thus, due to the multicollinearity present between the yield components, a linear correlation does not provide adequate information on the relationship between grain yield and grain yield components (Khan and Dar, 2010).

Path analysis is a more reliable statistical technique, which quantifies the inter-relationships of different yield components and separates direct and indirect effects on grain yield (Zečević et al., 2004; El-Mohsen et al., 2012; Ojha et al., 2018).

The aims of this study were to: (I) establish the variability of analyzed traits in genotypes grown on different soil types; (II) determine the inter-relationship of grain yield and grain yield components; (III) establish a direct and indirect contribution of the yield components to the grain yield; (IV) determine the appropriate selection criteria for increasing the grain yield on both soil types.

2. Materials and methods

2.1. Materials and plot design

The research included twenty seven genotypes of winter wheat (*Triticum aestivum* ssp.), consisted of local landraces (Banatka and Grbljanka), old varieties (Bankut 1205, KG-75, Šumadija, Kosmajka, Gružanka, Morava, Zastava, KG-56, Orašanka, KG-58, KG-78, Lepenica, Jugoslavija, Oplenka, Ljubičevka, Srbijanka, and Šumadinka), and modern varieties (NSR-5, Renesansa, Pesma, Aleksandra, Perfekta, Harmonija, Rujna, and Premija).

The experiment was concluded according to a randomized block design, in two localities: Kumane, Vojvodina Province (45.522º N, 20.195º E), on Solonetz soil type; and Rimski Šančevi, Vojvodina Province (45.322º N, 19.836º E), on Chernozem soil type, during two vegetation seasons (2015/2016 and 2017/2018).

Kumane locality was chosen as a treatment with increased soil salinity. The argiluvian (Bt) horizon (58-85 cm) of Solonetz soil had the highest content of adsorbed Na (13.45 meq / 100 g). Due to the high content of clay and Na in Bt horizon, Solonetz is considered a soil of unfavorable physical and chemical properties. Also, the high content of exchangeable Na affects an increase in the pH of Solonetz soil (pH > 9) (Belić et al., 2012).

Rimski Šančevi locality was chosen as a control treatment, characterized by Chernozem soil type. Chernozem is considered an ideal soil, with a favorable mechanical composition, good water permeability, and stable aggregates. In addition, this soil is well provided with humus (3-4%) and plant nutrients (Hadžić et al., 2002).

At both localities, the examined genotypes were sown by continuous sowing with row spacing of 10 cm. The basic plot area was 2 m^2 with a distance between the plots of 25 cm.

In both vegetation seasons, the harvest was done in the last decade of June, when grain moisture was below 14%. Yield components (plant height, spike length, spike weight, grain weight per spike, number of grains per spike, grain weight per plant, thousand grain weight, and grain yield) were analyzed in the phenophase of full maturity in three replicates.

2.2. Meteorological conditions

Mean monthly temperatures did not differ significantly between analyzed localities, during both vegetation seasons. In Rimski Šančevi locality, the sum of precipitation was higher (602 mm in the 2015/2016 vegetation season and 594 mm in the 2017/2018 season) compared to the sum of precipitation observed in Kumane locality (560 mm in 2015/2016 and 461 mm in 2017/2018 vegetation season). The 2017/2018 vegetation season was characterized by a lack of precipitation and higher temperatures, which influenced the earlier maturation of plants (Figure 1), http://www.hidmet.gov.rs/.

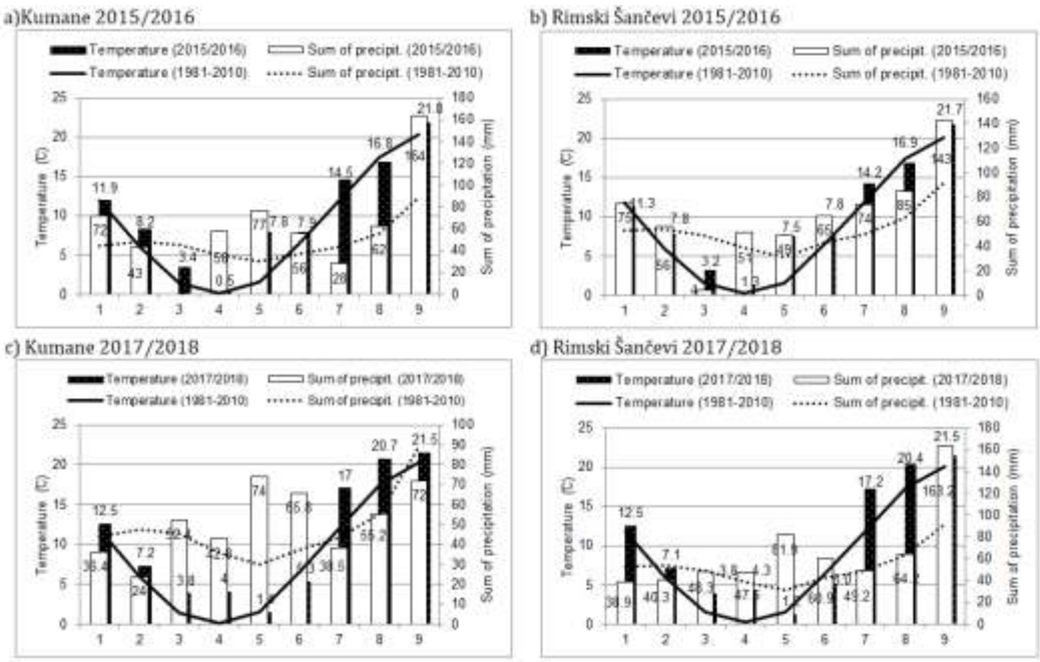

Figure 1. Meteorological conditions in Kumane locality (a, c) and Rimski Šančevi locality (b, d) in 2015/2016 and 2017/2018 vegetation season

2.3. Statistical analysis

Analyses of variance and covariance, correlation, and multiple linear regression for all collected data, were conducted, using the IBM SPSS Statistics Trial Version 22.0 (https://www.ibm.com/). The values of mean squares (MS) were used to estimate components of the variance (genotypic variance σ^2_g, phenotypic variance σ^2_p, genotype × year variance $\sigma^2_{g\times y}$, and ecological variance σ^2_E) (Comstock and Robinson, 1952), as follows:

$$\sigma^2_g = \frac{MS1 - MS2}{r \cdot y} \quad (1)$$

$$\sigma^2_{g\times y} = \frac{MS2 - MS3}{y} \quad (2)$$

$$\sigma^2_E = \frac{\sigma^2_{g\times y}}{y} + \frac{MS3}{r \cdot y} \quad (3)$$

$$\sigma^2_p = \sigma^2_g + \frac{\sigma^2_{g\times y}}{y} + \frac{MS3}{r \cdot y} \quad (4)$$

Where: MS1, MS2 and MS3 denote the mean square of genotype, genotype × year, and error, respectively; r = replications, y = years

The mean values ($\overline{x}$) were used to determine genotypic coefficient of variation CV_g and phenotypic coefficient of variation (CV_p), according to Singh and Chaudhry (1985), using equation:

$$CV_g(\%) = \frac{\sqrt{\sigma^2_g}}{\bar{x}} \times 100 \quad (5)$$

$$CV_p(\%) = \frac{\sqrt{\sigma^2_p}}{\bar{x}} \times 100 \quad (6)$$

The genotypic (r_g) and phenotypic (r_p) correlation coefficients were calculated by the method described by Falconer (1989), using equations:

$$r_{g(xy)} = \frac{\mathbf{COV}_{g(xy)}}{\sqrt{\sigma^2_{g(x)} \cdot \sigma^2_{g(y)}}} \quad (7)$$

$$r_{p(xy)} = \frac{\mathbf{COV}_{p(xy)}}{\sqrt{\sigma^2_{p(x)} \cdot \sigma^2_{p(y)}}} \quad (8)$$

where: cov_g = genotypic covariance, cov_p = phenotypic covariance; x and y = mean values of traits

Test of significance (at 5 and 1% probability levels) of correlation was done using a t-test at n-2 degree of freedom.

Path analysis was calculated using Dewey and Lu (1959) method.

3. Results and discussions

Table 1 shows the values of genetic parameters of the analyzed traits in wheat grown on chernozem. The phenotypic coefficient of variation (CV_p) was higher in relation to the genotypic coefficient of variation (CV_g) for all analyzed traits. This result indicates that factors of environment had a high effect on the variation of analyzed traits. The lowest values of genotypic (CVg) and phenotypic (CVp) coefficient of variation were recorded for thousand grain weight (CVg = 4.73% and CVp = 8.12%) and number of grains per spike (CVg = 1.51% and CVp = 9.36%). However, the difference between the values of the calculated coefficients of variation is larger for the number of grains per spike, due to the more pronounced influence of ecological variance. Amin et al. (2015) point out that phenotypic selection on the number of grains per spike may be unsuccessful due to the pronounced influence of the non-additive source of variation. Also, a high share of ecological variance in the total phenotypic variance was determined for spike weight, grain weight per spike, grain weight per plant, and grain yield. This is in conformity with the results of Sabit et al. (2017) for spike weight, Petrović et al. (2010) and Knežević et al. (2014) for grain weight per spike, Shankarrao et al. (2010) and Rohani and Marker (2016b) for grain weight per plant and Birhanu et al. (2016) and Meles et al. (2017) for grain yield. The share of ecological variance in the total phenotypic variance of plant height and spike length was approximately 30%, which resulted in small differences between the calculated values of the coefficients of variance (CVg and CVp). Desheva and Cholakov (2014), Branković et al. (2015), Rahman et al. (2016), and Kumar et al. (2017) obtained similar results, where they concluded that variability of plant height is under the higher influence of genetics. This can be explained by a complex gene system which, in addition to minor, also includes major genes (Rht genes) that regulate plant growth (McIntosh et al., 2015).

Table 1.
Analysis of genetic parameters in wheat genotypes grown on Chernozem

Trait	$\bar{x}$	Components of variance[1]				MS genotype	CV_g (%)	CV_p (%)
		σ^2_g	σ^2_p	$\sigma^2_{g\times y}$	σ^2_E			
PH (cm)	98.00	76.21	95.59	34.25	26.16	573.55	8.91	9.98
SL (cm)	9.15	0.70	0.90	0.32	0.30	5.40	9.17	10.36
SW (g)	2.40	0.01	0.06	0.08	0.11	0.39	2.99	10.59
GWS (g)	1.60	0.02	0.08	0.10	0.09	0.27	7.94	17.44
NGS	39.90	0.37	13.94	23.17	19.55	79.27	1.51	9.36
GWP (g)	5.44	0.06	0.66	1.01	0.91	3.30	4.40	14.98
TGW (g)	38.77	3.36	9.92	12.68	7.20	59.50	4.73	8.12
GY (t ha^{-1})	6.60	0.13	0.89	1.36	1.04	3.85	5.39	14.33

Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield; [1] σ^2_g, σ^2_{ph}, σ^2_{g*y} and σ^2_E indicate the genetic, phenotypic, genotype and phenotype interaction and environment variance, respectively

Genetic parameters of analyzed traits in genotypes grown on Solonetz soil are shown in Table 2. The highest value of the CVg was recorded for plant height (11.1%), while the highest value CVp was observed for grain weight per plant (13.81%). The lowest difference between the calculated coefficients of variation (CVg and CVp) was found for plant height, due to the greater influence of genotype in the variation of this trait.

Table 2.
Analysis of genetic parameters inwheat genotypes grown on Solonetz

Trait	$\bar{x}$	Components of variance[2]				MS genotype	CV_g (%)	CV_p (%)
		σ^2_g	σ^2_p	$\sigma^2_{g\times y}$	σ^2_E			
PH (cm)	78.70	76.95	95.80	34.59	18.85	574.78	11.15	12.44
SL (cm)	7.25	0.24	0.48	0.34	0.24	2.89	6.76	9.58
SW (g)	1.59	0.01	0.04	0.05	0.04	0.25	4.47	12.95
GWS (g)	1.14	0.00	0.02	0.04	0.02	0.14	2.02	13.81
NGS	27.34	0.26	7.15	10.39	6.89	42.91	1.87	9.78
GWP (g)	3.70	0.00	0.23	0.30	0.23	1.40	0.36	13.06
TGW (g)	38.13	0.32	4.36	7.54	4.03	26.14	1.49	5.47
GY (t ha^{-1})	4.56	0.02	0.39	0.59	0.37	2.33	2.85	13.68

Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield; [2] σ^2_g, σ^2_{ph}, σ^2_{g*y} and σ^2_E indicate the genetic, phenotypic, genotype and phenotype interaction and environment variance, respectively

All other analyzed traits had a pronounced difference between coefficients of variation, due to the influence of environmental factors. Kaya and Akcura (2014) also found a high share of ecological variance in the phenotypic variation of grain yield, which was due to the large difference between vegetation seasons. An equal share of genotypic and ecological variance was present in the phenotypic variation of spike length. Also, Singh and Upadhyay (2013) obtained almost equal values of genotypic and ecological variance in the total phenotypic variation of spike length, where they concluded that selection based on spike length is not efficient, due to the dominant influence of non-additive genes.

A correlation analysis was performed with the aim of studying the inter-relationship between the grain yield and yield components, separately for each locality (Table 3 and Table 4). At Rimski Šančevi locality, spike length, spike weight, grain weight per spike, number of grains per spike, and grain weight per plant were in significant ($P < 0.01$) and positive association. Grain yield was significantly and positively correlated with all yield components, except plant height, where the highest correlation coefficient had with grain weight per spike (0.906**) and grain weight per plant (0.884**). Similarly, Ebrahimnejad and Rameeh (2016) established that grain yield was in positive association with spike elements, such as spike weight, grain weight per spike, and number of grains per spike. Also, Nukasani et al. (2013) found that grain yield had a positive correlation to the grain weight per spike and number of grains per spike. Plant height achieved a positive correlation only with spike length (0.358**), Table 3.

Table 3.
Correlation analysis of analyzed traits in wheat genotypes grown on Chernozem

Trait	PH	SL	SW	GWS	NGS	GWP	TGW	GY
PH	-	0.358**	0.153	0.111	0.052	0.098	0.153	0.070
SL	0.358**	-	0.344**	0.294**	0.400**	0.252**	-0,143	0.227**
SW	0.153	0.344**	-	0.808**	0.763**	0.791**	0.542**	0.851**
GWS	0.111	0.294**	0.808**	-	0.826**	0.848**	0.583**	0.906**
NGS	0.052	0.400**	0.763**	0.826**	-	0.817**	0.346*	0.830**
GWP	0.098	0.252**	0.791**	0.848**	0.817**	-	0.625**	0.884**
TGW	0.153	-0.143	0.542**	0.583**	0.346**	0.625**	-	0.666**
GY	0.070	0.227**	0.851**	0.906**	0.830**	0.884**	0.666**	-

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

On Solonetz, all analyzed traits were in significant and positive correlation, due to increased soil salinity influenced reduction of all traits. The highest correlation coefficients were determined between grain weight per spike and grain yield (0.978**), then between grain weight per spike and number of grains per spike (0.978**), as well as between grain weight per spike and spike weight (0.903**). Also, grain yield was in a highly significant ($P < 0.01$) correlation with grain number per spike (0.917**), spike weight (0.885**), and grain weight per plant (0.846**). This is in accordance with the results published by Knežević et al. (2008), Petrović et al. (2009) and Zečević et al. (2010). Plant height is positively correlated with all analyzed traits, which is in line with the results of Petrović et al. (2016) and Banjac (2015), Table 4.

Table 4.
Correlation analysis of analyzed traits in wheat genotypes grown on Solonetz

Trait	PH	SL	SW	GWS	NGS	GWP	TGW	GY
PH	-	0.431**	0.253**	0.225**	0.164*	0.325**	0.391**	0.286**
SL	0.431**	-	0.701**	0.673**	0.675**	0.701**	0.575**	0.680**
SW	0.253**	0.701**	-	0.903**	0.850**	0.821**	0.667**	0.885**
GWS	0.225**	0.673**	0.903**	-	0.926**	0.846**	0.615**	0.978**
NGS	0.164*	0.675**	0.850**	0.926**	-	0.793**	0.471**	0.917**
GWP	0.325**	0.701**	0.821**	0.846**	0.793**	-	0.471**	0.846**
TGW	0.391**	0.575**	0.667**	0.615**	0.471**	0.671**	-	0.593**
GY	0.286**	0.680**	0.885**	0.978**	0.917**	0.846**	0.593**	-

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

In order to obtain more accurate results on the inter-relationship of analyzed traits, the genotypic and phenotypic correlations were calculated (Table 5 and Table 6). On both localities, values of genotypic correlations were higher compared to values of phenotypic correlations, showing the existence of inherent association among the traits, which is in line with results presented by Munir et al. (2007), Ajmal et al. (2009), Nukasani et al. (2013), Rohani and Marker (2016a), and Matković Stojšin et al. (2018). Plant height had significant and negative correlations with all analyzed traits, at the genotypic and phenotypic levels, except with spike length ($r_g = 0.629^{**}$, $r_p = 0.422^{*}$). Also, spike length was in negative genotypic and phenotypic correlations with other analyzed traits, where a statistically significant negative genotypic correlation ($r_g = -0.314^{*}$)was achieved only with grain weight per plant. Grain yield was positively and significantly ($P < 0.01$) correlated with all analyzed traits, at the genotypic and phenotypic levels, except with plant height and spike length. Therefore, indirect selection of spike traits will lead to an increase in grain yield. Also, highly significant genotypic and phenotypic correlations were found between the spike elements (Table 5).

Table 5.
Genotypic – r_g (above diagonal) and phenotypic – r_p (below diagonal) correlation between analyzed traits in wheat genotypes grown on Chernozem

Trait[1]	PH	SL	SW	GWS	NGS	GWP	TGW	GY
PH	-	0.629**	-0.647**	-0.624**	-0.773**	-0.748**	-0.053	-0.626**
SL	0.422*	-	-0.208	-0.269	-0.398*	-0.314*	-0.221	-0.146
SW	-0.446*	-0.025	-	0.726**	0.636**	0.883**	0.693**	0.768**
GWS	-0.595**	-0.128	0.624**	-	0.561**	0.692**	0.522**	0.664**
NGS	-0.539**	0.063	0.548**	0.544**	-	0.695**	0.148	0.633**
GWP	-0.597**	-0.216	0.722**	0.648**	0.659**	-	0.664**	0.781**
TGW	-0.015	-0.340	0.631**	0.504**	0.120	0.628**	-	0.631**
GY	-0.483*	-0.123	0.719**	0.627**	0.573**	0.737**	0.616**	-

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

In genotypes grown on Solonetz, plant height was significantly ($P < 0.01$) and negatively correlated with all examined traits, at both, genotypic and phenotypic levels, except with spike length and thousand grain weight. Similarly was noticed for spike length, where this trait was in a highly significant and negative genotypic correlation with grain weight per spike (r_g = -0.506**), number of grains per spike (r_g = -0.728**), grain weight per plant (r_g = -0.539**), and grain yield (r_g = -0.621**), while the coefficients of phenotypic correlations with these traits were statistically insignificant ($P > 0.05$). The plant height and spike length had the highest differences between the values of genotypic and phenotypic correlations in relationship with other analyzed traits. This indicates the presence of a great influence of the environmental factors on Kumane locality.

Grain yield was positively correlated with spike weight (r_g = 0.962**, r_p = 0.876**), grain weight per spike (r_g = 0.953**, r_p = 0.943**), grain weight per plant (r_g = 0.978**, r_p = 0.915**), and thousand grain weight (r_g = 0.642**, r_p = 0.546**). The association between spike weight, grain weight per spike, number of grains per spike, and grain weight per plant were significant and positive ($P < 0.01$) at both, phenotypic and genotypic levels. The highest values of correlation coefficients were found between grain weight per spike and number of grains per spike (r_g = 0.974**, r_p = 0.829**), as well as grain weight per spike and grain weight per plant (r_g = 0.965**, r_p = 0.892**). It was established that thousand grain weight was in positive association with all traits, except with spike length (Table 6).

Table 6.
Genotypic – r_g (above diagonal) and phenotypic – r_p (below diagonal) correlation between analyzed traits in wheat genotypes grown on Solonetz

Trait[1]	PH	SL	SW	GWS	NGS	GWP	TGW	GY
PH	-	0.268	-0.766**	-0.542**	-0.522**	-0.512**	0.340	-0.601**
SL	0.240	-	-0.344	-0.506**	-0.728**	-0.539**	-0.314	-0.621**
SW	-0.176	-0.315	-	0.878**	0.858**	0.951**	0.409*	0.962**
GWS	-0.133	-0.321	0.886**	-	0.974**	0.965**	0.672**	0.953**
NGS	-0.307	-0.246	0.795**	0.829**	-	0.804**	0.308	0.932**
GWP	-0.009	-0.326	0.868**	0.892**	0.727**	-	0.763**	0.978**
TGW	0.194	-0.104	0.477*	0.571**	0.152	0.685**	-	0.642**
GY	-0.023	-0.377	0.876**	0.943**	0.828**	0.915**	0.546**	-

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

Path analysis in wheat genotypes grown on Chernozem shows that plant height and spike length had a negative, but statistically insignificant ($P > 0.05$), direct effect on grain yield. Also, the indirect effect of these traits was not statistically significant. When observing the influence of all traits on grain yield, grain weight per spike had the highest direct effect (0.317**) and the highest total effect (0.906) on grain yield, which makes this trait a good selection criterion in plant breeding for increasing grain yield. Also, number of grains per spike, spike weight, thousand grain weight, and grain weight per plant had a significant direct effect on grain yield. This is in agreement with the results of Ojha et al. (2018). Similarly, Matković Stojšin et al. (2018b) established that spike weight had a positive direct effect on grain yield per plant. The grain weight per plant had the highest total indirect effect (0.739), mostly through the grain weight per spike, on grain yield (Table 7).

Table 7.
Direct and indirect effects of grain yield components on grain yield in wheat genotypes grown on Chernozem

Trait[1]	Direct effect	Indirect effect								Total effect
		PH	SL	SW	GWS	NGS	GWP	TGW	Total indirect effect	
PH	-0.046	-	-0.008	0.032	0.035	0.012	0.014	0.031	0.116	0.070
SL	-0.022	-0.016	-	0.072	0.093	0.093	0.037	-0.029	0.249	0.227
SW	0.209**	-0.007	-0.008	-	0.256	0.177	0.115	0.109	0.642	0.851
GWS	0.317**	-0.005	-0.006	0.169	-	0.192	0.123	0.117	0.589	0.906
NGS	0.232**	-0.002	-0.009	0.159	0.262	-	0.118	0.070	0.598	0.830
GWP	0.145*	-0.005	-0.006	0.165	0.269	0.190	-	0.126	0.739	0.884
TGW	0.201**	-0.007	0.003	0.113	0.185	0.080	0.091	-	0.465	0.666
Corrected R^2=0.908										
Dependent variable: grain yield										

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

The path coefficient analysis in wheat genotypes grown in Kumane locality gave somewhat different results compared to the genotypic and phenotypic correlation analysis (Table 8). Plant height had a significant ($P < 0.05$) and positive direct effect (0.079*) on grain yield, as well as a significant indirect effect via grain weight per spike (0.200) on grain yield. In contrast to the results of genotypic and phenotypic correlations, path analysis showed that spike length, spike weight, number of grains per spike, grain weight per plant, and thousand grain weight had a non-significant ($P > 0.05$) direct effect on grain yield. However, these traits had a high indirect effect through grain weight per spike on grain yield. Grain weight per spike had the greatest positive direct effect (0.891**) and the greatest total effect (0.979) on grain yield. Therefore, the selection of mentioned trait will increase the grain yield. This is in conformity with results published by Ashfaq et al. (2003), Nukasani et al. (2013), and Desheva (2016).

Table 8.
Direct and indirect effects of grain yield components on grain yield in wheat genotypes grown on Solonetz

Trait[1]	Direct effect	Indirect effect								Total effect
		PH	SL	SW	GWS	NGS	GWP	TGW	Total indirect effect	
PH	0.079*	-	-0.002	0.000	0.200	0.010	0.016	-0.018	0.207	0.286
SL	-0.004	0.034	-	0.000	0.600	0.043	0.034	-0.026	0.685	0.681
SW	0.000	0.020	-0.003	-	0.805	0.054	0.040	-0.031	0.886	0.886
GWS	0.891**	0.018	-0.003	0.000	-	0.059	0.041	-0.028	0.088	0.979
NGS	0.064	0.013	-0.003	0.000	0.825	-	0.039	-0.022	0.853	0.917
GWP	0.049	0.026	-0.003	0.000	0.754	0.051	-	-0.007	0.820	0.869
TGW	-0.046	0.031	-0.002	0.000	0.548	0.030	0.008	-	0.615	0.569
Corrected R^2=0.963										
Dependent variable: grain yield										

** $P < 0.01$; * $P < 0.05$; Abbreviation: PH – plant height, SL – spike length, SW – spike weight, GWS – grain weight per spike, NGS – number of grains per spike, GWP – grain weight per plant, TGW – thousand grain weight, GY – grain yield

4. Conclusions

Ecological variance had a significantly higher share in the phenotypic variation of spike weight, grain weight per spike, grain weight per plant, and grain yield, compared to genotypic variance. On the other hand, phenotypic variation of plant height and spike length was more influenced by the factor of genotype. Grain yield and all spike elements was in positive association at the genotypic and phenotypic level, on both examined soil types. The presence of a significant positive correlation between grain yield and plant height in genotypes grown on Solonetz is a result of the fact that stressful environmental conditions reduced values of all traits in all analyzed genotypes, where genotypes could not show their genetic potential. In favorable environmental conditions, grain weight per spike, followed by number of grains per spike and spike weight, had the greatest positive direct effect on grain yield. Therefore, these yield components are considered a good criterion in breeding for higher grain yield in favorable conditions. Under salinity stress conditions, grain weight per spike had a significant and positive direct impact on grain yield. Also, in abiotic stress conditions, all other analyzed traits had a significant indirect effect mainly through the grain weight per spike on grain yield. Thus, indirect selection of grain weight per spike will affect the increase in grain yield in stressful environmental conditions.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References

Ajmal, S.U., Zakir, N., Mujahid, M.Y. (2009). Estimation of genetic parameters and character association in wheat. *Journal of Agricultural and Biological Science*, 1(1), 15-18.

Amin, M.F., Hasan, M., Barma, N.C.D., Rahman, M.M., Hasan, M.M. (2015). Variability and heritability analysis in spring wheat (*Triticum aestiv*um L.) genotypes. *Bangladesh Journal of Agricultural Research*, 40(3), 435-450.

Ashfaq, M., Khan, A.S., Ali, Z. (2003). Association of morphological traits with grain yield in wheat (*Triticum aestivum* L.). *International Journal of Agriculture and Biology*, 5(3), 262-264.

Banjac, B. (2015). *Yield potential and adaptation of wheat to stressful conditions of solonetzes* (Doctoral dissertation). Faculty of agriculture, University of Novi Sad (in Serbian)

Baye, A., Berihun, B., Bantayehu, M., Derebe, B. (2020). Genotypic and phenotypic correlation and path coefficient analysis for yield and yield-related traits in advanced bread wheat (Triticum aestivum L.) lines. Cogent Food and Agriculture, 6(1), 1752603.

Belić, M., Nešić, Lj., Dimitrijević, M., Petrović, S., Ćirić, V., Pekeč, S., Vasić, J. (2012). Impact of reclamation practices on the content and qualitative composition of exchangeable base cations of the solonetz soil. *Asutralian Journal of Crop Science*, 6(10), 1471-1480.

Birhanu, M., Sentayehu, A., Alemayehu, A., Ermias, A., Dargicho, D. (2016). Genetic variability, heritability and genetic advance for yield and yield related traits in bread wheat (*Triticum aestivum* L.) genotypes. *Global Journal of Science Frontier Research*, 16(7),12-15.

Branković, G., Dodig, D., Knežević, D., Kandić, V., Pavlov, J. (2015). Heritability, genetic advance and correlations of plant height, spike length and productive tillering in bread wheat and durum wheat. *Contemporary Agriculture,* 64(3-4), 150-157.

Comstock, R.R., Robinson, H.F. (1952). Genetic parameters, their estimation and significance. Proceedings of the 6th international Grassland Congress, 1, Nat. publ. Co., Wash., D.C., U.S.A., 248-291.

Crouch, J.H., Payne, T.S., Dreisigacker, S., Wu, H., Braun, H.-J. (2009). Improved discovery and utilization of new traits for breeding. In: Dixon, J., Braun, H. J., Kosina, P. Crouch, J. (Eds.), *Wheat facts and futures,* CIMMYT D. F., Mexico, 42-51.

Desheva, G., Cholakov, T. (2014). Variability, heritability and genetic progress for some yield components in common winter wheat genotypes (*Triticum aestivum* L.). *Genetics and Plant Physiology*, 4(3-4), 191-200.

Dewey, D.R., Lu, K.H. (1959). A correlation and *path* coefficient analysis of components of crested wheatgrass seed production. *Agronomy Journal*, 51, 515-518.

Dimitrijević, M., Petrović, S., Banjac, B. (2013). Variation of phenotypic markers of wheat yield on alkalized soil. *Selekcija i semenarstvo*, 19(2), 1-9. (In Serbian)

Ebrahimnejad, S., Rameeh, V. (2016): Correlation and factor analysis of grain yield and some important component characters in spring bread whear genotypes. *Cercetări Agronomice în Moldova*, 49, 1(165), 5-15.

El-Mohsen, A.A.A., Hegazy, S.R.A., Taha, M.H. (2012). Genotypic and phenotypic interrelationships among yield and yield components in Egyptian bread wheat genotypes. *Journal of Plant Breeding and Crop Science*, 4(1), 9-16.

Falconer, D.S. (1989). *Introduction to quantitative genetics* (3rd Edition), Burnt Mill, Harlow, Essex, England: Longman, Scientific and Technical, New York: Wiley, 438 p.

FAOSTAT (2021). Available online: http://www.faostat.fao.org/ (accessed on 22 May 2021)

Giraldo, P., Benavente, E., Manzano-Agugliaro, F., Gimenez, E. (2019). Worldwide research trends on wheat and barley: a bibliometric comparative analysis. *Agronomy*, 9, 352.

Grčak, M., Grčak, D., Župunski, V., Jevtić, R., Lalošević, M., Radosavac, A., Kondić, D., Živić, J., Paunović, A., Zećević, V., Mićanović, D., Knežević, D. (2019). Effect of cereals +pea intercropping on spike index of spring wheat, triticale, oat and pods index of pea. *Acta Agriculturae Serbica*, 24(48),167-180.

Hadžić, V., Nešić, Lj., Belić, M., Furman, T., Savin, L. (2002). Land potential of Serbia. *Traktori i mašine*, 7(4), 43-51. (In Serbian)

IBM SPSS Statistics, Trial Version 22.0. Available online: https://www.ibm.com/ (accessed on 17 February 2021)

Iqbal, M.A., Rahim, J., Naeem, W., Hassan, S., Khattab, Y., El-Sabagh, A. (2021). Rainfed winter wheat (*Triticum aestivum* L.) cultivars respond differently to integrated fertilization in Pakistan. *Fresenius Environmental Bulletin*, 30(4), 3115-3121.

Kaya, Y., Akcura, M. (2014). Effects of genotype and environment on grain yield and quality traits in bread wheat (*T. aestivum* L.). *Food Science and Technology*, 34(2), 386-393.

Khan, G.H., Shikari, A.B., Wani, S.H., Vaishnavi, R. (2017). Variability parameters in wheat – a review. *International Journal of Pure & Applied Bioscience*, 5(4), 651-662.

Khan, M.H., Dar, A.N. (2010): Correlation and Path coefficient analysis of some quantitative traits in wheat. *African Crop Science Journal*, 18(1), 9-14.

Knežević, D., Zečević, V., Đukić, N., Dodig, D. (2008). Genetic and fenotypic variability of grain mass per spike of winter wheat genotypes (*Triticum aestivum* L.). *Kragujevac Journal of Science*, 30, 131-136.

Kneževiž, D., Zečević, V., Kondić, D., Marković, S., Šekularac, A. (2014). Genetic and phenotypic variability of grain mass per spike in wheat under different dose od nitrogen nutrition. *Turkish Journal od Agricultural and Natural Sciences*, Special Issue, 1, 805-810.

Knežević, D., Radosavac, A., Zelenika, M., (2015). Variability of grain weight per spike of wheat grown in different ecological conditions. *Acta Agriculturae Serbica*, 20(39), 85-95.

Knežević, D., Mićanović, D., Zečević, V., Branković, G., Kondić, D., Radosavac, A., Matkovic Stojsin, M., Srdić, S., Urošević, D. (2018). Variability of length of spike and number of spikelets per spike in wheat (*Triticum aestivum* L.). *Book of proceedings of the IX International Scientific Agriculture Symposium "Agrosym 2018*", Jahorina, October 04-07, 2018, 673-677.

Knežević, D., Laze, A., Paunović, A., Đurović, V., Đukić, N., Valjarević, D., Kondić, D., Mićanović, D., Živić, J., Zečević, V. (2020). Approaches in cereal breeding. *Acta Agriculturae Serbica,* 25(50), 179-186.

Madić, M., Paunović, A., Knežević, D., Zečević. V. (2009). Grain yield and yield components of two-row winter barley cultivars and lines. *Acta Agriculturae Serbica*, 14(27), 17-22.

Madić, M., Knežević, D., Đurović, D., Paunović, A., Stević, V., Tomić, D., Đekić, V. (2019). Assessment of the correlation between grain yield and its components in spring barley on an acidic soil. *Acta Agriculturae Serbica,* 24(47), 41-49.

Marković, M.S., Knežević, D., Nešović. M.N., Djukić, H.N. (2021). Heat-induced accumulation of proline and yield components in genetically divergent cereal varieties. *Genetika*, 53(1), 219-233.

Matković Stojšin, M., Zečević, V., Petrović, S., Dimitrijević, M., Mićanović, D., Banjac, B., Knežević, D. (2018). Variability, correlation, path analysis and stepwise regression for yield components of different wheat genotypes. *Genetika*, 50(3), 817-828.

Matković Stojšin, M., Petrović, S.,, Sucur Elez, J., Malencić, Dj., Zečević, V., Banjac, B., Knežević, D. (2022). Effect of

Salinity Stress on Antioxidant Activity and Grain Yield of Different Wheat Genotypes. *Turkish Journal of Field Crops*, 27(1),33-40

McIntosh, R.A., Dubcovsky, J., Rogers, W.J., Morris, C., Appels, R., Xia, X.C. (2015). Catalogue of gene symbols for wheat: 2015-2016. Supplement. Available at: http://shigen.nig.ac.jp/wheat/komugi/genes/macgene/supplement2015.pdf

Meles, B., Mohammed, W., Tsehaye, Y. (2017). Genetic variability, correlation and *path* analysis of yield and grain quality traits in bread wheat (*Tritium aestivum* L.) genotypes at Axum, Northern Ethiopia. *Journal of Plant Breeding and Crop Science*, 9(10), 175-185.

Munir, M., Chowdhry, M.A., Malik, T.A. (2007). Correlation studies among yield and its components in bread wheat under drought conditions. *International Journal of Agriculture and Biology*, 9(2), 287-290.

Nukasani, V., Potdukhe, N.R., Bharad, S., Deshmukh, S., Shinde, S.M. (2013). Genetic variability, correlation and *path* analysis in wheat. *Journal of Wheat Research*, 5(2), 48-51.

Ojha, R., Sarkar, A., Aryal, A., Rahul, K.C., Tiwari, S., Poudel, M., Pant, K.R., Shrestha, J. (2018). Correlation and path coefficient analysis of wheat (*Triticum aestivum* L.) genotypes. *Farming and Management*, 3(2), 136-141.

Petrović, S., Dimitrijević, M., Banjac, B. (2016). Variability and interrelationship of wheat yield components on solonetz and chernozem. *Annals of Agronomy*, 40(1), 47-52. (In Serbian)

Petrović, S., Dimitrijević, M., Belić, M., Banjac, B., Vukosavljev, M. (2009). Spike stability parameters in wheat grown on solonetz soil. *Genetika*, 41(2), 199-205.

Petrović, G., Karabašević, D., Vukotić, S., Mirčetić, V., Radosavac, A. (2020). The impact of climate change on the corn yield in Serbia. *Acta Agriculturae Serbica*, 25(50), 133-140.

Rahman, M.A., Kabir, M.L., Hasanuzzaman, M., Rahman, M.A., Rumi, R.H., Afrose, M.T. (2016). Study of variability in bread wheat (*Triticum aestivum* L.). *International Journal of Agronomy and Agricultural Research*, 8, 66-76.

Republic Hydrometeorological Institute of Serbia. Available online: http://www.hidmet.gov.rs/ (Accessed on 15 April 2021)

Rohani, S.K., Marker, S. (2016a). Correlation and *path* coefficient analysis of some quantitative traits in wheat (*Triticum aestivum* L.). *International Journal of Multidisciplinary Research and Development*, 3, 15-20.

Rohani, S.K., Marker, S. (2016b). Evaluation of genetic variability for some quantitative traits in wheat (*Triticum aestivum* L.). *International Journal of Multidisciplinary Research and Development*, 3, 12-14.

Roljević Nikolić, S., Knežević, D., Paraušić, V. (2021). Modeling the relationship between the characteristics of agricultural holdings and presence of organic farming. *Acta Agriculturae Serbica,* 26(52), 123-130.

Sabit, Z., Yadav, B., Rai, P.K. (2017). Genetic variability, correlation and *Path* analysis for yield and its components in F5 generation of bread wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry*, 6(4), 680-687.

Shankarrao, B.S., Mukherjee, S., Pal, A.K., De, D.K. (2010). Estimation of variability for yield parameters in bread wheat (*Triticum aestivum* L.) grown in Gangetic West Bengal. *Electronic Journal of Plant Breeding*, 1(4), 764-768.

Shewry, P.R. (2018). Do ancient types of wheat have health benefits compared with modern bread wheat? *Journal of Cereal Science*, 79, 469-476.

Shewry, P.R., Hey, S.J. (2015).The contribution of wheat to human diet and health. *Food Energy Security*, 4(3), 178-202.

Singh, B., Upadhyay, P.K. (2013). Genetic variability, correlation and path analysis in wheat (*Triticum aestivum* L.). *International Journal of Plant Sciences*, 8(2), 230-235.

Singh, R.K., Chaudhary, B.D. (1985). *Biometrical methods in quantitative genetic analysis*. Kalyani Publishers, New Delhi, Ludhiana, India, 39-78.

Yagdi, K., Sozen, E. (2009). Heritability, variance components and correlations of yield and quality traits in durum wheat (*Triticum durum* Desf.). *Pakistan Journal of Botany*, 41(2), 753-759.

Zečević, V., Boskovic, J., Dimitrijević, M., Petrović, S. (2010). Genetic and phenotypic variability of yield components in wheat (*Triticum aestivum* L.). *Bulgarian Journal of Agricultural Science*, 16(4), 422-428.

Zečević, V., Knežević, D., Mićanović, D. (2004). Genetic correlations and *path* coefficient analysis of yield and quality components in wheat. *Genetika*, 36(1), 13-21.