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INTERRELATIONSHIP OF GRAIN FILLING RATE AND OTHER TRAITS THAT AFFECT THE YIELD OF WHEAT *(TRITICUM AESTIVUM* L.*)*

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ABSTRACT

Knowledge of the relationship between grain yield and yield components is very important for efficient breeding for yield, considering that it is the most important economic trait and has a very complex mode of inheritance and low heritability. The aim of this study was to determine the correlation and the direct and indirect effects of grain filling rate and the traits that affect the yield of wheat. The experiment was conducted during two growing seasons 2008/2009 and 2009/2010 with 20 different varieties of common wheat. Weight and number of grains per spike, 1000 grain weight, plant height, duration and rate of grain filling were analyzed. Correlation coefficients were calculated as well as the direct and indirect effects of these traits on grain yield. Highly significant positive correlation was found between the rate of grain filling and 1000 grain weight, grain weight per spike and number of grains per spike. Also, a significant positive correlation was found between 1000 grain weight and grain weight per spike. According to the path analysis, the duration of grain filling, grain filling rate and grain weight per spike showed a positive but not significant direct effect on grain yield. The plant height had the greatest direct negative effect on yield. According to the results, it was concluded that traits such as grain filling rate together with plant height, might be of importance as criteria in the selection of future breeding for yield in the particular agro-climatic conditions.

Key words: wheat, correlation, path analysis, yield, grain filling rate.

INTRODUCTION

Increasing yield is one of the most important goals of wheat breeding. Wheat yield is complex in nature and therefore it is easier to breeding for yield through traits with simpler genetic background. Numerous studies suggest that plant height, grain weight per spike, number of grains per spike and 1000 grain weight are the most important traits that affects the yield of wheat (Simane et al., 1993; Royo, 1997; Royo and Tribo, 1997; Kumar and Hunshal, 1998; Denčić et al., 2000; Garcia et al., 2003). The final grain yield also depends on the rate and duration of each phase of plant development, including grain filling. Grain capacity to accumulate dry matter is determined immediately after flowering, and is largely dependent on the formation of endosperm cells (Brocklehurst, 1977). Detailed understanding of the grain filling process and its impact on the maturity period and the final grain weight can help in breeding efforts to increase yield.

When selecting desired genotypes for breeding programs, it is important to know the nature and extent of variation present in the breeding material. In addition, it is important to establish the relationship of each trait with the yield and its direct and indirect effects on yield (Hristov et al., 2011). Genotypic and phenotypic correlations are important for determining the correlation between the properties that contribute to increased yield (Akram et al., 2008). Introducing correlation between traits is of great importance for the selection process that takes place within the breeding program. Of the many methods that can be used for this purpose, analysis of correlation coefficients is one of the most widely used (Hristov et al., 2011). Although the correlation coefficients are important for determining the properties that directly affect the yield, however they are insufficient to determine the indirect effects of these traits on grain yield (Bhatt, 1973; Mebrahtu et al., 1991). The indirect effect is common in cereals because of properties that are formed

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at different stages of development, influencing each other, especially where previously established properties influence on later formed (Doffing and Knight, 1992).

Path analysis is a statistical method that provides data to determine the interrelationships of different traits that affect yield. Using it we can determine which traits have a significant effect on grain yield, so that they can help in establishing selection criteria. Path analysis allows the distribution of correlation coefficients in their components, where one component is the coefficient that measures the direct effect of the dependent variable over the independent variable, and the second component is the indirect effect on the dependent variable over the independent variable by some other dependent variables (Dewey and Lu, 1959).

The aim of this study was to determine correlation and the direct and indirect effect of grain weight per spike, number of grains per spike, 1000 grain weight, plant height, duration and rate of grain filling on grain yield in wheat.

MATERIAL AND METHODS

During two seasons 2008/2009 and 2009/2010, a trial was conducted at the Experimental Field of the Institute of Field and Vegetable Crops – Novi Sad, Serbia. In order to better understand the meteorological conditions during the growing season of wheat in these years, air temperatures and precipitation per month were analyzed during the growing seasons.

Meteorological data for both growing seasons were obtained from the hydro-meteorological station Rimski Sancevi, which is located near the experimental field and are presented in Table 1.

Table 1. Temperature and precipitation values for the growing seasons 2008/2009 - 2009/2010 and multi-year averages for that region

Months	2008/2009		2009/2010		Multi-year averages	
	Temperatures (^{0}C)	Precipitation (mm)	Temperatures (^{0}C)	Precipitation (mm)	Temperatures (^{0}C)	Precipitation (mm)
October	13.2	18.4	11.7	25.6	11.7	47.6
November	7.6	57.5	8.0	63.1	5.9	51.2
December	3.7	43.1	3.5	97.4	1.5	46.2
January	-1.5	40.8	-0.6	76.2	-0.5	37.3
February	2.1	47.3	1.8	65.7	1.8	31.8
March	6.7	34.4	6.8	38.7	6.4	37.1
April	14.6	3.6	12.3	63.7	11.4	48.8
May	18.6	50.4	16.9	113.7	16.8	59.6
June	19.6	127.2	20.2	171.8	19.9	85.7
Average	9.4		8.9		8.3	
Total		422.7		715.9		615.5

For this study, 20 genotypes of winter wheat (*Triticum aestivum* L.) were selected. Selected genotypes are different in origin, from Serbia (11), Croatia (1), Hungary (2), Austria (1), Romania (1), France (1), Turkey (1), Mexico (1) and the United States (1). The experimental design was a randomized block design with three replications. The plot size was 2 m^2. Each genotype was sowed in 6 rows with spacing of 15 cm between rows. Sowing rate was 450 viable seeds per m^2. Standard agricultural practices were used.

Grain weight per spike, number of grains per spike and plant height were measured at physiological maturity. From each replication 4 samples (plants) were measured and the mean value was calculated. Samples were taken from the middle rows. Grain yield per ha and 1000 grain weight were determined after harvest.

To determine the grain filling parameters (duration (GFD) and rate (R)), sampling was initiated ten days after anthesis and continued at 3-day intervals until harvest maturity (13% moisture in grain). Random samples of 10 spikes per plot were harvested on each sampling date. Five grains from the middle of each of the l0 spikes were removed and bulked. The 50 grains were oven dried at 80^0C for 48 h and subsequently weighed to determine dry weight. Additional plots were planted next to the existing ones, the same randomized block design with three replications, because taking spikes for determining the parameters of grain filling could have an impact on the yield calculation after the harvest.

Dry matter accumulation over time was expressed as a function of accumulated growing degree days (GDD) from anthesis. Accumulated GDD were calculated by summation of daily degree days (Tn). Daily degree days were determined by: Tn = ((Tmax + Tmin)/2) – Tb), where: Tn = daily degree day, Tmax = maximum daily temperature, Tmin = minimum daily temperature, and Tb = base temperature. Below the base temperature it is assumed that plants will be unable to develop. In this study a base temperature of 5^0C was used (Yasuda and Shimoyama, 1965). The upper and lower limits of maximum and minimum temperatures were set at 35^0C and Tb, respectively. Grain filling rate was calculated as ratio of final grain dry weight and grain filling duration (GFD = cumulated degree days) and it is expressed in mg dry matter $^0C^{-1}$ grain^{-1}.

Coefficients of variation and correlation for the observed traits were calculated. The significance of correlation was determined by t-test. For a more detailed analysis of the mutual influences, path analysis was performed, and the significance of the main effects was determined by F-test. The correlation coefficients and path analysis were calculated by the method of Snedecor and Cochran (1987), and Dewey and Lu (1959).

RESULTS AND DISCUSSION

Variability of traits such as yield, number of grains per spike, plant height and grain filling duration was greater among genotypes, while the values of variation coefficients between the years were higher for grain weight per spike, 1000 grain weight and grain filling rate (Table 2).

Table 2. Genotypic and environmental mean values for the 7 investigated traits of 20 varieties of common wheat grown during the 2008-2010

Traits	Variation due to					
	Genotype (n=20)	CV (%)	Years (n=2)	CV (%)	Average (n=40)	CV (%)
Yield (t/ha)	3.3-9.4	22	6.5-6.6	2	6.5	26
Grain weight/spike (g)	1.4-2.5	19	1.5-2.3	27	1.9	30
No grain/spike	33.5-63.8	17	44.9-52.3	11	48.5	21
1000 grain weight (g)	33.1-47.1	11	34.3-43.2	16	38.8	18
Plant height (cm)	67.7-114.2	14	82.1-86	3	84.1	14
Rate (mg dm $^0C^{-1}$ grain^{-1})	0.0438-0.0678	11	0.05-0.06	13	0.0553	16
GFD (^{0}C)	641.4-751.6	4	683-710.5	3	696.7	5

The results show that material chosen for this study had significant genetic variation. Mean values of the analyzed traits for 20 wheat varieties involved in this study are shown in Table 3.

Table 3. Mean values of the analyzed traits for 20 varieties of common wheat grown during the 2008-2010

Varieties	Yield (t/ha)	Grain weight/spike (g)	No grain/ spike	1000 grain weight (g)	Plant height (cm)	Rate (mg dm $^0C^{-1}$grain^{-1})	GFD (^0C)
Banatka (RS)	3.32	1.43	33.52	41.31	114.20	0.0643	641.35
Bankut 1205 (HU)	4.04	1.54	38.00	39.34	112.50	0.0586	660
Cipovka (RS)	6.14	1.92	51.00	38.25	84.65	0.0514	721.05
Dragana (RS)	7.81	1.55	36.85	41.55	91.49	0.0600	716.2
Simonida (RS)	7.86	2.20	52.84	42.35	84.04	0.0580	730
NS-40S (RS)	9.36	2.14	51.33	42.17	84.53	0.0601	701.16
Zvezdana (RS)	7.18	1.78	41.02	42.88	71.00	0.0561	716
Prima (RS)	7.30	1.82	44.67	40.77	71.15	0.0549	751.6
Nevesinjka (RS)	6.50	2.54	63.18	38.80	83.44	0.0552	694.5
Venera (RS)	6.40	1.98	45.17	43.91	89.17	0.0597	732
Siete Ceros (MX)	4.16	1.77	50.02	35.16	86.44	0.0500	701.15
Apache (FR)	7.16	1.67	47.85	35.31	74.20	0.0525	645.65
Balaton (AT)	6.36	2.45	51.17	47.13	79.32	0.0678	676.3
Sana (HR)	7.44	2.23	58.50	37.44	75.60	0.0555	681.3
Sloga (RS)	5.44	2.14	63.82	33.71	67.70	0.0488	686
GK-Zugoly (HU)	7.50	1.47	44.50	33.11	81.10	0.0482	683
NS3-5299/2 (RS)	6.52	1.41	45.35	30.65	82.20	0.0438	689.6
Aksel 2000 (TR)	6.58	1.67	47.34	34.42	86.80	0.0497	688.8
Jackson (US)	6.41	1.62	45.35	35.60	82.20	0.0496	716.2
Alex (RO)	7.18	2.50	59.35	41.90	80.30	0.0610	701.7
Average	6.53	1.89	48.54	38.8	84.10	0.0553	696.7

The correlations between the studied traits are shown in Table 4. Grain weight per spike was in high significant positive correlation with the number of grains per spike, 1000 grain weight and grain filling rate. The high positive correlation of grain filling rate with 1000 grain weight and grain weight per spike indicates that genotypes with higher grain filling rate usually had a higher grain weight. Gebeyehou et al. (1982) reported a similar relationship between grain weight and rate of grain filling. Wiegand and Cuellar (1981) found that the final grain weight is proportional to grain filling rate, because the duration of the grain filling is greatly influenced by temperature stress in terms of terminal stress.

Having this in mind, many authors suggest that the selection of genotypes with high levels of grain filling rate could be a successful strategy for increasing yield in breeding programs (Van Sanford, 1985; Bruckner and Frohberg, 1987; Knott and Gebeyehou, 1987).

Table 4. The correlation coefficients between observed traits of wheat

Traits	r	Grain weight/ spike	No. grain/ spike	1000 grain weight	Plant height	Rate	GFD	Yield
Grain weight/spike	r	-	0.784**	0.503*	-0.355	0.521*	0.200	0.284
No. grain/spike	r		-	-0.124	-0.561*	-0.061	0.097	0.235
1000 grain weight	r			-	0.166	0.898**	0.242	0.158
Plant height	r				-	0.304	-0.390	-0.565**
Rate	r					-	-0.032	0.028
GFD	r						-	0.437

*P<0.05l; **P<0.01.

Grain filling duration was positively but not significantly correlated with grain yield (Table 4). These results are in agreement with those obtained by Wardlaw (1970), Weigand and Cuellar (1981), who stated that the duration of the grain filling is positively correlated with grain yield, both in modern wheat varieties and in the old indigenous populations, under conditions of adequate light and optimal temperatures.

Plant height affects yield, changing the relationship between vegetative and generative mass, which is reflected in the harvest index and other characteristics of the vegetative part of the plant, affecting the translocation of nutrients from the vegetative to the generative organs of plants, and this is reflected in grain yield (Borojević and Borojević, 2005). Plant height was in significant negative correlation with yield. This was expected, because shorter varieties have better translocation of assimilates to the generative organs compared with taller varieties. A negative significant correlation was also found between plant height and number of grains per spike which is consistent with the results obtained by Ramazan (2009).

Grain filling parameters, rate and duration were in not significant negative correlation r=-0.032 (Table 4). Brdar et al. (2006) found that the duration and rate of grain filling are correlated negatively, because rapid thermal unit accumulation during grain filling reduces the duration and increases the rate. This happens to a certain point, beyond which compensation (correlation) is no longer achievable.

The negative correlation between grain yield and plant height, can lead to incorrect choice in selection, because the question is whether this is due to the negative correlation between these properties or it comes from pleiotropic effect. Properties such as the number of grains per spike, grain weight per spike and 1000 grain weight were positively but not significantly correlated with yield (Table 4).

Our results show that the properties that affect grain yield have a direct or indirect effect on grain yield, or both of these effects. Many breeders have used path analysis, to help them to identify properties that can be used as a selection criteria in breeding for yield (Dewey and Lu, 1959; Ahmed et al., 2003; Garcia et al., 2003). Direct and indirect effects of the studied traits on grain yield are shown in Table 5.

Table 5. Path coefficients – direct (bold) and indirect effects of observed traits on yield

Traits	Direct effects	Grain.weight /spike	No. grain/spike	1000 grain weight	Plant height	Rate	GFD
Grain weight/spike	0.135	-	-0.179	-0.029	0.217	0.098	0.043
No. grain/spike	-0.229	0.105	-	0.007	0.342	-0.011	0.021
1000 grain weight	**-0.057**	0.068	0.028	-	-0.101	0.169	0.052
Plant height	**-0.610***	-0.048	0.129	-0.010	-	0.057	-0.084
Rate	**0.188**	0.070	0.014	-0.051	-0.185	-	-0.007
GFD	**0.215**	0.027	-0.022	-0.014	0.238	-0.006	-

*P<0.05; **P<0.01; $R^2 = 0.42$.

The largest positive but not significant effect on grain yield was found for the duration of grain filling (0.215), followed by the grain filling rate (Table 5). Grain weight per spike, one of the traits that had largest influence on the yield, showed a positive direct effect on grain yield and a negative indirect effect via number of grains per spike and 1000 grain weight. The value of correlation coefficient between grain weight per spike and grain yield was lower than expected. 1000 grain weight and number of grains per spike had a direct negative effect on grain yield. These results are not in agreement with those obtained by Ramazan (2009), who found that 1000 grain weight and number of grains per spike had a direct positive effect on grain yield. Disagreement with these results is probably due to differences between the genotypes and the conditions in which the experiment was conducted. Plant height had a significant negative direct effect on grain yield (-0.610), and an indirect positive effect through the duration of grain filling (GFD) and the number of grains per spike.

Grain yield can be analyzed in terms of three primary yield components: number of spikes per unit land area, number of grains per spike and grain weight per plant (Sofild et al., 1977). These components develop sequentially, with later-developing components under control of earlier developing ones (Dofing and Knight, 1992). Fertilization and pollination have a large influence on these traits (Mladenov et al., 2011). The negative direct effect of the number of grains per spike on grain yield, which was established in this study, is in agreement with the results obtained by Koksal (2009), but not in accordance with the results obtained by Mladenov et al. (2011), De Pauw and Shebeski (1973), and Pochaba and Wegrzyn (2001).

Significant negative direct effect of plant height on grain yield is not in accordance with the results obtained by Pochaba and Wegrzyn (2001), Kashif and Khaliq (2004), because this trait in their study showed a positive correlation with grain yield.

CONCLUSIONS

Based on the obtained results it can be concluded that genetic variability existed for all properties in the material used for this study. Grain filling duration was not significantly correlated with grain yield, and it could be concluded that the extension of the period of grain filling is not a simple strategy that can be used to increase the yield. A significant positive correlation was found between rate of grain filling, grain weight per spike and 1000 grain weight. According to the results, in the analyzed germplasm grain weight was more associated with grain filling rate than with the duration of grain filling. Using selection for higher grain filling rate should result in higher grain weight, because the relation between these traits was strong. Because duration and rate of grain filling were not correlated, increasing grain weight by increasing the rate of grain filling should be possible without undesirable modification of grain filling duration. Plant height was in high significant negative correlation with grain yield and number of grains per spike, and also showed the highest direct effect on grain yield, but in a negative direction. According to the results of the present study, developing cultivars with high grain filling rate and short stem should be an appropriate strategy to improve grain yield in this agro-climatic area.

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