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Correlation and path coefficient analyses of phenological traits, yield components and quality traits in wheat[1]

Correlação e coeficiente de trilha de características fenológicas, componentes de rendimento e de qualidade em trigo

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HIGHLIGHTS:
The results showed that with certain genotypes, different criteria should be considered for grain yield improvement in different conditions.
The highest grain yield was obtained for 350 and 400 (seeds per m²) across all planting dates and genotypes.
The delay in planting reduced most traits expected protein concentration and gluten index.

ABSTRACT: This study was conducted to characterize the phenological traits, yield components and quality traits affecting wheat grain yield. Three wheat genotypes were evaluated during three planting dates (November 20, December 5, and December 20) and at four seeding densities 300, 350, 400 and 450 seeds per m^2 for two years. Multivariate analyses were conducted based on the interaction effects of planting date and seeding density (PS), planting date and genotype (PG) and seeding density and genotype (SG) mean values. The results of correlation analysis showed that grain yield was significantly and positively correlated with biomass yield (0.91**), days to spiking (0.81**), days to anthesis (0.83**), and days to maturity (0.57*) for PS; with biomass yield (0.94**), days to spiking (0.87**), days to anthesis (0.75*), and harvest index (0.83**) for PG; with gluten index (0.73**), harvest index (0.68*), and 1000-grain weight for SG. Path analysis revealed that biomass yield for PS and PG, harvest index for PG and SG, and gluten index for SG exhibited the highest positive direct effect. Stepwise regression analysis also revealed important effect of biomass yield, harvest index, and days to maturity for improving grain yield in different agronomical conditions.

Key words: *Triticum aestivum*, multivariate analyses, planting date, seeding densities

RESUMO: Este estudo foi conduzido para caracterizar características fenológicas, componentes do produção e características de qualidade que afetam o rendimento de grãos do trigo. Três genótipos de trigo foram avaliados em três épocas de plantio (20/11, 05/12 e 20/12) e em quatro densidades de semeadura (PS) de 300, 350, 400 e 450 sementes por m^2 por dois anos. As análises multivariadas foram realizadas com base nos efeitos de interação dos valores médios da data de plantio e PS, data de plantio e genótipo (PG), e PS e valores médios de genótipo (SG). Os resultados da análise de correlação mostraram que o rendimento de grãos foi significativamente e positivamente correlacionado com o rendimento de biomassa (0,91**), dias para 'spiking' (0,81**), dias para antese (0,83**) e dias para maturidade (0,57*) para PS; com rendimento de biomassa (0,94**), dias para 'spiking' (0,87**), dias para antese (0,75*) e índice de colheita (0,83**) para PG; com índice de glúten (0,73**), índice de colheita (0,68*) e peso de 1000 grãos para SG. A análise de trilha revelou que rendimento de biomassa para PS e PG, índice de colheita para PS e PG, e o índice de glúten para SG exibiram o maior efeito direto positivo. A análise de regressão 'stepwise' também revelou importante efeito do índice de colheita de rendimento de biomassa e dias até a maturidade para melhorar o rendimento de grãos em diferentes condições agronômicas.

Palavras-chave: pão de trigo, análises multivariadas, data de plantio, densidades de semeadura

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Introduction

Wheat (*Triticum aestivum* L.) is a cereal staple food crop and the most important crop cultivated in the world (Hannachi et al., 2013; Yadi et al., 2016). Its unique gluten content and associated bread-making properties assure its relevance in society (Rathod et al., 2019).

Management practices such as planting date, seeding density, and cultivar selection play a very important role in determining the grain yield and end-use quality of bread wheat (Yadi et al., 2016).

Different varieties of wheat vary in the range of adaptation, potential yield, growth type, and maturity group (NourMohamadi et al., 2015). Optimum plant densities vary greatly between areas, climatic conditions, sowing time, and varieties (Zecevic et al., 2014; Ghassemi et al., 2016).

Investigating the relationships of the traits at different planting dates and densities provides a clear idea of which characteristics can be improved in different environmental conditions.

Wheat grain yield is determined by the integration of many characteristics that affect plant growth throughout the growing period, and each characteristic changes to a different extent and direction under the effect of environmental factors (SadeghGolMoghadam et al., 2011; Rymuza et al., 2012; Farhadiannezhad et al., 2019). Therefore, toward a clear understanding of the type of plant traits, correlation and path coefficient analysis are logical steps (Kashif & Khaliq, 2004). Correlation studies along with path coefficient analysis offer a better understanding of the relationship between different traits and grain yield (Sharma, 1995). Correlation is valuable for revealing the magnitude and direction of the relationship between several yield component characteristics and grain yield. However, the path coefficient, is a standardized partial regression coefficient that identifies the direct effect of the predictor variable on its response variable, and the second component is the indirect effect of the predictor variable (Rajput, 2019).

Indirect selection through traits related to grain yield is among the most important strategies in wheat breeding (Garcia Del Moral et al., 2003). Due to the significant and positive correlation of wheat grain yield with traits such as plant height, spikelets per spike, and spike length, these traits can be used as indirect selection criteria for grain yield improvement (Ohja et al., 2018; Devesh et al., 2019).

Multiple statistical techniques of agronomic traits may be informative in a wheat breeding program because agronomic traits are a reflection of gene effects. The objective of this investigation was to associate some agronomic traits of wheat using correlation, path coefficient, and stepwise regression analyses in different crop management conditions including PS, PG, and SG, which afford valuable information selection criteria for breeding new high yielding wheat cultivars.

Material and Methods

During 2016-2018, field experiments were conducted at Baikola Agricultural Research Station, located in Mazandaran, Iran (36° 46' N latitude and 53° 13' E longitude, 15 m above sea level). The experimental design comprised in randomized blocks in a split-split plot arrangement of treatments with three repetitions. The main plots were cultivated on the following planting dates, P_1: November 20, P_2: December 5, and P_3: December 20, the subplots utilized the following seeding densities: S_1:300, S_2:350, S_3:400, and S_4:450 (seeds per m^2), and the sub-sub plots utilized three wheat genotypes (G) including Morvarid, Gonbad, and Ehsan with enough genetic variation for days to maturity, yield components, and grain yield. The wheat cultivars were seeded by hand. Each experimental plot consisted of six rows with 6.6 m length at 20 cm spacing, with a space of 1.5 m between two sequential blocks serving as a corridor. The two sidelines were considered as margins, and four middle lines were used to determine all the traits. In the previous year of each experiment, the field experiment was cultivated with Canola. The soil physico-chemical properties were analyzed by sampling at depths of 0-30 cm and water analysis was conducted in a laboratory (Table 1).

Soil samples were found to have 45 kg ha^{-1} mineral nitrogen (N) in the upper 30 cm depth. The experiment received 50 kg ha^{-1} of P (111 kg of superphosphate with 45% of P_2O_5), 75 kg ha^{-1} of K (150 kg of potassium sulfate with 50% of K_2O), and 100 kg ha^{-1} of N (217 kg of urea with 46% of N).

At sowing, the pre-plant fertilizer including concentrated superphosphate (P), potassium sulfate (K), and a third of the urea (N) were broadcast and incorporated into the soil. The remaining urea fertilizer was divided into two equal parts; one part was topdressed at tillering and the other part was topdressed before the "boot stage". All plant protection measurements were adopted to control the attack of insects.

Traits such as days to spiking, days to anthesis, days to maturity, 1000-grain weight (g), grain yield (kg ha^{-1}), protein (%), gluten index (%), and biomass yield (kg ha^{-1}) were observed in each sub-sub plot. Harvest index was determined by using Eq. 1, according to White & Wilson (2006).

$$HI(\%) = \frac{Y}{BY} 100 \qquad (1)$$

where:

HI - harvest index, %;

Y - economical or grain yield, kg ha^{-1}; and,

BY - biomass yield, kg ha^{-1}.

Table 1. Soil physico-chemical properties of experimental location

Cropping seasons	Soil texture	Size fraction (g kg^{-1})			N	K	P	OM	TNV	EC	pH
		Clay	Silt	Sand	(ppm)			(%)		(dS m^{-1})	
2016-2017	Loam	200	300	500	15	173	14.5	2.24	2.4	6.4	7.0
2017-2018		200	340	460	14	180	13.6	2.20	3.3	6.3	7.3

N – Nitrogen; K – Potassium; P - Phosphorus; OM - Organic matter; TNV - Total neutralizing value; EC - Electrical conductivity; ppm - Parts per million

The quantities of wet and dry gluten in the tested flour samples were determined by manual washing or the Gluten Index Method (GIM), a fully automatic rapid method (Curic et al., 2001). In addition to wet gluten quantities, gluten index values for all samples were detected using the Glutamatic 2200 system (Perten Instruments AB, Stockholm, Sweden). Three replicates from each flour sample were analyzed three times, respectively. Total protein was determined by the Kjeldahl procedure (Curic et al., 2001; Wieser & Kieffer, 2001).

The correlation coefficient, path coefficient, and stepwise regression analyses were estimated based on the interaction effect between planting date and seeding density (PS), planting date and genotype (PG), and seeding density and genotype (SG) mean values.

Path analysis was conducted using genotypic correlations considering grain yield as the response variable and days to spiking, days to anthesis, days to maturity, 1000-grain weight, protein (%) and gluten index, and biomass yield as predictor variables.

All analyses were performed using MS-Excel and SAS software version 9 (SAS, 2004). The correlation diagram was prepared using the SPSS software.

Results and Discussion

Planting dates had a significant effect on the majority of traits (Table 2). These results corroborated the findings of other authors namely Rezaei et al. (2011), and Shirinzadeh et al. (2017), showing that planting dates have a significant effect on yield-associated traits. Delay in planting resulted in a decrease in phenological traits and 15-day delay in planting, led to six-day reduction of days to spiking (Table 3).

The simple regression for grain yield and days to spiking in different planting dates (grain yield = - 18623 + 155.2 × days to spiking) which was calculated based on Table 3, indicated that one-day decrease in the number of days to spiking would result in a 155.2 kg ha^{-1} decrease in grain yield. Days to anthesis also decreased with delay in planting. The equation between grain yield and days to anthesis (grain yield = -32184 + 228.9 × days to anthesis) for different planting dates, showed that one-day decrease in the mean value of days to anthesis results in a 228.9 kg ha^{-1} reduction in grain yield. Days to maturity ranged from 184 to 170 days for the first and third planting days, respectively. But Feyzbakhsh & Soqi (2017) reported that delayed planting was associated with increased days to anthesis and maturity. Grain yield was significantly affected by planting date and its mean value for the first, second, and third planting dates was 5442, 4043, and 3401 kg ha^{-1}, respectively. These results were supported by Farooq et al. (2016), who reported that in late planting, the economic yield decreased due to the short growing period. Biomass yield decreased by 20% from the first to the second planting date and 14% from the second to the third planting date. Late planting had a negative effect on yield contributing traits, therefore it caused a reduction in grain yield (Sasani et al., 2019). Harvest index mean values ranged from 37.01 to 33.39% for the first and third planting

Table 2. Combined analysis of variance for measured traits of bread wheat genotypes in different planting dates and seeding densities treatments

SOV	DF	Mean square								
		Days to spiking	Days to anthesis	Days to maturity	1000-grain weight (g)	Grain yield (kg ha^{-1})	Biomass yield (kg ha^{-1})	Harvest index (%)	Protein (%)	Gluten index (%)
Year (Y)	1	3536.5**	7993.5**	2583.4**	280.9**	8320600**	20973062*	145.0*	12.9**	759.4**
Rep (Year)	4	0.6	0.4	1.6**	172.4**	1886380**	42014371**	55.7**	3.33**	975.0**
PD	2	3103.6**	1596.9**	1071.5**	365.5**	78356665**	339215708**	259.5**	1.02 ns	345.5*
Y × PD	2	9.8**	1.6 ns	10.1**	16.7ns	2237654**	23707518	78.8 ns	0.17 ns	34.0 ns
Error a	8	0.9	0.5	1.1	9.4	167585	3221859	2.4	0.26	75.3
SD	3	224.5**	84.8**	150.5**	315.1**	1720355**	63400697**	326.7**	5.38**	447.2**
Y × SD	3	4.9**	1.5 ns	1.2*	4.3 ns	82753 ns	4832559	52.1 ns	0.24 ns	9.8 ns
PD × SD	6	3.4**	3.2 ns	10.9**	1.6 ns	4147384**	22308691**	20.1 ns	0.11 ns	8.7 ns
Y × PD × SD	6	2.3*	2.0 ns	0.3 ns	1.2 ns	226185 ns	7096438 ns	21.3 ns	0.17 ns	7.6 ns
Error b	36	0.9	1.9	0.4	5.2	192965	5895813	31.0	0.61	49.1
Genotype (G)	2	363.2**	1198.7**	1086.4**	3857.6**	17898269**	12142775*	657.4**	5.02**	1806.8**
Y × G	2	7.4**	0.1 ns	3.1 *	17.4*	53865 ns	4937666 ns	25.7 ns	0.00 ns	76.8 ns
PD × G	4	21.4**	3.1**	2.4*	19.4*	553973*	3453976 ns	9.0 ns	0.11 ns	13.5 ns
Y × PD × G	4	5.4**	1.7 ns	1.5 ns	2.3 ns	429766 ns	5323386 ns	3.2 ns	0.10 ns	13.6 ns
SD × G	6	10.0**	10.6**	14.0**	6.7 ns	195150 ns	1812743 ns	6.3 ns	0.08 ns	9.1 ns
Y × SD ×G	6	1.5ns	4.0**	0.3	1.4 ns	72621 ns	626649 ns	4.2 ns	0.10 ns	4.7 ns
PD × SD × G	12	5.4**	3.3**	7.7**	1.2 ns	62660 ns	2492593 ns	13.8 ns	0.03 ns	4.4 ns
Y × PD × SD × G	12	2.8**	1.7*	2.9**	1.8 ns	234860 ns	2483951 ns	9.9 ns	0.10 ns	7.9 ns
Error c	96	0.9	0.8	0.8	6.7	217715	3616203	26.4	0.638	40.6
CV (%)	-	0.65	0.56	0.49	6.40	10.86	15.24	14.74	6.63	9.71

Rep (Year) - Blocks within years; PD - Planting date; SD – Seeding density; *, **, ns - Significant at p ≤ 0.05 and p ≤ 0.01, and not significant by F test, respectively

Table 3. Response of wheat to different planting dates across all the seeding densities and genotypes for yield and yield components

Planting dates	Days to			1000-grain weight (g)	Grain yield	Biomass yield	Harvest index	Protein	Gluten index
	spiking	anthesis	maturity		(kg ha^{-1})		(%)		
P_1	154 a	164 a	184 a	42.65 a	5442 a	14794 a	37.01 a	11.91 b	64.08 b
P_2	148 b	159 b	180 b	40.82 b	4043 b	12136 b	34.22 b	12.14 a	65.94 a
P_3	141 c	155 c	170 c	38.17 c	3401 c	10493 c	33.39 b	12.08 a	66.88 a

P_1 - November 20; P_2 - December 5; P_3 - December 20; Means in each column followed by the same letter were not significantly different at p ≤ 0.05 by Duncan's test dates, respectively. Protein concentration was not significantly affected by planting dates. The gluten index of the second and third dates was significantly higher than in the first planting across all seeding densities and genotypes.

Seeding densities had significant effect on all the traits (Table 4). Increasing the number of plants per unit area resulted in more competition for light among the plants and the wheat cultivars entered the reproductive phase quicker at higher densities. The number of days to spiking ranged from 150 to 145 days for 300 and 450 seeds m^{-2}, respectively.

Days to anthesis and days to maturity also decreased with an increasing number of seeds per unit area. The 1000-Grain weight was significantly affected by seeding densities as a large number of small seeds were formed at higher seeding densities. The highest grain yield (4486 kg ha^{-1}) was produced from 400 seeds m^{-2} and it was similar with 350 seeds m^{-2} and progressively reduced in 450 and 300 seeds m^{-2}. These results also confirmed the findings of Li et al. (2016) who reported that a low and high density could decrease the effect on grain yield.

High mean value estimates of biomass yield were related to seed density of 400 and 450 seeds m^{-2}. The harvest index had a negative relation with biomass yield as the highest values for harvest index were obtained for 300 and 350 seeds m^{-2}. Although protein concentration and gluten index were affected by seed quantity, their differences were not considerable at different seed levels. Also, the high mean values of these traits were related to lower seed density.

Figure 1A shows the correlation analysis for the interaction between planting date and seeding density mean values. Biomass yield significantly and positively correlated with days to spiking (0.64*), days to anthesis (0.65*), and grain yield (0.91**), indicating that increase in these traits would increase grain yield. Also, grain yield significantly correlated with days to maturity (0.58*) indicating that an increase in these traits would increase grain yield. Also, grain yield significantly correlated with days to maturity (0.57*).

This indicates that these traits had the same trend of variation for different levels of planting dates and seeding densities. There was a significant correlation between gluten index and protein concentration (0.96**), which indicated the same trend of variation of gluten index and protein concentration (Figure 1B).

The correlation coefficients for days to spiking (0.87**), days to anthesis (0.76*), biomass yield (0.94**), and harvest index (0.83**) indicate the dependency of yield on these traits amongst the genotypes across the different planting dates. Figure 1C presents the correlation analysis of the interaction between seeding density and genotype (G) mean values. Grain yield significantly correlated with 1000-grain weight (0.62*), harvest index (0.68*), and gluten index (0.73**), therefore any variation of the mentioned traits will have a significant

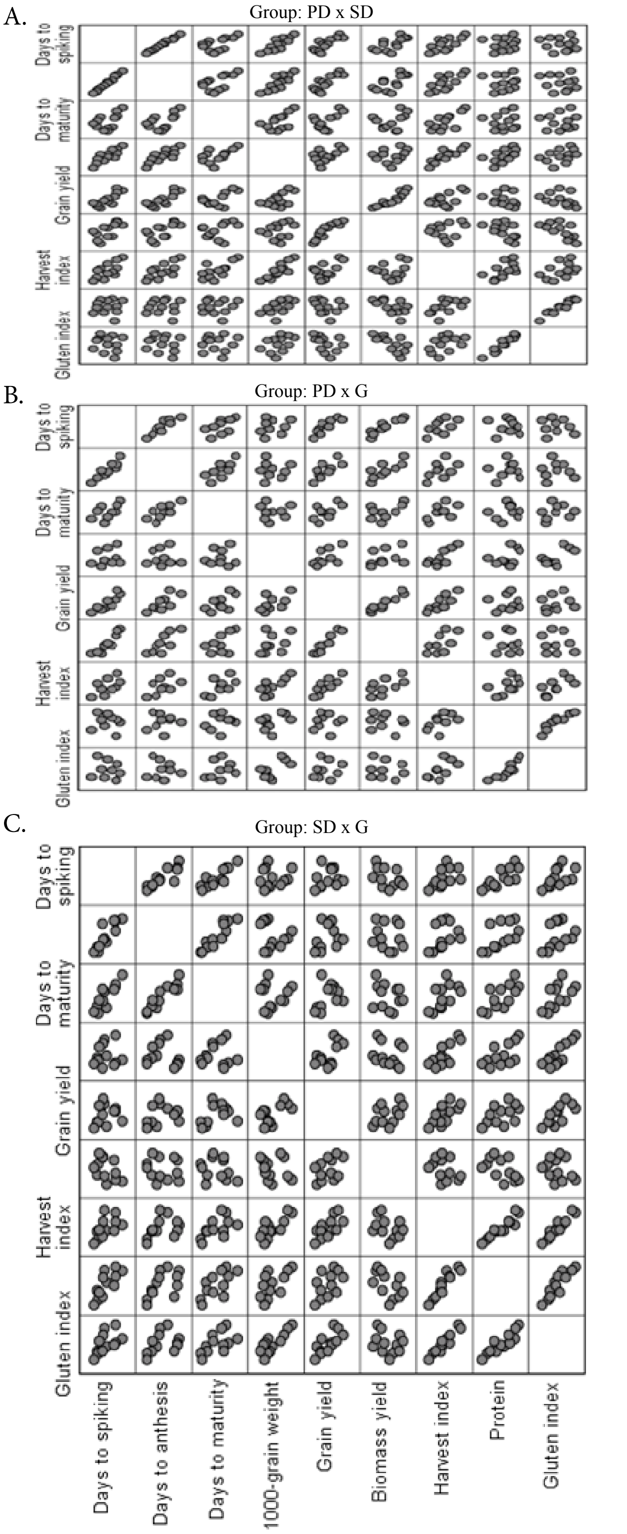

Figure 1. Correlation coefficients among measured traits for interaction between planting dates (PD) × seeding densities (SD) (A), interaction between planting dates × genotypes (G) (B), and interaction between seeding densities × genotypes (C)

Table 4. Response of wheat to different seeding densities, across all the planting dates and genotypes, for yield and yield components

Seeding densities	Days to			1000-grain weight (g)	Grain yield	Biomass yield	Harvest index	Protein	Gluten index
	Spiking	Anthesis	Maturity		(kg ha^{-1})			(%)	
SD_1	150 a	161 a	182 a	43.37 a	4090 c	11215 b	36.59 ab	12.37 a	68.82 a
SD_2	147 b	160 b	181 b	41.40 b	4395 ab	11927 b	37.13 a	12.20 a	66.70 a
SD_3	147 b	159 b	179 c	39.74 c	4486 a	13332 a	33.94 bc	11.95 ab	65.02 ab
SD_4	145 c	158 c	179 c	37.69 d	4211 bc	13423 a	31.83 c	11.64 b	62.00 b

SD_1 - 300; SD_2 - 350; SD_3 - 400 and SD_4 - 450 seeds m^{-2}; Means in each column followed by the same letter were not significantly different at p ≤ 0.05 by Duncan's test effect on grain yield. Mecha et al. (2017) and Chitralekha et al. (2018) reported a strong positive correlation of total biomass and harvest index on grain yield. Other researchers indicated a positive correlation between grain yield and other traits such as harvest index, days to maturity (Rathod et al., 2019; Dabi et al., 2016), and 1000 grain yield (Singh et al., 2012). Sukhpreet & Gill (2018) stated that grain yield showed a significant and positive association with biological yield and grain protein concentration.

For PS mean values, days to spiking, days to anthesis, and days to maturity had a positive direct effect on grain yield and also indirect effect via biomass yield on grain yield (Table 5). In different planting dates and seeding densities, the direct effect of 1000-grain weight and harvest index on grain yield was positive and insignificant, but its indirect effect via biomass yield on grain yield was positive and high in magnitude.

Table 5. Path coefficient analysis among measured traits

Pathway of association	PS	PG	SG
Direct effect of days to spiking on GY	0.721**	0.762**	0.173
Indirect effect of days to spiking on GY via:			
Days to anthesis on GY	-0.182	0.231	0.162
Days to maturity on GY	0.032	0.082	-0.160
1000-grain weight on GY	-0.036	0.241	0.165
Biomass yield on GY	0.746	0.610	0.804
Harvest index on GY	0.432	0.367	0.866
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.627	0.496	0.056
Direct effect of days to anthesis on GY	0.745**	0.763**	0.367
Indirect effect of days to anthesis on GY via:			
Days to spiking on GY	0.333	-0.272	-0.047
Days to maturity on GY	0.032	0.082	-0.160
1000-grain weight on GY	-0.036	0.241	0.165
Biomass yield on GY	0.746	0.610	0.804
Harvest index on GY	0.432	0.367	0.866
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.697	0.566	0.073
Direct effect of days to maturity on GY	0.568**	0.728*	0.387
Indirect effect of days to maturity on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
1000-grain weight on GY	-0.036	0.241	0.165
Biomass yield on GY	0.746	0.610	0.804
Harvest index on GY	0.432	0.367	0.866
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.321	0.314	0.152
Direct effect of 1000-grain weight on GY	0.334	0.501	0.633*
Indirect effect of 1000-grain weight on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
Days to maturity on GY	0.039	0.091	-0.152
Biomass yield on GY	0.746	0.610	0.804
Harvest index on GY	0.432	0.367	0.866
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.352	0.423	0.286
Direct effect of biomass yield on GY	0.825**	0.863**	0.413
Indirect effect of biomass yield on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
Days to maturity on GY	0.039	0.091	-0.152
1000-grain weight on GY	-0.036	0.241	0.165
Harvest index on GY	0.432	0.367	0.866
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.736	0.423	0.283

Continued in the next column

Continuation of Table 5

Pathway of association	PS	PG	SG
Direct effect of harvest index on GY	0.363	0.803**	0.723**
Indirect effect of harvest index on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
Days to maturity on GY	0.039	0.091	-0.152
1000-grain weight on GY	0.746	0.610	0.804
Biomass yield on GY	0.333	-0.177	-0.056
Protein on GY	-0.036	0.066	0.327
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.426	0.732	0.513
Direct effect of Protein on GY	-0.240	0.065	0.496
Indirect effect of Protein on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
Days to maturity on GY	0.039	0.091	-0.152
1000-grain weight on GY	-0.036	0.241	0.165
Biomass yield on GY	0.432	0.367	0.866
Harvest index on GY	0.333	-0.177	-0.056
Gluten index on GY	0.072	-0.262	-0.123
Total correlation	0.066	0.006	0.164
Direct effect of gluten index on GY	-0.380	0.156	0.762**
Indirect effect of gluten index on GY via:			
Days to spiking on GY	0.333	-0.177	-0.056
Days to anthesis on GY	-0.182	0.155	0.183
Days to maturity on GY	0.039	0.091	-0.152
1000-grain weight on GY	0.746	0.610	0.804
Biomass yield on GY	0.432	0.367	0.866
Harvest index on GY	0.333	-0.177	-0.056
Protein index on GY	-0.036	0.066	0.327
Total correlation	0.179	0.036	0.661

GY - Grain yield; *, ** - Significant at p ≤ 0.05 and p ≤ 0.01 by F test, respectively; PS - Planting dates and seeding densities interaction effect; PG - Planting dates and genotypes interaction effect; SG - Seeding densities and genotypes interaction effect

Biomass yield had a positive direct effect on yield for (PS and PG). Protein concentration had a negative direct effect on grain yield for PS. The direct effect of gluten index on grain yield was negative and insignificant. For PG mean values, days to spiking, days to anthesis, days to maturity, and harvest index had a positive direct effect on grain yield. The genotypic correlation of 1000-grain weight with grain yield was low, but its indirect effect via biomass yield on grain yield was high in magnitude. Significant and positive direct effects of harvest index on grain yield (0.803**) were determined. For SG mean values, the direct effects of days to spiking, days to anthesis, days to maturity and protein concentration on grain yield were positive and not significant. The 1000-grain weight and gluten index had positive direct effects on grain yield, but also its indirect effect via biomass yield and harvest index was positive and high in magnitude. For SG, the harvest index had positive and significant direct effects on grain yield. Also, its indirect effect through biomass yield on grain yield would be effective for grain yield improvement. Days to maturity, and days to heading recorded a maximum positive direct effect on grain yield (Avinashe et al., 2015; Dabi et al., 2016). Days to maturity, 1000-grain weight, and biological yield had a positive direct effect on grain yield (Singh et al., 2012).

Stepwise regression analysis revealed different results for PS, PG, and SG mean values (Table 6). For PS, the traits biomass yield, harvest index, and days to maturity, and also for PG and SG, biomass yield and harvest index recorded important

Table 6. Stepwise regression analysis of nine studied traits

Step	Variable entered	Partial R^2	Model R^2	F-test
Interaction Planting dates × Seeding densities				
1	X5:Biomass yield	0.837	0.837	*
2	X6: Harvest index	0.160	0.998	*
3	X3: Days to maturity	0.001	0.999	*
Final regression model: GY (grain yield) = - 6621.3 + 0.395 X5 + 129.77 X6 + 10.63 X3				
Interaction Planting dates × Genotypes				
1	X5: Biomass yield	0.896	0.896	*
2	X6: Harvest index	0.101	0.997	*
Final regression model: GY (grain yield) = -4819.6 + 0.367 X5 + 130.13 X6				
Interaction Seeding densities × Genotypes				
1	X5: Biomass yield	0.528	0.528	*
2	X6: Harvest index	0.465	0.993	*
Final regression model: GY (grain yield) = -4648.9 + 0.34 X5 + 131.8 X6				

* - Significant at p ≤ 0.05 by F test

effects on grain yield. Due to their low relative contributions, the other traits were not included in the models. A positive regression coefficient of variables implies that defining a logical index selection with these variables, considering their correlation coefficients with grain yield, might be an adequate strategy for increasing wheat grain yield (Ashraf et al., 2014; Chamkouri, 2015). Zarei et al. (2013), Hannachi et al. (2013), Kohan et al. (2016), and Mansouri et al. (2018) reported that biomass yield and harvest index are the most important grain yield predictors.

Conclusions

1. The relationships between grain yield and its components and plant traits were different.

2. Grain yield had a significant positive relationship with days to maturity for the interaction effects of planting dates and seeding densities, 1000-grain weight, and gluten index for the interaction effects of seeding densities and genotypes.

3. Days to spiking, days to anthesis, and biomass yield significantly and positively correlated with grain yield for PS and PG mean values, and harvest index for PG and SG mean values.

4. Biomass yield for PS and PG, and harvest index for PG and SG exhibited the highest positive direct effect, and these traits had an indirect positive effect on grain yield.

5. Biomass yield, harvest index, and days to maturity for PS, biomass yield, and harvest index for PG and SG were more important than other measured traits for the grain yield prediction model.

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