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Genetic Structure of Wheat (*Triticum aestivum* L.) Grain Characteristics by Using Image Processing and Generation Mean Analysis Techniques

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ABSTRACT

Wheat (*Triticum aestivum* L.) is known to be the world-leading cereal grain and the most important food in the world of agriculture. Wheat offers a great wealth of material for genetic studies due to its wide ecological distribution and host of variation for various morphological and physiological characters. To evaluate the genetic control of physical traits of grain in two crosses of winter wheat (*Triticum aestivum* L.), the cultivars N-92-9, Kohdasht and Ehsan, and populations F1, BC1, F2 and BC2 of their crosses were studied on a randomized complementary block design (RCBD) in three replications. Employing image-processing area, length, width, eccentricity, equivalent diameter, solidity, perimeter, and grain weight were recorded. There were significant differences observed between generations concerning area, length, width, eccentricity, equivalent diameter, solidity, perimeter, and grain weight. For most of the traits, the $(F/(H\times D))^{0.5} < 1$ implied the different sign and magnitude of the effect of controlling genes in these traits. Broad-sense heritability and narrow-sense heritability were estimated ranging from 0.594 to 0.965 and 0.05 to 0.769, respectively, for the two crosses, which accounted for the highest estimation compared to other traits. Regarding area, length, width, equivalent diameter, perimeter, and grain weight, dominance had a greater role in their genetic inheritance control, and hence, it is recommended to use selection-based breeding for manipulation of length and eccentricity in Kohdasht × Ehsan. Additionally, a hybrid method is considered to be employed for the breeding area, length, width, equivalent diameter, perimeter, and weight grain in N-92-9 × Ehsan and Kohdasht × Ehsan.

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Introduction

Wheat (*Triticum aestivum* L.) is the most important and widely grown agricultural crop in the world. It is one of the major cereal crops widely cultivated in Iran and all around the world, which provides us with high calories and protein. Wheat has wider (tropical) adaptability and in tropical, subtropical, and temperate zones, it is capable of tolerating severe cold as well as snow and resumes growth with a grain setting in warm weather in spring (Ninghot *et al.,* 2016). The determination and choice of selection and genetic breeding procedures for any crop is largely dependent upon the knowledge of the type and the relative amount of genetic components and their interaction in the plant materials under investigations. Information on the type of gene action involved in the inheritance of a trait is helpful for the selection of the breeding procedures (Ninghot *et al.,* 2016). Choosing the most appropriate method to achieve a breeding goal depends on the genetic tissue of the target population and the genetic structure of the traits. When the breeder aims to breed multiple traits simultaneously, it is essential to estimate the breeding parameters primarily, to decide on the kind of breeding traits, and then select the appropriate breeding method based on the available information (Kearsey and Pooni, 1996). Generation means analysis is a useful technique to estimate components of variance, heritability, and genetic effects control of the traits (Mather and Jinks, 1982; Kearsey and Pooni, 1998). In an experiment, studying the genetic parameters in wheat, it was concluded that increasing and non-increasing effects play a role in the inheritance of all the traits studied (Akhtar and Chowdhry, 2006). Breeders use information from economic traits studies in wheat to identify the type of action of controlling genes (Khattab *et al.,* 2010). Generation means analysis along with estimating additive effect and dominance effect, can estimate genetic effects, epistasis such as additive × additive, additive × dominance; and dominance × dominance (Singh and Singh*,* 1992). According to this method, the additive, dominance effect, and epistasis of genes and degree of dominance at each cross are estimated based on averages (Hallauer *et al.,* 1982). Studying the nature of gene action in some traits in wheat gave scientists the possibility to report that the effect of epistasis played a pivotal role in controlling certain traits Dvojković *et al.* (2010), Erkul *et al.* (2010), and Sultan *et al.* (2011)). There is numerous evidence that the epistasis effect cannot always be neglected (Ghannadha, 1998). Some agriculturally important traits, such as yield, have complex heritability and in many cases, the selection for these traits is ineffective or less effective even after many years of continuous work (Brown and Caligari, 2011).

Akhtar and Chowdhary (2006) showed that the additive or additive × additive effects are greater in the grain area, whereas dominance or dominance × dominance ones were greater for all traits, except for grain eccentricity and equivalent diameter. For most traits, the effects of dominance and dominance × dominance were of greater importance compared to the effects of incremental and other types of epistasis (Bilgin *et al.*, 2016).

Erkul *et al.* (2010), in their research on wheat cultivars, stated that a three-parameter model controls trait grain weight under normal heritability conditions. Correlation analysis indicated that eccentricity and solidity have a significant positive effect on grain yield. The maximum positive direct effects attributed to area, length, width, equivalent diameter, perimeter, and grain weight. The results of this study also revealed that the selection of superior genotypes for grain yield should be based on the maximum and positive grain traits (Moghaddam *et al.,* 1997).

Sharma *et al.* (1980) and Novoselovic *et al.* (2004) pointed out that in wheat, dominance and epistasis effect of additive × additive for grain weight is more important than the additive effect and the epistasis effect.

Prakash *et al.,* (2006) found that dominance, additive effect, additive × dominance interaction, and additive × additive interactions involve in the control of wheat traits. Martinez *et al.* (2001) reported that the dominance effect had the highest contribution to traits of grain area, length, width, eccentricity, equivalent diameter, solidity, perimeter, and weight.

In this research, to determine appropriate breeding methods for physical traits in wheat using generation mean analysis, genetic breeding parameters, amount of dominance, additive and epistasis effects were estimated and determined; subsequently, broad-sense heritability for each trait, number of controlling genes and ultimately the best breeding method were identified.

Materials and Methods

Growth conditions

The studied plant population included two crosses between Kohdasht ×Ehsan and N-92-9 × Ehsan. These cultivars will be utilized as parents in crosses to create diversity and ultimately produce new cultivars that have a high yield potential (Ehsan and N-92-9) cultivars and endure heat stress at the end of the season (Kohdasht). Therefore, this information on capability, broad and narrow-sense heritability, and Genetics are important to hybridization programs. The above-mentioned crosses conducted at the Research center of Gorgan University of Agricultural Sciences and Natural Resources and its segregating generations were planted at Gonbad Kavous University. Land preparation and planting practices performed according to the standard of cereal experiments.

The experiment carried out based on a complementary randomized block design (RCBD) with three replications in the laboratory of the Faculty of Agriculture. P1 (female parent), P2 (male parent), and F1 (First generation), BC1 (F1× female parent), and BC2 (F1× male parent) and F2 generations were evaluated. In the first cross, Kohdasht as a male parent (P1) and Ehsan as the female parent (P2) were used. In the second cross, Ehsan as male parent (P1) and N-92-9 as the female parent (P2) were employed.

The image processing was performed in a botanical laboratory. To do this, the grains produced on the research farm were used. The grain image was taken under the light of a lab environment (fluorescent lamp). The camera embedded in HuaweiY7prime 2016 was utilized for image processing with a camera with 13 megapixels' resolution. All images were taken at a constant distance of 30 cm. To reduce background noise and for calibration, the grain image was projected on A3 paper. In this paper, regular geometric shapes are printed in circles and squares of specified dimensions.

Imaging and image processing

The images were taken in a way that all of the grains and regular shapes of the circle and squares fit perfectly within the image and the grains were not in contact with each other. To extract the geometric properties of the grain by using image processing, a digital grain image must first be stored.

The images were stored in computer memory in RGB JPG format. A digital image is a finite set of digital values that represents a two-dimensional image. These digital values or pixels are stored in computer memory as two-dimensional arrays of integers.

The steps in processing digital images of grain are as follow (Figs. 1 and 2): Image rotation, image blur, and so forth. A set of operations that done to correct or reduce these errors is called preprocessing. The preprocessing operation performed by moving the images from RGB space to HSV image space.

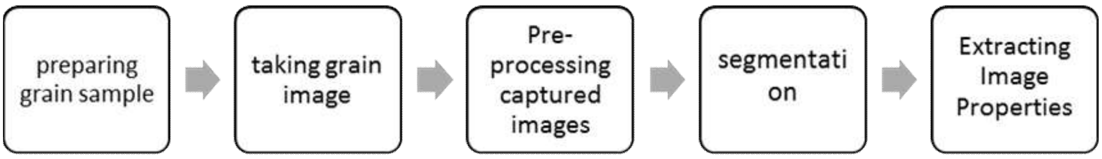

Fig. 1. Basic steps of measuring the grain's geometric properties using image processing.

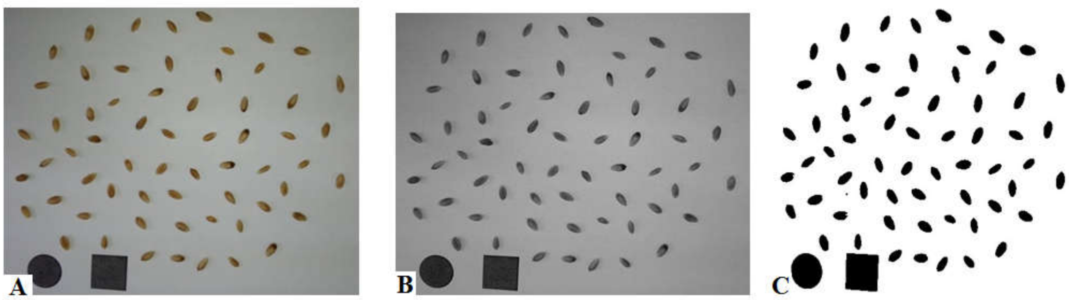

Fig. 2. Steps of digital wheat grain image analysis in MATLAB software: A) Image of grains in colored space RGB; B) Gray image of grains; C) Binary image of grains.

1. Processing: The stored digital image might involve certain errors, such as noise and failure, In the HSV, space noises of pod particles and awn and other image additions were eliminated using special noise thresholds.

2. Segmentation: In the image preparation phase, the exact location of the grain in the image should be determined by applying Edge Detection Algorithms.

3. Extracting Image Properties: Following the determination of the exact location of the grain in the image, the geometric properties of the grain were specified. For this purpose, mathematical methods or artificial intelligence were used. These specifications are:
Area (area of pixels within grain image), length (maximum size on grain long axis (a)), width (maximum size on grain transverse axis (b)) (Fig. 3), and eccentricity (a number between zero and one). The closer the index is to 1, the more oblong the grain shape would be, and the closer to zero it is, the rounder it would be. Equivalent diameter, equivalent solidity (circle diameter equal with grain area), the perimeter (the area ratio to the area to polygon incorporating grain), and grain weight were measured and recorded separately for each generation. Equivalent solidity is obtained by the following formula: solidity: $((4*\text{Area})/\pi)^{0.5}$.

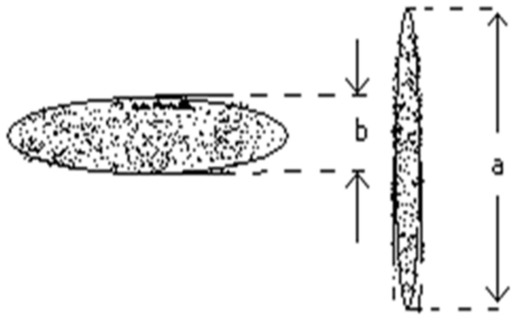

Fig. 3. Wheat grain geometric dimensions: (a) length, (b) width.

Analysis of the epistatic effect

To evaluate the presence, absence, and type of epistasis effect, the following scale tests were calculated based on the Mather *et al.* (1982):
A= 2BC1.1– P1– F1
B= 2BC1.2 – P2 –F1
C= 4F2- 2F1– P1– P2

Generation mean analysis

The model used for investigation of the genetic structure of genes controlling the physical traits of wheat grains by Generation Mean Analysis method is as follows (Mather and Jinks, 1982):
$Y= m+ \alpha[d]+ \beta[h]+ \alpha^2[i]+ 2\alpha\beta[j]+ \beta^2[i]$
Where Y is the average of one generation, m shows mean of all generations in a cross, [d] represents the sum of the additive effect, [h] is the sum of the dominance effect, and [i] concerns a sum of the additive interactions. [j] which is the sum of additive and dominance interactions, [l] that represents the sum of Dominance interactions and β^2, $2\alpha\beta$, α^2, β, α are products of genetic parameters. Genetic components coefficients were calculated according to Mather et al., 1982. Weighted least square was utilized to estimate the parameters. Models were fitted using the goodness of fit test (X2). Variance components were calculated for the following six generations (P1, P2, F1, BC1, BC2, and F2) (Mather *et al.,* 1982):
(1) $E_w =1/4(V_{p1}+ V_{p2}+ 2V_{F1})$
(2) $D =4V_{F2} - 2(V_{BC1}+ V_{BC2} - E_w)$
(3) $H =4(V_{BC1}+ V_{BC2} - V_{F2} - E_w)$
(4) $F =VB_{C1} - VB_{C2}$
where E_W is the environmental component of heritability, D concerns the additive component of genetic variance, H shows the dominance component of genetic variance, and F is the correlation of d and h on all gene loci. The values of F and H represent the dominance average and the deviation of dominance for each gene loci, respectively. The degree of dominance was estimated according to the ratio of the dominance effect to the additive effect by $(H/D)^{1/2}$ and $F/(D/H)^{1/2}$ formula.

Estimation of broad and narrow-sense heritability

The following equation was used to estimate broad-sense heritability (genetic variance to phenotypic variance ratio):
$H^2_{b.s} = V_{F2} - E_W/V_{F2}$ (Mather and Jinks, 1982) in which Ew was calculated with five formulae as follow:
1: $(V_{P1}+ V_{P2})/2$
2: $(V_{P1}\times V_{P2})^{1/2}$
3: V_{F1}
4: $(V_{P1}+ V_{P2}+ V_{F1})/3$
5: $(V_{P1}+ V_{P2}+ 2V_{F1})/4$.
To estimate Narrow-sense heritability (an additive component of genetic variance to phenotypic variance ratio) (H^2n.s) the following formula (Warner, 1952) was used:
$H^2n.s = (2V_{F2} - (V_{BC1} + V_{BC2}))/V_{F2}$

Estimation of the number of effective genes

The following equations employed to estimate the number of effective genes for the studied traits (Lande, 1981):

1: N= (XP2 – XP1)2/8(VF2 – VF1)

2: N= $(X_{P2} - X_{P1})^2/8\ [V_{F2} - (0.5V_{F1} + 0.25V_{P1} + 0.25V_{P2})]$

3: N= (XP2 – XP1)2/8 (VBC1 – VBC2)

4: N= (XP2 – XP1)2/ [8(VBC1 – VBC2)] – [(X2F1+ 0.5VP1+ 0.5VP2)]

5: N= (XP2 – XP1)2/4 [VBC1 – 0.5(VF1+ VP1)

6: N= (XP2 – XP1)2/4 [VBC2 – 0.5(VF1+VP2)]

Statistical analysis

MATLAB statistical software was used for image processing and SAS 9.1.3 for analysis of variance and estimation of genetic effects (Ew, D, H, and F).

Results

The results of the analysis of variance demonstrated a significant difference between different generations for some of the studied traits in 1% and 5% of probability levels. Therefore, it is possible to analyze the genetics and investigate how inherited traits are studied (Table 1A). Generation mean and standard error of traits studied in different generations of crosses N-92-9 ×Ehsan and Kohdasht × Ehsan are presented in Table 1B. The information obtained from these analyses is crucial to the choice of breeding strategy and the selection method or production of inbred or hybrid varieties.

For instance, if a trait is controlled by recessive genes, selection should be delayed until the last generations in which lines are more homozygous, or if heritability is low, more replications are needed, or selection should be done by correlated trait with high-heritability (Hill *et al.,* 1999). Hence, knowing the ways of genetic control of traits is very important in choosing a breeding method. When 6-parameter model was fitted, the components [i], [h], and [l] were significant at 1% and 5% probability levels and d, [j] were non-significant (Table 1C). The significance of the additive × dominance [j] interaction in the crosses indicates that it cannot be fixed. Accordingly, the selection of [j] should not be made. The negative sign of parameter [j] depends on the position of the parent and its sign would change as the parent position changes. In both crosses given the value<1, parameter shows the average dominance $(H/D)^{0.5}$, so in the cross, N-92-9 ×Ehsan and Kohdasht × Ehsan relative dominance $(F/(H\times D))^{0.5}$ are apparent (Table 2).

This result is in line with the findings by other researchers (Verma *et al.,* 2007; Eshghi and Akhundova, 2010). However, other researchers (Islam and Darrah, 2005; Baqizadeh, 2003) reported the relation of overdominance for most of the grain morphology traits (Table 2). The results indicate the outstanding role of dominance variance in the heritability of traits area, length, width, equivalent diameter, perimeter, and weight. These results imply that early selection might improve these traits. These findings confirm the role of genetic effects in controlling these traits.

According to generation mean analysis for area, length, width, equivalent diameter, perimeter, weight at N-92-9 × Ehsan Cross and area, length, width, equivalent diameter, perimeter, weight at Kohdasht × Ehsan cross, the dominance effect showed a sign that cannot affect most traits, and the additive effect was significant but less contributed to these variations.

The sum of the dominance effect [l] + [h] or [l] alone was greater than the sum of the additive effect [i] + [d] or any of these components individually, showing the importance of dominance effects in accounting for genetic variation of these traits, and its implication is that selection should be made in more advanced generations (Mather and Jinks, 1982).

Existence of two-way epistasis on traits area, length, width, equivalent diameter, solidity, perimeter, grain weight at N-92-9-Ehsan cross and area, length, and the equivalent diameter at Kohdasht × Ehsan cross was significant in their dominance components. The dominance ×dominance sign also indicates that this type of epistasis causes problems in the selection of desirable plants with these traits. It also implies that selection is delayed until high levels of gene fixation and hybrid is achieved. Higher values of [d] than [h] for all traits except solidity and eccentricity of the grain in both crosses denote lack of correlation of the gene; in other words, traits reducing genes are assembled in one parent and traits enhancing genes in another one.

Table 1. Analysis of weight variance, estimation of the mean and variance and gene effects of the traits in different generations

A) Analysis of weight variance of traits in different generations

		S.O.V	df	Area	Length	Weight	Eccentricity	Equivalent Diameter	Solidity	Perimeter	Weight
Means of squares	**N-92-9×Ehsan**	Block	2	117.634**	0.760	0.189	0.00008	87.320**	0.329**	2.847**	0.014*
		Generations	5	238.869**	8.185**	0.820*	0.002	159.416**	2.134**	1.728**	0.007
		Error	10	15.296	0.876	0.317	0.0006	14.348	0.417	0.383	0.112
		C.V(%)		3.911	0.936	0.563	0.024	15.050	8.482	14.434	6.672
	Kohdasht×Ehsan	Block	2	0.256	0.0001	7.366	0.0004*	0.235	0.0006	89.249**	0.0002
		Generations	5	3.127**	0.016*	70.201**	0.002**	2.720**	0.002**	87.598**	0.002**
		Error	10	0.366	0.005	9.872	0.00009	0.275	0.0005	19.047	0.0003
		C.V(%)		0.605	0.068	3.142	0.01	9.434	2.140	18.570	40.971

B) Estimation of the mean and variance of different generations of wheat

Generation		Area		Length		Weight		Eccentricity		Equivalent Diameter		Solidity		Perimeter		Weight	
		$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2	$\bar{X}$	σ^2
N-92-9×Ehsan	P_1	29.734	12.055	8.787	0.133	4.325	0.112	0.869	0.0002	6.136	0.127	0.962	0.0001	24.362	9.205	0.055	0.00002
	P_2	26.784	13.238	8.218	0.164	4.162	0.154	0.859	0.0006	5.817	0.147	0.962	0.0002	22.757	9.103	0.053	0.00002
	F_1	2.0844	10.712	7.099	0.270	3.749	0.101	0.848	0.00007	5.138	0.162	0.964	0.00004	18.568	2.855	0.034	0.0005
	F_2	28.626	34.832	7.726	1.545	4.151	0.674	0.877	0.002	5.493	0.941	0.934	0.012	26.907	24.164	0.048	0.002
	BC_1	19.714	32.525	6.900	1.616	3.707	0.518	0.870	0.0009	4.582	0.528	0.857	0.012	19.973	22.434	0.031	0.003
	BC_2	17.946	10.371	6.157	1.255	3.589	0.300	0.875	0.003	4.854	0.713	0.920	0.003	17.404	4.496	0.028	0.00009
Kohdasht×Ehsan	P_1	27.794	11.763	8.562	0.198	4.143	0.106	0.873	0.0002	5.927	0.142	0.958	0.00008	24.728	7.805	0.046	0.0004
	P_2	27.774	16.366	7.930	0.136	4.471	0.225	0.821	0.001	5.928	0.187	0.960	0.0003	23.752	17.879	0.044	0.00003
	F_1	18.309	9.166	6.436	0.159	3.635	0.153	0.820	0.0007	4.812	0.156	0.956	0.00007	18.331	3.265	0.026	0.00004
	F_2	31.456	26.593	8.352	0.791	4.826	0.921	0.801	0.008	6.196	0.816	0.927	0.001	27.709	38.787	0.052	0.002
	BC_1	22.771	15.375	7.196	0.351	4.047	0.275	0.822	0.003	5.368	0.205	0.954	0.001	22.221	33.028	0.032	0.00003
	BC_2	24.541	22.333	7.031	0.616	5.829	0.923	0.863	0.007	5.068	0.815	0.951	0.0006	24.370	24.400	0.029	0.002

C) Estimates of gene effects for grain traits in a wheat cross

	Traits	Additive effect [d]	Dominant effect [h]	Additive× Additive[i]	Additive× Dominant[j]	Dominant ×Dominant[l]
N-92-9×Ehsan	**Area**	1.486 ± 1.027	-109.422 ± 17.264**	-37.957 ± 7.110**	-2.674 ± 4.59	64.061 ±10.665**
	Length	0.285 ± 0.215	-16.075 ± 3.613**	-4.791 ± 1.488**	0.918 ± 0.961	9.881 ± 2.232**
	Width	0.082 ± 0.132	-5.908 ± 2.206**	-2.012 ± 0.909*	-0.074 ± 0.587	3.402 ± 1.363**
	Eccentricity	0.005 ± 0.007	0.017 ± 0.114	-0.017 ± 0.047	-0.018 ± 0.031	0.050 ± 0.070
	Equivalent Diameter	0.160 ± 0.156	-10.402 ± 2.618**	-3.103 ± 1.078**	-0.863 ± 0.696	6.461± 1.617**
	Solidity	0.0003 ± 0.016	-0.657 ± 0.261**	-0.181 ± 0.108	-0.128 ± 0.070	0.478 ± 0.161**
	Perimeter	0.803 ± 0.819	-50.367 ± 13.763**	-17.937± 5.669**	3.533 ± 3.659	27.438 ± 8.503**
	Weight	0.002 ± 0.003	-0.231 ± 0.042**	-0.076 ± 0.017**	0.006± 0.011	0.135 ± 0.026**
Kohdasht× Ehsan	**Area**	0.010±0.970	-56.397 ± 16.317**	6.72± -24.679**	-3.560 ± 4.338	10.08 ±22.243*
	Length	0.145 ± 0.317*	2.428 ±-13.7**	1.01± -5.491**	-0.304 ± 0.646	1.5 ±6.399**
	Width	-0.165±0.156	2.611 ±-4.344	1.076± -2.457*	-0.608 ± 0.694	1.216 ± 1.613
	Eccentricity	0.014 ± 0.027*	0.308 ± 0.229	0.150 ± 0.094	-0.134 ± 0.061*	-0.185 ± 0.141
	Equivalent Diameter	-0.0007± 0.147	2.465 ± -9.544**	1.016 ± -3.912**	0.601 ± 0.656	4.518 ± 1.523**
	Solidity	-0.002± 0.006	0.182 ± 0.087*	0.103 ± 0.036**	0.008±0.023	-0.082 ± 0.054
	Perimeter	0.488± 1.077	18.110 ± 33.775-	7.459 ± 17.854-*	-5.474 ± 4.815	11.188± 10.012
	Weight	0.002±0.005	-0.122 ± 0.068	-0.061 ± 0.028*	0.037 ± 0.018*	0.042± 0.042

* and **= Significant at 5% and 1% probability levels, respectively; Block: presented to some times the grains are collected; S.O.V= Analysis of variance; C.V= Coefficient of variation

Table 2. Genetic parameters and components of variation for grain traits.

	(F)		(H)		(D)		$(F/(H\times D))^{0.5}$		$(H/D)^{0.5}$	
Traits	C.1	C.2	C.1	C.2	C.1	C.2	C.1	C.2	C.1	C.2
Area	22.154	-6.958	-14.461	-2.001	76.895	54.187	-0.011	-0.108	0.036	0.002
Length	0.361	-0.265	4.467	0.052	0.857	1.556	0.055	2.015	27.201	0.002
Width	0.218	-0.648	0.108	0.471	1.294	1.607	0.838	0.211	0.007	0.086
Eccentricity	-0.003	-0.004	0.007	0.006	0.0007	0.014	52.665	9.051	98.810	0.165
Equivalent Diameter	-0.185	-0.61	0.602	0.175	1.581	1.545	0.158	0.593	0.145	0.013
Solidity	0.009	0.0004	0.012	0.002	0.019	0.002	0.450	65.235	0.409	3.146
Perimeter	17.938	8.628	-13.014	42.35	54.835	56.399	-0.009	0.004	0.057	0.564
Weight	0.003	-0.002	0.004	-0.0007	0.003	0.005	33.468	-67.544	2.014	0.026

EW is the non-genetic component, D is the additive component, H is the dominant component of the variance, and F is the independent contribution of h and d to all gene loci. The values of F and H represent the average dominance and the deviation of dominance at each gene loci, respectively.

Regarding important traits such as grain length, solidity, perimeter, and in N-92-9 × Ehsan cross and grain equivalent diameter, solidity, and weight in Kohdasht × Ehsan cross, additive× dominance effect is shown to be higher. However, dominance was significant for the grain area which had a significant dominance effect. Interactions of additive × additive and dominance × additive in genes play an important role in improving yield. As a result, in wheat breeding programs, not only the additive and the dominance effect but also the interactions of the genes must be considered in the selection of parents and selection in segregating generations.

In both crosses, the epistasis effect was observed for most yield components, and therefore, selection of optimal epistatic components could be effective for breeding high yield hybrids wheat. Non-significance of epistasis effect and j in traits of grain eccentricity and solidity in N-92-9 × Ehsan cross and eccentricity of grain in Kohdasht × Ehsan indicates no Epistasis effect and no additive effects on the genetic control of these traits (Table 3). In both crosses, opposite signs of dominance effect [h] and dominance epistasis × dominance [l] represent double epistasis. The major part of both crosses was concerning negative epistasis, additive × additive, additive × dominance interactions. Investigating genes actions, traits sense heritability, and morphology traits of grain and some traits related to them in wheat generations of P1, P2, F1, F2, BC1 and BC2, derived from the N-92-9 × Ehsan and Kohdasht × Ehsan crosses, in most traits an epistasis model was appropriate to describe variation in the generation mean.

The results revealed that all gene effects including additive (d), dominance (h), additive epistasis× additive (i), dominance × dominance (I), and additive ×dominance (J) were effective in the heritability of studied traits. Similar results reported for the area, length, width, equivalent diameter, perimeter, and weight and additive effects (Cheloei *et al.*, 2012). Additive and dominance × dominance for traits grain area, length, width, equivalent diameter, perimeter, and weight Epistasis, especially additive × dominance, and dominance, were identified as leading controlling factors.

In most traits, except grain eccentricity and Equivalent Diameter, the value of parameter F was positive at the N-92-9 × Ehsan cross, indicating the dominance of the Parent alleles with a larger mean over the Parent alleles. In other words, the genes controlling these traits enhance them. Also, the mean degree of dominance [d/h] was greater than one for most traits, which indicates the importance of dominance for these traits. For traits with the value of dominance variance (H) greater than additive variance (D), including grain length, eccentricity, and grain weight at N-92-9-Ehsan cross, since the average degree of dominance is less than one, it indicates relative dominance. For these traits, the Narrow-sense heritability was close to the broad-sense heritability, and selection in the early generations could be of a greater (H) effect.

Baqizadeh, 2003 reported a greater amount of additive variance (D) for all traits studied compared to dominance variance (H). It should be noted that the dominance variance (H) depends on the sign of the parameters [j] and d in most cases [j]. Consequently, it depends on the P1 or P2 sign in which the parent will change, yet the other parameter signs remain unchanged. In general, it could be concluded that different traits have different genetic effects.

Furthermore, in most traits except for Solidity and grain weight, the N-92-9 × Ehsan cross parameter $(F/(H \times D))^{0.5}$ was observed to be lower than one, indicating different signs and magnitude of controlling gene in these traits.

Genetic average dominance $(H/D)^{0.5}$ of all traits at Kohdasht × Ehsan cross and all traits, except length, eccentricity, and N-92-9 × Ehsan cross weight, was not greater than 1. This represents a dominant effect and a greater contribution of the dominant effect in the genetic control of these traits than the additive effect.

The importance of the dominance effect has also been obtained in the results of Oching and Compton (1994) and Petrovic (1998), rather than the additive effect for the grain area. The degree of dominance indicates that the presence of overdominance for length, eccentricity, solidity, and weight of grain at N-92-9-Ehsan cross and solidity at cross-Kohdasht-Ehsan for other traits with partial dominance was observed.

In general, average dominance values at N-92-9 × Ehsan cross were between 0.007 to 98.810, and at Kohdasht × Ehsan cross were between 0.002 and 3.146 for all traits (Table 4). The degree of dominance in the traits of length, eccentricity, and weight in N-92-9-Ehsan's cross indicated relative dominance towards the larger parent. The estimated low value of broad-sense heritability is due to the importance of environmental effects and genotype×environment interactions in the occurrence of these traits. The slight difference between the two broad-sense heritability and narrow-sense heritability in some traits (area, length, width, equivalent diameter, perimeter, and weight) shows the relatively greater importance of incremental effects. The additive effect is also in this group of traits and there is a high difference in sense heritability in other traits (eccentricity and solidity of the grain). The major contributor to the no additive effect of genes and the existence of over dominance in the genetic control of these traits is similar to results from the degree of dominance.

The breeding rate of traits under selection depends on narrow-sense heritability, and high narrow-sense heritability, which can accelerate selection programs (Chen and Line, 1995). Low narrow-sense heritability in some traits (solidity for Kohdasht-Ehsan cross and grain for N-92-9 cross, respectively) shows that breeding in early breeding does not have good genetic efficiency to improve these traits and should be extended to more advanced generations to increase the share. The comparison between a broad-sense heritability and narrow-sense heritability estimation showed the same importance of additive and non-additive effects in genetic control of traits. The average number of genes for traits evaluated at the N-92-9-Ehsan cross was between 0.014 and 7.376, and at the Kohdasht × Ehsan cross ranged from 0.044 to 4,515 (Table 3), considering that one trait is controlled by a small number of major genes or a large number of secondary genes.

This can represent the selection strategy to several researchers (Mulitze and Baker, 1985). Genetic factors in segregation, which are quantitatively identified by genetics, are of great importance, and herein, the number of segregating units is estimated to be necessarily similar to the different number of gene loci. For this reason, the number of effective factors should be used instead of the number of genes (Lande, 1981). The results of different methods of calculating the minimum gene number require specific assumptions such as the absence of linkage, epistasis, dominance, or uneven effects on different gene loci. Therefore, the probable existence of any of the above-mentioned factors would lead to a lower estimate of the traits of the controlling genes (Ghannadha, 1998).

In general, N-92-9 × Ehsan cross for traits grain area, length, width, equivalent diameter, solidity, perimeter, weight, and Kohdasht × Ehsan cross traits of an area, length, and equivalent diameter were also observed in most of the components of epistasis.

Table 3. Estimation of the number of genes and narrow and broad heritability for the studied traits.

	Formulae 1		Formulae 2		Formulae 3	
	C.1	C.2	C.1	C.2	C.1	C.2
Area	0.046	2.870	25.529	0.0008	0.050	7.186
Length	0.012	0.079	0.020	0.032	0.041	0.189
Width	0.006	0.018	0.002	0.011	0.016	0.021
Eccentricity	0.007	0.047	2.207	2.485	0.006	0.085
Equivalent Diameter	0.017	1.894	0.011	8.197	0.069	2.050
Solidity	0	0.0006	0	4.351	0	0.002
Perimeter	0.016	0.004	5.843	3.660	0.018	0.014
Weight	0.0004	0.0003	8.71	9.363	0.0002	0.0003
	Formulae 4		**Formulae 5**		**Formulae 6**	
	C.1	C.2	C.1	C.2	C.1	C.2
Area	0.085	8.4	0.105	2.037	1.375	1.046
Length	0.005	0.012	0.021	0.579	0.029	0.214
Width	0.004	0.029	0.017	0.185	0.039	0.037
Eccentricity	0.0002	0.005	0.033	0.266	0.01	0.110
Equivalent Diameter	0.007	6.597	0.067	4.465	0.046	3.886
Solidity	0.0	4.438	0.0	0.002	0.0	0.003
Perimeter	0.019	0.009	0.04	0.009	0.430	0.018
Weight	0.0002	0.0003	0.0004	0.006	0.006	0.0006
	Average of genes number		**h^2b**		**h^2n**	
	C.1	C.2	C.1	C.2	C.1	C.2
Area	7.376	3.334	0.965	0.594	0.769	0.583
Length	0.022	0.183	0.865	0.794	0.142	0.778
Width	0.014	0.044	0.827	0.828	0.787	0.670
Eccentricity	0.378	0.611	0.883	0.919	0.05	0.75
Equivalent Diameter	0.037	4.515	0.842	0.804	0.682	0.75
Solidity	0.110	1.467	0.993	0.870	0.75	0.4
Perimeter	3.886	0.619	0.951	0.793	0.886	0.520
Weight	0.003	1.562	0.87	0.899	0.455	0.685

C1 and C2, presented N-92-9 × Ehsan, Kohdasht × Ehsan, respectively.

Therefore, the selection of optimal epistatic compounds is effective for breeding through the production of high-yielding wheat hybrids. Hence, in wheat breeding programs, not only the additive effect and the dominance effect but also the genetic interactions must be considered in parent selection and selection in segregating generations. The results indicated that there is a good genetic basis for the successful selection of genotypes in traits evaluated in this study. The existence of a dominance effect on the genetic control of the traits studied made the selection rather difficult and ambiguous, as the contribution of non-additive genetic variance was superior to additive genetic variance in most cases. Generation means analysis showed that in any case, the effects of epistasis and dominance, together with increasing effect, play a role in controlling the studied agricultural traits, including grain weight. This reveals the need to produce hybrid varieties of wheat (Longin *et al.*, 2012).

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Conflicts of Interest

The authors declare no conflicts of interest.

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ساختار ژنتیکی ویژگی‌های دانه گندم با استفاده از تکنیک‌های پردازش تصویر و تجزیه میانگین نسل ها

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چکیده

گندم (*Triticum aestivum* L.) به عنوان مهمترین غلات در جهان و مهمترین مواد غذایی در کشاورزی شناخته شده است. گندم به دلیل توزیع اکولوژیکی گسترده و تنوع مورفولوژیکی و فیزیولوژیکی، پتانسیل بالایی برای مطالعات ژنتیکی دارد. به منظور بررسی نحوه کنترل ژنتیکی صفات فیزیکی دانه در دو تلاقی گندم پائیزه(*Triticum aestivum* L.) ، ارقامN-92-9 ، کوهدشت و احسان و جمعیت-هایF1 ، F2، BC1 و BC2 حاصل از تلاقی آن‌ها بر پایه طرح بلوک‌های کامل تصادفی در سه تکرار ارزیابی شدند. مساحت، طول، عرض، خروج از مرکز، محیط، قطر، میزان سختی و وزن دانه با استفاده از پردازش تصویر ثبت شدند. تفاوت معنی‌دار بین نسل‌ها برای مساحت، طول، عرض، خروج از مرکز، محیط، قطر، میزان سختی و وزن دانه وجود داشت. برای بیشتر صفات مقدار ($F/(\sqrt{D\times H})$ کوچک‌تر از یک بود که بیانگر متفاوت بودن علامت و بزرگی اثر ژن‌های کنترل کننده این صفات می‌باشد. برای مساحت دانه وراثت پذیری عمومی با دامنه۰/۹۶۵ تا ۰/۵۹۴ و وراثت پذیری خصوصی با دامنه ۰/۷۶۹ تا ۰/۰۵ برای دو تلاقی برآورد گردید که بیشترین برآورد را در مقایسه با سایر صفات دارا بود. برای صفات مساحت، طول، عرض، محیط، میزان سختی و وزن دانه اثر غالبیت نقش بیشتری در کنترل وراثت ژنتیکی آن‌ها داشت و بر این اساس پیشنهاد می‌شود که برای اصلاح صفات طول و خروج از مرکز دانه در Kohdasht × Ehsan روش‌های اصلاحی مبتنی بر انتخاب و برای اصلاح صفات مساحت، طول، عرض، محیط، میزان سختی و وزن دانه در N-92-9 × Ehsan و صفات مساحت، طول، عرض، محیط، قطر، میزان سختی و وزن دانه در Kohdasht × Ehsan استفاده از هیبرید مدنظر قرار گیرد.

واژگان کلیدی: گندم؛ هیبرید؛ انتخاب؛ تجزیه میانگین نسل‌ها؛ وراثت پذیری

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