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COMBINING ABILITY AND GENE ACTION FOR GRAIN YIELD AND ITS CHEMICAL COMPOSITION UNDER NORMAL CONDITION AND HEAVY METAL STRESS IN BREAD WHEAT

Shymaa S. El Gharbawy*, M.I. Abdulhamid, R.M. Aly and A.H. Salem

Agron. Dept., Fac. Agric., Zagazig Univ., Egypt

ABSTRACT

Five diverse bread wheat genotypes (Sids 13, Giza 168, Gemmeiza 11, Line 1 and Line 2) were crossed in a half- diallel model in 2012/2013 season at the Experimental Farm, Faculty of Agriculture, Zagazig University, Egypt. The five parents and their ten F1 hybrids were evaluated for grain yield, its components and the chemical composition of grains under normal condition and heavy metals (Zn, Pb and Cd) stress in two adjacent experiments during 2013/2014 season. Each experiment was designed in a randomized complete block design with three replicates. Heavy metals stress reduced number of productive tillers/plant (1%), number of grains/spike (11.7%), 1000- grain weight (g) (11.6%) and grain yield / plant by (23%), while increased the grain content of each protein (1%), proline (13%), Zn (33%), Pb (51.7%) and Cd (32%) compared to the normal condition. Significant differences among parental wheat genotypes and their F1 crosses for grain yield/ plant, its components and chemical composition of wheat grains were recorded. Sids 13 proved to be better general combiner for grain yield /plant ,while L1 was good general combiner for grain yield/plant, protein and proline contents in wheat grains under both normal and stress environments. Both additive and dominance gene action were involved in the inheritance of wheat grain yield /plant, its components and the chemical composition of wheat grains with the prevailed type of dominance under both environments . Narrow sense heritability was high for proline content (67.73%), Cd content (61.05%) under stress condition and number of productive tillers/plant (50.31%) under the normal condition : moderate for grain yield /plant (47.25% and 32.06%), protein content (31.75% and 47.05%) under both environments, number of grains /spike (33.34 %) and Pb content (32.34%) under stress, the contents of proline (45.99%) and Zn (34.9%) under the normal condition. Whereas it was low for number of productive tillers /plant (26.91%), Zn content (24.7%) under stress, number of grains/spike (21.77%), Pb content (29.22%) and Cd content (21.66%) under the normal condition as well as 1000-grain weight (20.1% and 27.4%) under both environments, with the same respect.

Key words: Heavy metal, wheat, combining ability, gene action, diallel cross.

INTRODUCTION

Wheat is a potential source of food for over growing world population. Heavy metals such as Zinc (Zn), Lead (Pb) and Cadmium (Cd) are among the widespread toxic pollutants and have a notable adverse effects on wheat growth and productivity. The uptake of heavy metals not only constrains crop yield but can also a major hazard to the health of humans and the entire ecosystem.

Wheat breeding have devoted effect to develop superior genotypes for grain yield and adaptation to heavy metals stress. Heavy metals is a key factor responsible for grain yield and losses due to adverse effect on food safety and marketability (Gill, 2014). High yielding and tolerance to heavy metal condition are two different mechanisms that are often found to be oppose to each other.

Agricultural crops differ widely in their tolerance to toxicity of heavy metals (Belimov *et*

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* **Corresponding author:** **Tel.** : +201093260191
E-mail address: shymaa.elgharbawy@gmail.com

al., 2003). It has been shown that legume crops are less tolerant to heavy metal toxicity than cereals and grasses (Mazen, 1995). However, there are evidence that intraspecific genetic variation exists in the tolerance of (*Triticum aestivum* L.) to heavy metals. Thus wheat cultivars ACSAD 903 and Sakha 94 were more tolerant to lead than ACSAD 925 (Awaad *et al.,* 2010), wheat cultivar Sehar 06 performed well under Cd stress, while Inqlab 91 had poor performance (Ahmad *et al.,* 2012)and wheat cultivar Chakwal 97 was more tolerant to lead stress than Sehar 06 (Bhatti *et al.,* 2013)

Information on the combining ability of parents and their behavior in hybrid combinations prerequisite. Among various genetic techniques, combining ability analysis outlined by Griffing (1956) which partition the total genetic variation into general combining ability (GCA) of the parents and specific combining ability (SCA) of the crosses have been widely used. The GCA and SCA variances provide estimation for additive and non-additive gene action, respectively (Falconer, 1989). Many workers have reported GCA and SCA effects for yield and yield components in wheat (Farooq *et al.,* 2006; Hassan *et al.,* 2007; Kashif and Khan, 2008; Awaad *et al.,* 2010; Anwar *et al.,* 2011; Jain and Sastry, 2012).

Keeping in view the importance of wheat as a major food and the excessive use of Zn, Pb and Cd in various industries, the present investigation has been conducted to study the impact of heavy metals on the performance, combining ability and genetic behavior which ultimately results in phenotypic variation between normal and heavy metals stress for wheat grain yield, its components and chemical composition of grains.

MATERIALS AND METHODS

Field experiments were performed during the two successive seasons 2012/2013 and 2013/2014 at the Experimental Farm, Faculty of Agricultural, Zagazig University. Five diverse bread wheat genotypes *i.e.* Sids 13, Giza 168, Gemmeiza 11, Line 1 and Line 2 (Table1) were sown in the first season 2012/2013 on two sowing dates (20 and 30 November) in order to overcome the differences in flowering time and facilitate hybridization. All possible parental combinations excluding reciprocals were made among the five parental genotypes giving ten crosses. Necessary precautions were adopted during the crossing operations to avoid contamination of the genetic material.

Seeds of the ten F1 hybrids along with their five parents were sown in the second season 2013/2014 and evaluated under two sets of conditions. The first set was sprayed with distilled water after 45 and 90 days from sowing and used as normal condition (control). The second set was sprayed with mixture of heavy metals Zn, Pb and Cd after 45 and 90 days from sowing. The mixture of heavy metals was prepared using Zinc sulphate, Lead acetate and Cadmium carbonate with concentrations of 500, 250 and 250 mg/l, respectively. This toxic dose was previously used by Gough *et al.* (1979) and Chen *et al.* (2003). The two sets of conditions were conducted in two adjacent experiments. Each experiment was designed in a randomized complete block design (RCBD) with three replications. For each experiment, each cross was planted in a plot of five rows, 3m length each (2 rows for each parent and 1 row for the F1 cross). Inter and intra row spacings were kept at 20cm and 10cm, respectively. All recommended agronomic practices for wheat production and inputs like irrigation, manuring and weed control… *ect.*, were kept uniform for all entries from sowing till harvesting to minimize environmental variation to the maximum extent.

For data collection, ten competitive plants for each parent and cross were tagged at random in each replicate. Observations were recorded for number of productive tillers/plant, number of grains/ spike, 1000-grain weight (g) and grain yield/plant (g). In addition, chemical compositions of protein (%), proline (%), Zn (mg/ 100g dry weight), Pb (mg/100 g dry weight) and Cd (mg/ 100g dry weight) were determined in the grains of the studied materials.

Grain protein content (%) was determined using the micro kjeldahl method to estimate the total nitrogen in the grains and multiplied by 5.75 to determine the percentage of protein according to AOAC (1980). The amino acid proline (%) in the grains was determined using the procedure of Bates *et al.* (1973). The heavy metals Zn, Pb and Cd were determined in wheat

Table 1. Name, origin and pedigree of the studied parental bread wheat genotypes

Name	Pedigree	Origin
Sids 13	ALMAZ – 19 = KAUZ "S" // TSI / SNB "S" LCW 94 – 0375 - 4AP - 2 AP - O30AP – OAPS - 3AP –OAPS - O50AP – OAP - OSD	Egypt
Giza 168	MIL/BUC//Seri:CM93046-8m-oy-om-2y-OB.	Egypt
Gemmeiza 11	BOW "S" /KVZ "S" //7C/Seri 82/3/ Giza 168/Sakha61 GM 78922 – GM – 1 GM – 2 GM – 1 GM - OGM	Egypt
Line 1	Sakha 93/Sids6 CGZ(16)GM-2GM-OGM	Egypt
Line 2	Giza 168/Sids7 CGZ(7)4GM-2GM.OGM	Egypt

grains using the method outlined by Jones and Case (1990). Analysis of the extract was performed using atomic absorption spectrophotometer at wave length of 540, 660 and 645nm, respectively.

Statistical Analysis

The collected data were subjected to analysis of variances proposed by Steel *et al.* (1997). Estimation of general (GCA) and specific (SCA) combining ability were computed according to Griffing, (1956) designated as method 2, model 1 for the studied characters. To obtain information on genetic mechanisms of the studied characters, the relative magnitude of the genetic components of variance was estimated using diallel analysis procedure as outlined by Hayman (1954) and Mather and Jinks (1982).

RESULTS AND DISCUSSION

One of the major difficulties in improving tolerance to heavy metal in wheat is the proper methodology that must insure an efficient evaluation of large number of crop plants (Piotto *et al.,* 2014). Development of wheat genotypes tolerant to heavy metal and high yielding is different from other approaches on account various selection criteria under heavy metal stress. Scarce information is available on combining ability, gene action and heritability for wheat genotypes traits tolerant to heavy metals. The diallel analysis of wheat genotypes under heavy metal stress provides information related to these genetic parameters and help to select the breeding strategies.

The availability of genetically based variation for wheat yield components like number of productive tillers/plant, number of grains/spike, 1000-grain weight (g) and grain weight/plant (g) as well as chemical composition of grains like protein (%), proline (%), Zn, Pb and Cd contents are a pre-requisite for the selection of new high yielding wheat genotypes tolerant to heavy metal stress. The present wheat materials were studied to generate information on the effect of heavy metal stress on the performance, general and specific combining ability, gene action and heritability for wheat grain yield and chemical composition of grains.

Yield and its Components

Grain weight/plant represent the final product of the physiological processes which occur in the plant. The results given in Table 2 show the effect of heavy metals stress on the mean performance of wheat grain yield and its components. It is evident that heavy metals treatment reduced grain weight/plant by 23% compared to the normal condition (control). This reduction was attributed with the reduction in number of grains/spike (13%) and 1000-grain weight (13%). Similar findings were reported by Athar and Ahmad (2002) and Chibuike and Obiora (2014) who indicated that heavy metals reduced growth, performance ,grain yield and dry weight of wheat plants.

The results revealed significant differences among parental wheat genotypes and their F1 crosses for number of productive tillers/plant, number of grains/spike, 1000-grain weight, and

Table 2. Mean performance of five wheat parents and their F1 crosses for yield and yield component characters under normal and heavy metal conditions

Characters Genotypes	No. of productive tillers/plant		No. of grains / spike		1000- grain weight (g)		Grain weight /plant(g)	
	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
Sids13	6.00	5.3	65.07	61.54	50.53	41.07	18.44	13.28
Giza168	4.47	2.6	73.13	63.73	43.63	43.30	13.26	7.04
Gemmeiza11	5.40	4.8	69.73	63.60	57.20	54.27	21.36	16.22
L1	5.50	5.3	67.50	66.87	52.47	51.47	19.01	18.10
L2	4.03	4.5	61.20	48.85	49.67	46.27	10.06	10.09
P1 x P2	10.17	7.87	72.27	65.53	52.40	39.50	38.40	19.78
P1 x P3	6.20	6.87	76.67	62.20	41.53	41.52	18.90	17.71
P1 x P4	7.90	7.63	89.47	74.73	51.27	39.53	36.01	22.31
P1 x P5	6.13	6.07	71.90	61.47	47.63	44.60	21.48	16.55
P2 x P3	6.67	6.87	62.72	56.15	43.07	33.41	17.92	12.79
P2 x P4	5.77	8.47	80.13	62.47	57.07	47.47	26.36	25.11
P2 x P5	5.40	5.60	58.17	55.90	53.37	52.37	16.62	16.43
P3 x P4	6.53	5.67	62.43	60.27	53.07	43.10	21.34	14.49
P3 x P5	3.73	5.00	77.67	68.93	52.17	44.20	15.32	14.98
P4 x P5	5.13	5.60	68.20	60.40	51.07	46.43	17.28	15.76
LSD	0.87	0.65	7.02	4.93	4.96	4.44	0.73	0.81

grain weight/plant, under both normal and stress conditions (Table 2). These results provide evidence that the studied genotypes were genetically different in genes controlling grain yield and its components. The obtained results were previously supported by Jain and Sastry (2012) and Barraclough *et al.* (2014).

It is evident that parental wheat genotypes Gemmeiza 11 and Sids 13 and the crosses Sids 13 x Giza 168 and Sids13 x L1 performed well for grain yield under normal condition and had poor performance under heavy metal stress. On the other hand, parental wheat genotype L1 and the crosses Sids 13 x Gemmeiza 11 and Giza 168 x L1 performed well for grain yield/plant under both normal and stress conditions, suggesting that the latter wheat genotypes are more tolerant to heavy metal stress. Similar findings were also reported by Ahmad *et al.* (2012) and Bhatti *et al.* (2013).

The analysis of variance showed highly significant differences among parental genotypes, their F1 crosses and parents *vs* crosses for number of productive tillers/plant, number of grains/spike, 1000-grain weight and grain weight/plant under both the normal and heavy metals stress conditions (Table 3). This result suggested the presence of considerable amount of genetic variability for genes controlling yield and yield components and valid for further genetic assessments.

The estimates of mean squares due to general (GCA) and specific (SCA) combining ability effects (Table 4) indicated highly significance difference for all studied characters under both environments, revealing that both additive and non-additive variations were present in the inheritance of grain yield and its components under the normal and heavy metal stress conditions. The findings of the present study for number of productive tillers/plant, number of grains/spike, 1000-grain weight and grain weight/plant in which both additive and non-additive gene action played important role in the inheritance of these characters were in conformity with several of the earlier findings (Hasnain *et al.*, 2006; Chowdhary *et al.*, 2007 ; Akram *et al.*, 2011).

Table 3. Mean squares of five wheat parents and their F1 crosses for yield and yield component characters under normal and heavy metal conditions

SOV	d.f	No. of productive tillers/plant		No. of grains / spike		1000 grain weight (g)		Grain weight /plant(g)	
		Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
Replicates	2	0.11	0.26	11.59	1.51	22.57	13.28	0.98	0.67
Genotypes	14	7.46**	6.68**	206.24**	107.60**	65.48**	89.64**	177.02**	60.29**
Parents	4	1.95**	3.74**	61.64**	147.39**	72.30**	91.36**	64.28**	60.37**
Crosses	9	8.91**	4.00**	269.55**	97.92**	69.51**	80.51**	199.27**	42.97**
P. vs. C.	1	16.47**	42.57**	214.85**	35.63**	1.91**	164.89**	427.76**	215.76**
Error	28	0.27	0.15	17.49	8.63	8.74	7.01	0.19	0.23

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

Table 4. Mean squares for general (GCA) and specific (SCA) combining ability for yield and yield components characters under normal and heavy metal conditions

SOV	d.f	No. of productive tillers/plant		No. of grains / spike		1000 grain weight (g)		Grain weight /plant(g)	
		Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
Genotypes	14	7.46**	6.68**	206.24**	107.60**	65.48**	89.64**	177.02**	60.29**
GCA	4	10.95**	4.36**	116.68**	149.27**	41.49**	84.49**	230.78**	62.91**
SCA	10	6.07**	7.61**	242.06**	90.94**	75.08**	91.70**	155.52**	59.23**
Error	28	0.27	0.15	17.49	8.63	8.74	7.01	0.19	0.23
$\sigma2$ GCA/ $\sigma2$ SCA		1.80	0.57	0.48	1.64	0.55	0.92	1.48	1.06

* and ** , are significant at 0.05 and 0.01 levels of probability , respectively.

The obtained results indicated the possibility of utilizing integrated breeding strategies including pedigree selection,. diallel hybridization and recurrent selection, *etc*... would be useful for utilizing additive and non-additive variations for selection of transgressive genotypes and developing superior genotypes thereafter.

The magnitude of GCA was larger than SCA for number of productive tillers/plant under the normal condition, number of grains/spike under heavy metal stress and grain weight/plant under both conditions, indicating the predominance of additive gene action in the heridity of these characters under certain environments. However, the ratio between GCA and SCA variances was less than unity for number of productive tillers/plant under stress condition, number of grains/spike under the normal condition and 1000-grain weight under both conditions, indicating the important role of non-additive gene action in the heredity of these characters under such condition.

Estimates of GCA effects of the parental wheat genotypes are shown in (Table 5). It is quite evident that both wheat genotypes Sids 13 and Line1 proved to be better general combiners for grain weight/plant with GCA values (3.85**

Table 5. General combining ability (GCA) effects for yield and yield components under normal and heavy metal conditions

Genotype	No. of productive tillers/plant		No. of grains /spike		1000 grain weight (g)		Grain weight /plant(g)	
	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
Sids 13	0.97**	0.54**	2.56**	1.99*	-1.22*	-2.87**	3.85**	0.95**
Giza168	0.19	-0.18*	-0.42	-0.79	-1.33*	-1.15**	0.16	-1.15**
Gemmeiza11	-0.24*	-0.18*	-0.51	0.24	0.25	0.48	-1.21**	-0.55**
L1	0.10	0.39**	1.82*	2.65**	2.14**	1.72**	2.05**	2.52**
L2	-1.02**	-0.57**	-3.45**	-4.09**	0.16	1.82**	-4.84**	-1.77**
S.E.(gi-gj)	0.101	0.075	0.816	0.573	0.577	0.517	0.085	0.095

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

and 2.05**) under the normal condition and (0.95** and 2.52**) under heavy metal stress, in the same respect. Sids 13 also proved as best combiner for number of productive tillers/plant and number of grains/spike under both normal and stress conditions. L1 was good combiner for 1000-grain weight under both conditions. The comparison of GCA effect values showed that wheat genotypes Giza 168, Gemmeiza 11 and L 2 were the poorest general combiners for most of the studied characters. These results suggest that the two parental wheat genotypes Sids 13 and L 1 can be further used as the source material in the development of segregating generation.

The estimates of SCA effects of the crosses for yield and its components are shown in Table 6. It is evident that the cross combination Sids 13 x Giza 168 showed positive and significant SCA values for grain weight/plant (13.6** and 3.94**) and number of productive tillers/plant (3.07** and 1.63**) under both normal and stress environments with the same respect. The cross Giza 168 x L1 gave the highest SCA value (7.71**) for grain weight under heavy metal stress condition. These crosses involved one poor general combiner (Giza 168) while the other was a good combiner (Sids 13 or L1). It is obvious that a parent with low GCA effect may have the potential to be exploited through hybridization with good general combiner (Akram *et al.,* 2011). The cross Sids 13 x L1 which involved the two good general combiners showed the best SCA effects for number of productive tillers/ plant, number of grains/spike and grain weight/ plant under both conditions.

The estimates of genetic variation for grain weight/plant and its component characters are given in Table 7. Although the additive component D was significant for number of productive tillers/plant under stress and 1000-grain weight under the normal condition, it was positive for all studied characters under both conditions. The dominance components H_1 and H_2 were positive and significant for grain weight/plant and its components under the normal and stress environments. These results indicate the contribution of both additive and dominance effects in controlling the mechanism of inheritance of these characters. The magnitude of H_1 was larger than D, suggesting more contribution of the over-dominance effects in controlling the inheritance of these characters as compared to additive ones. These results are in accordance with the finding of Badieh *et al.* (2012).

The magnitude of dominance values H_1 and H_2 were approximately equal to each other for number of productive tillers/plant under both conditions, confirming the existence of approximately equal proportion of positive and negative alleles in the parents. However, number of grains/spike, 1000-grain weight and grain weight/plant had unequal positive and negative alleles in the parents.

Table 6. Specific combining ability (SCA) effects for yield and yield components under normal and heavy metal conditions

Crosses	No. of productive tillers/plant		No. of grains /spike		1000 grain weight (g)		Grain weight /plant(g)	
	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
P1 x P2	3.07**	1.63**	-0.29	2.16*	4.54**	-1.04	13.60**	3.94**
P1 x P3	-0.47**	0.63**	4.20**	-2.21*	-7.91**	-0.65	-4.52**	1.26**
P1 x P4	0.89**	0.83**	14.67**	7.92**	-0.06	-3.88**	9.33**	2.80**
P1 x P5	0.25	0.22	2.37	1.39	-1.71	1.09	1.69**	1.33**
P2 x P3	0.78**	1.35**	-6.77**	-5.48**	-6.27**	-10.49**	-1.81**	-1.55**
P2 x P4	-0.46**	2.38**	8.32**	-1.57	5.85**	2.33**	3.37**	7.71**
P2 x P5	0.30	0.47**	-8.38**	-1.39	4.13**	7.13**	0.52**	3.31**
P3 x P4	0.73**	-0.42**	-9.30**	-4.80**	0.27	-3.67**	-0.28*	-3.52**
P3 x P5	-0.94**	-0.13	11.21**	10.61**	1.34	-2.67**	0.59**	1.25**
P4 x P5	0.12	-0.09	-0.58	-0.33	-1.64	-1.68*	-0.71**	-1.04**
S.E.(sij - sji)	0.160	0.119	1.291	0.907	0.913	0.817	0.135	0.150

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

Table 7. Components of genetic variances and their derived parameters for yield and yield components under normal and heavy metal conditions

Genetic component	No. of productive tillers/plant		No. of grains / spike		1000 grain weight (g)		Grain weight /plant(g)	
	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals	Normal	Heavy metals
D	0.61	1.22	18.17	48.00**	22.76*	29.42	21.39	20.09
H_1	7.89*	8.70**	330.95**	127.11**	110.93**	123.71*	207.98*	74.74*
H_2	6.11*	6.66**	272.09**	102.81**	78.09**	94.17*	153.10	57.58*
F	-0.76	2.02	37.86	45.47	45.10	40.40	7.63	23.62
E	0.04	0.02	2.37	1.13	1.34	1.03	0.03	0.04
h^2	4.19*	10.88**	53.48	8.40	-0.37	41.55	109.49	55.21**
$(H_1/D)^{1/2}$	3.59	2.67	4.27	1.63	2.21	2.05	3.12	1.93
$H_2/4H_1$	0.19	0.19	0.21	0.20	0.18	0.19	0.18	0.19
KD/KR	0.71	1.90	1.65	1.82	2.63	2.01	1.12	1.88
h^2/H_2	0.69	1.63	0.20	0.08	0.00	0.44	0.72	0.96
h(n.s)	50.31	26.91	21.77	33.34	20.10	27.40	47.25	32.06

* and **,, are significant at 0.05 and 0.01 levels of probability , respectively.

The value of F which measure the relative frequency of dominant to recessive alleles in the parents. F_1 was positive and insignificant for almost studied characters, implying the excess of dominant alleles in the parents. However, F value proved to be negative for number of productive tillers/plant under the normal condition, indicating the excess of recessive alleles in the parents. Negative F values indicate the important role of recessive genes for number of productive tillers/plant under the normal condition and positive F value under heavy metal stress, showing the important role of dominant genes for this character. Thus, heavy metals stress had an effect on the inheritance of number of productive tillers/plant.

Grain weight/plant and its components had not been significantly affected by environmental component E under both the normal and stress environments. These results indicate that the environmental factors were not important in determining these characters.

The measurement of net dominance (h^2) was positive and significant for grain weight/plant under stress and number of productive tillers/plant under both environments. h^2 had positive sign for all characters under study, except 1000-grain weight under the normal condition which exhibited negative sign. It indicated the direction of dominance mean that positive sign showed dominance of genes with increasing effect at most of loci and negative sign illustrated dominance of genes with decreasing effect (Ali *et al.*, 2008).

The value of $(H_1/D)^{1/2}$ is the measure of average degree of dominance (Table 7), it was more than unity for grain weight/plant and its component characters under both environments which confirmed the greater contribution of non-additive genes in the inheritance of these characters. These results are in accordance with the finding of Nazeer *et al.* (2011) and Awaad *et al.* (2013) who reported that dominance genetic variance played a major role in controlling grain weight/plant in all studied wheat crosses. The preponderance of dominance effects for these characters, suggesting that selection for these characters in early generations may not be useful and it had to be delayed till late segregation generations. Hence utilization of heterosis breeding could be rewarding for these characters.

The estimates of the ratio $H_2/4H_1$ were deviated from 0.25 for all the studied characters under both environments (Table 7), confirming the unequal distribution of positive and negative alleles among the parents. In this connection asymmetrical alleles were also reported for number of grains/spike and spike grain weight (Nazeer *et al.*, 2011).

The proportion of dominance and recessive genes (KD/KR) in the parents revealed that dominant genes were more frequent than recessive ones for all studied characters under both environments, except for number of productive tillers/plant under the normal condition which exhibited more recessive genes than dominant ones, thus heavy metal stress had an effect on the genetic mechanism of number of productive tillers/plant confirming the previous results of the frequency of dominant and recessive alleles in the parents measured by F.

Narrow sense heritability is a parameter used for effectively isolating the magnitude of additive genetic variation from the total phenotypic variation. Selection efficiency for a plant character depends on the magnitude of narrow sense heritability and genetic variation (Falconer and Mackay, 1996). Narrow sense heritability is directly proportional to additive genetic variance. The estimates of narrow sense heritability were relatively high (50.31%) under the normal conditions and relatively low (26.91%) under heavy metal stress for number of productive tillers/plant, indicating better chance for improving this character following phenotypic selection procedure under the normal condition. In this connection, relatively high narrow sense heritability for this character was reported by Kulshreshrtha and Singh (2011). While, Farshadfar *et al.* (2013) recorded very low (2%) value of narrow sense heritability in this respect. Number of grains/spike present low heritability (21.77%) under normal condition and moderate (33.34%) under stress condition. Moderate narrow sense heritability (44%) for number of grains/spike was also recorded by Kulshreshrtha and Singh (2011). 1000-grain weight presented low (20.1 and 27.4%) narrow sense heritability under the normal and stress environments, respectively. Low estimate of narrow sense heritability (14%) for 1000-grain weight was estimated by Farshadfar *et al.*

(2013). Grain weight/plant presented moderate narrow sense heritability (47.25 and 32.06%) under the normal and stress environments, respectively. Such moderately high narrow sense heritability for grain weight/plant was reported by Akram *et al.* (2009), Farooq *et al.* (2010) and Kulshreshrtha and Singh (2011). However, Erkul *et al.* (2010) found low narrow sense heritability for grain weight/plant. The differences in genetic materials, environmental factors and analytical technique used in this study could account for these differences.

Chemical Composition of Grains

Data presented in Table 8 show the effect of heavy metal stress on the content of protein, proline, Zn, Pb and Cd in wheat grains of five parental genotypes and their ten crosses. Heavy metal treatment resulted in an increment of 1% for protein, 13% for proline, 33% for Zn, 51.7% for Pb and 32% for Cd. The increments of chemical composition of wheat grains due to heavy metals (Zn, Pb and Cd) stress were previously recorded for proline (Weihong *et al.*, 2009 ; Awaad *et al.*, 2010), Pb and Cd (Nan *et al.*, 2002).

The results presented in Table 8 showed significant differences among parental wheat genotypes and their F1 crosses for the chemical composition of wheat grains *i.e.* the content of protein, proline, Zn, Pb and Cd under both normal and stress environments. These results provide evidence that the studied genotypes were genetically different for genes controlling the chemical composition of wheat grains. The obtained results are in accordance with the finding of Loncaric *et al.* (2012) who concluded that soil and wheat genotypes have significant impact on potential daily intake of toxic and essential heavy metals by wheat grains.

The analysis of variance (Table 9) revealed highly significant differences among parental genotypes, their F1 crosses and parent *vs* crosses for all parameters of grains chemical composition under both normal and stress environments. These results suggested the presence of considerable amount of genetic variability for genes controlling the chemical composition of wheat grains. In addition the significance values of parents *vs* crosses, indicated the heterotic pattern in this respect.

The estimates of mean squares due to general (CCA) and specific (SCA) combining ability (Table 10) illustrated highly significant differences for all parameters of grains chemical composition under both normal and stress conditions, these results indicated that both additive and non-additive variations were involved in the genetic mechanism of grains chemical composition. However, the magnitude of GCA was larger than SCA for protein (%), praline (%) in wheat grains under both normal and stress environments, Zn content under the normal and Cd content under stress environments, indicating the predominance of additive gene action in the genetic mechanism of these characters. Similar findings were also reported by Khodadadi *et al.* (2012) for protein content and Awaad *et al.* (2010) for proline content in wheat grains. These results are inconformity with the calculated ratio between GCA and SCA variances which was more than unity for the above mentioned characters. However, this ratio was less than unity for Zn content under stress, Pb content under both environments and Cd content under normal condition, showing that the non-additive gene action played an important role for these traits under these environments. These results suggested that heavy metal stress resulted in altering the inheritance pattern for Cd content by converting it from dominance gene action towards additive one.

Estimation of GCA effects for the parental wheat genotypes (Table 11) revealed that wheat genotype L1 proved to be better general combiner for protein content with GCA values of 0.22** and 0.29**, proline content with values of 0.06** and 0.26**, Zn content with values of 0.42** and 1.66**, Pb content with value of 0.01** and 0.01** under both the normal and stress environments, respectively. Gemmeiza 11 was good combiner for proline content, and L 2 for Zn content. Wheat genotype Sids 13 was the poorest general combiner for almost studied parameters of grain chemical composition.

The estimates of SCA effects of the crosses for the chemical composition of wheat grains (Table 12) revealed that the cross P2 x P3 showed positive and significant SCA values for protein content (0.46** and 0.43**) and proline content (0.32** and 0.36**) under both the

Table 8. Mean performance of five wheat parents and their F1 crosses for grains chemical content under normal and heavy metal conditions

Characters / Genotypes	Protein (%) Normal	Protein (%) Heavy metal	Proline (%) Normal	Proline (%) Heavy metal	Zn content (mg/100 g dry weight) Normal	Zn content (mg/100 g dry weight) Heavy metal	Pb content (mg/100 g dry weight) Normal	Pb content (mg/100 g dry weight) Heavy metal	Cd content (mg/100 g dry weight) Normal	Cd content (mg/100 g dry weight) Heavy metal
Sids 13	12.22	11.16	7.10	8.70	32.65	45.30	0.02	0.12	0.12	0.14
Giza 168	10.41	11.44	7.47	9.05	36.50	47.50	0.01	0.11	0.11	0.12
Gemmeiza 11	10.84	12.06	8.97	9.88	35.55	48.45	0.02	0.11	0.12	0.14
L1	12.09	12.19	7.27	10.05	34.50	51.50	0.02	0.13	0.11	0.20
L2	10.81	11.56	6.80	10.18	36.35	44.45	0.02	0.12	0.11	0.14
P1 x P2	11.31	11.30	8.22	8.87	34.58	46.40	0.02	0.12	0.12	0.13
P1 x P3	11.53	10.34	7.83	8.38	31.05	31.65	0.01	0.11	0.10	0.12
P1 x P4	11.00	11.03	7.86	8.40	33.30	40.35	0.01	0.11	0.11	0.18
P1 x P5	11.97	11.41	8.10	8.52	31.60	44.70	0.02	0.12	0.11	0.13
P2 x P3	11.47	12.16	9.19	9.81	30.65	41.35	0.01	0.01	0.11	0.15
P2 x P4	11.25	11.81	8.75	9.55	35.50	49.50	0.02	0.12	0.11	0.14
P2 x P5	11.13	11.56	8.10	8.84	34.15	46.30	0.01	0.11	0.11	0.11
P3 x P4	11.97	12.38	9.72	9.74	33.80	47.35	0.12	0.12	0.11	0.15
P3 x P5	11.41	11.06	9.52	9.99	32.55	49.35	0.02	0.13	0.11	0.18
P4 x P5	11.44	11.66	9.13	10.06	34.00	41.80	0.02	0.12	0.11	0.18
$LSD_{0.05}$	0.34	0.22	0.04	0.05	0.41	0.25	0.002	0.002	0.002	0.015

Table 9. Mean squares of five wheat parents and their F1 crosses for grains chemical content under normal and heavy metal conditions

SOV	d.f	Protein (%) Normal	Protein (%) Heavy metal	Proline (%) Normal	Proline (%) Heavy metal	Zn content (mg/100 g dry weight) Normal	Zn content (mg/100 g dry weight) Heavy metal	Pb content (mg/100 g dry weight) Normal	Pb content (mg/100 g dry weight) Heavy metal	Cd content (mg/100 g dry weight) Normal	Cd content (mg/100 g dry weight) Heavy metal
Replicates	2	0.04	0.02	0.00001	0.002	0.23	0.04	0.00001	0.000005	0.000004	0.0003
Genotypes	14	0.80**	0.86**	2.48**	1.35**	9.95**	71.27**	0.002**	0.0025**	0.0001**	0.002**
Parents	4	2.04**	0.56**	2.14**	1.30**	7.57**	23.27**	0.0001**	0.0001**	0.00004**	0.003**
Crosses	9	0.30**	1.04**	1.50**	1.38**	7.71**	86.40**	0.003**	0.0036**	0.00005**	0.002**
P. vs. C.	1	0.30**	0.44**	12.57**	1.25**	39.70	127.09**	0.0005**	0.0015**	0.0002**	0.000004
Error	28	0.04	0.02	0.001	0.001	0.06	0.02	0.000001	0.000002	0.000001	0.0001

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

Table 10. Mean squares for general (GCA) and specific (SCA) combining ability for grains chemical content under normal and heavy metal conditions

SOV	d.f	Protein (%)		Proline (%)		Zn content (mg/100 g dry weight)		Pb content (mg/100 g dry weight)		Cd content (mg/100 g dry weight)	
		Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal
Genotypes	14	0.80**	0.86**	2.48**	1.35**	9.95**	71.27**	0.002**	0.002**	0.0001**	0.002
GCA	4	1.31**	1.42**	3.67**	3.18**	10.75**	53.01**	0.0018**	0.00233**	0.00003**	0.005**
SCA	10	0.60**	0.64**	2.00**	0.62**	9.64**	78.57**	0.0024**	0.00255**	0.0001**	0.001**
Error	28	0.04	0.02	0.001	0.001	0.06	0.02	0.000001	0.000002	0.000001	0.0001**
σ2 GCA/σ2 SCA		2.20	2.2	1.83	5.14	1.12	0.7	0.76	0.91	0.51	5.3

* and ** , are significant at 0.05 and 0.01 levels of probability , respectively.

Table 11. General combining ability (GCA) effects for grains chemical Content under normal and heavy metal conditions.

Genotypes	Protein (%)		Proline (%)		Zn content (mg/100 g dry weight)		Pb content (mg/100 g dry weight)		Cd content (mg/100 g dry weight)	
	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal
Sids13	0.27**	-0.41**	-0.48**	-0.63**	-0.98**	-2.383**	-0.01**	0.007**	0.002**	-0.006**
Giza168	-0.34**	0.07*	-0.06**	-0.12**	0.74**	1.17**	-0.01**	-0.01**	0.0002	-0.02**
Gemmeiza 11	-0.04	0.12**	0.65**	0.24**	-0.51**	-0.54**	0.01**	-0.01**	-0.002**	0.0004
L1	0.22**	0.29**	0.06**	0.26**	0.42**	1.66**	0.01**	0.01**	-0.001**	0.02**
L2	-0.11**	-0.06*	-0.17**	0.25**	0.33**	0.10**	-0.01**	0.01**	0.001**	-0.001
S.E.(gi-gj)	0.04	0.03	0.005	0.01	0.048	0.03	0.0002	0.0002	0.0002	0.002

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

Table 12. Specific combining ability (SCA) effects for grains chemical Content under normal and heavy metal conditions

Crosses	Protein (%)		Proline (%)		Zn content (mg/100 g dry weight)		Pb content (mg/100 g dry weight)		Cd content (mg/100 g dry weight)	
	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal
P1 x P2	-0.01	0.10*	0.50**	0.29**	1.03**	2.55**	0.01**	0.01**	0.0029**	0.005
P1 x P3	-0.09	-0.91**	-0.61**	-0.56**	-1.25**	-10.49**	-0.02**	0.001*	-0.0091**	-0.02**
P1 x P4	-0.88**	-0.39**	0.02**	-0.56**	0.08	-3.99**	-0.02**	-0.01**	-0.0036**	0.01**
P1 x P5	0.42**	0.33**	0.48**	-0.43**	-1.53**	1.92**	0.01**	-0.003**	0.0002	-0.01*
P2 x P3	0.46**	0.43**	0.32**	0.36**	-3.37**	-4.34**	-0.01**	-0.08**	-0.0048**	0.02**
P2 x P4	-0.016	-0.08*	0.49**	0.07**	0.562**	1.61**	-0.008**	0.01**	0.0007*	-0.01**
P2 x P5	0.18**	0.02	0.06**	-0.63**	-0.70**	-0.03	0.0003	0.01**	-0.0011**	-0.02**
P3 x P4	0.40**	0.43**	0.74**	-0.10**	0.11	1.17**	0.08**	0.01**	0.0009*	-0.02**
P3 x P5	0.17**	-0.53**	0.76**	0.17**	-1.06**	4.73**	-0.004**	0.02**	-0.0019**	0.03**
P4 x P5	-0.06	-0.11*	0.97**	0.21**	-0.53**	-5.02**	-0.01**	-0.01**	0.0011**	0.01**
SE(sij-sji)	0.06	0.04	0.01	0.01	0.08	0.05	0.0004	0.0004	0.0003	0.003

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

normal and stress environments, respectively. The cross Gemmeiza 11 x L1 exhibited positive and significant SCA values for protein content (0.40** and 0.43**) under both conditions, and proline content (0.74**) under the normal condition.

The component of genetic variances for the chemical composition of wheat grains (Table 13) revealed that the additive component D was significant for protein content under the normal environment, proline content under both environments and Cd Content under heavy metal stress. It was positive for all the studied parameters of chemical composition of wheat grains. The dominance components H_1 and H_2 were positive and significant for protein, proline, Zn and Cd contents under both environments. These results indicate contribution of both additive and dominance with major role of dominance in controlling the genetic mechanism of these characters. The magnitude of H1 was larger than D revealing a great contribution of the over-dominance effect in controlling these parameters.

The dominance value of H_1 was more than H_2 for all the studied parameters of chemical composition of wheat grains under both the control and stress conditions. This indicated the unequal proportion of positive and negative alleles in the parents. These results were confirmed by the positive values of F for all parameters of grains chemical composition, implying the excess of dominant alleles in the parents.

The measurement of net dominance h^2 had positive sign for all the studied parameters of chemical composition of wheat grains , showing the existence of dominance genes with increasing effect at most of loci. These results were supported by the values of $(H_1/D)^{1/2}$ which were more than unity for all the studied parameters under both environments.

The ratio of $H_2/4H_1$ was deviated from 0.25 for all the studied parameters, confirming the unequal distribution of positive and negative alleles in the parents. These results were supported by the values of KD/KR which revealed that dominant genes were more frequent than recessive ones in the parents for all the studied parameters under both environments.

Narrow sense heritability exhibited high values (67.73 and 61.05%) for proline and Cd contents, respectively under stress environment, however, it was moderate (45.99%) for proline content and low (21.66%) for Cd content under the normal condition. Thus, heavy metal stress had an effect on the genetic mechanism of proline and Cd contents in wheat grains. Thus, it resulted in altering the inheritance pattern for proline and Cd contents from dominance gene action towards additive one, making selection for improving these parameters is easier. The values of narrow sense heritability for the other parameters ranged from low to moderate values in this respect. In this connection, moderate narrow sense heritability (44%) was reported for protein content in wheat grains (Khodadadi *et al.*, 2012) which supported the results obtained in the present study.

Table 13. Components of genetic variances and their derived parameters for grains chemical content under normal and heavy metal conditions

Genetic component	Protein (%)		Proline (%)		Zn content (mg/100 g dry weight)		Pb content (mg/100 g dry weight)		Cd content (mg/100 g dry weight)	
	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal	Normal	Heavy metal
D	0.67**	0.19	0.71**	0.43**	2.51	7.75	0.00003	0.00004	0.00001	0.001**
H_1	0.87**	0.87*	2.12**	0.82**	11.71*	103.67*	0.003	0.004	0.0001*	0.001**
H_2	0.62*	0.75*	1.82**	0.68**	9.37*	90.39*	0.003	0.003	0.0001*	0.001**
F	0.78**	-0.03	0.23	-0.15	2.32	6.21	-0.00011	-0.0002	0.00002	0.0001
E	0.006	0.002	0.0001	0.0001	0.01	0.003	0.0000002	0.0000003	0.0000002	0.00001
h^2	0.07	0.11	3.22**	0.32**	10.16**	32.53	0.00012	0.0004	0.00005*	-0.00001
$(H_1/D)^{1/2}$	1.14	2.17	1.72	1.37	2.16	3.66	10.43	9.00	2.60	1.15
$H_2/4H_1$	0.18	0.22	0.21	0.21	0.20	0.22	0.22	0.22	0.19	0.23
KD/KR	3.07	0.93	1.21	0.78	1.55	1.25	0.70	0.54	2.02	1.06
h^2/H_2	0.12	0.15	1.76	0.47	1.08	0.36	0.04	0.13	0.75	-0.01
h(n.s)	31.75	47.05	45.99	67.73	34.90	24.70	29.22	32.34	21.66	61.05

* and **, are significant at 0.05 and 0.01 levels of probability , respectively.

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القدرة على التآلف والفعل الجيني لمحصول الحبوب ومحتواها الكيميائي تحت الظروف الطبيعية وإجهاد العناصر الثقيلة فى قمح الخبز

شيماء سعيد الغرباوي - محمد ابراهيم عبدالحميد - رجب محمد علي - عبدالحميد حسن سالم

قسم المحاصيل - كلية الزراعة - جامعة الزقازيق - مصر

أجرى التهجين بين خمسة تراكيب وراثية من قمح الخبز هى (سدس ١٣، جيزة ١٦٨، جميزة ١١، سلالة ١، سلالة ٢) بنظام الهجن التبادلية باستثناء الهجن العكسية في الموسم الشتوي ٢٠١٢ /٢٠١٣ بالمزرعة التجريبية بكلية الزراعة جامعة الزقازيق، تم تقييم الخمسة آباء بالإضافة إلى العشرة هجن الناتجة عنها لمحصول الحبوب ومحتواها الكيميائي تحت الظروف الطبيعية و ظروف الإجهاد بالعناصر الثقيلة (الزنك – الرصاص – الكادميوم)، في تجربتين متجاورتين في الموسم الشتوي ٢٠١٣ / ٢٠١٤، صممت كل تجربة بنظام القطاعات كاملة العشوائية في ثلاث مكررات، وقد أظهرت النتائج أن الإجهاد بالعناصر الثقيلة أدى إلى نقص فى عدد الفروع المنتجة/النبات بمقدار (١%)، ونقص فى عدد الحبوب/ السنبلة (١١,٧%)، ووزن ال١٠٠٠ حبة (١١,٦%)، ومحصول حبوب النبات الفردى (٢٣%)، بينما أدى إلى زيادة محتوي الحبوب من البروتين بمقدار (١%) والبرولين (١٣%) والزنك (٣٣%) والرصاص (٥١,٧%) والكادميوم (٣٢%) مقارنة بالنباتات المزروعة تحت الظروف الطبيعية، كما أوضحت النتائج وجود اختلافات معنوية بين الخمسة أباء و كذلك الهجن الناتجة عنها لمحصول الحبوب ومحتواها الكميائي، وقد أظهر الصنف سدس ١٣ قدرة عامة عالية علي التآلف لصفات محصول حبوب النبات ونسبة البروتين والبرولين في الحبوب، وأوضحت النتائج تحكم الفعل الجيني المضيف و السيادي في وراثة محصول حبوب النبات ومحتواها الكيميائي تحت الظروف الطبيعية وظروف الإجهاد مع دور أكبر للفعل الجينى السيادي وقد كان معامل التوريث بالمعني الخاص مرتفعا لصفات محتوى الحبوب من البرولين (٦٧,٧٣%) و الكادميوم (٦١,٥٥%) تحت ظروف الإجهاد، وعدد الفروع المنتجة (٥٠,٣١%) تحت الظروف الطبيعية، كما كانت قيم معامل التوريث متوسطه لمحصول حبوب النبات (٤٧,٢٥%، ٣٢,٠٦%) ومحتوي الحبوب من البروتين (٣١,٧٥%، ٤٧,٥%) تحت الظروف الطبيعية و ظروف الإجهاد، وعدد حبوب السنبلة (٣٣,٣٤%)، ومحتوى الحبوب من الرصاص (٣٢,٣٤%) تحت ظروف الإجهاد، والبروتين (٤٥,٩٩%) والزنك (٣٤,٩%) تحت الظروف الطبيعية، بينما كانت قيمة معامل التوريث منخفضة لعدد الأفرع المنتجة (٢٦,٩١%)، ومحتوى الحبوب من الزنك (٢٤,٧%) تحت الإجهاد، وعدد حبوب السنبلة (٢١,٧٧%) ومحتوى الحبوب من الرصاص (٢٩,٢٢%) والكادميوم (٢١,٦٦%) تحت الظروف الطبيعية، وكذلك وزن ألف حبة (٢٠,١%، ٢٧,٤%) تحت الظروف الطبيعية و ظروف الإجهاد بنفس الترتيب.

المحكمـــــون:

١- **أ.د. محمد سعد مغازى عبد العاطى** أستاذ المحاصيل – كلية الزراعة – جامعة كفر الشيخ.

٢- **أ.د. حســــن عـــــوده عـــواد** أستاذ المحاصيل – كلية الزراعة – جامعة الزقازيق.