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Performance, Correlation and Path Coefficient Analysis for Grain Yield and its Related Traits in Diallel Crosses of Bread Wheat under Normal Irrigation and Drought Conditions

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Abstract: Seven parents of bread wheat namely; Giza 168 (P_1), Cham 6 (P_2), Line 1 (P_3), Line 2 (P_4), Sakha 94 (P_5), IB 18 (P_6) and Maryout 5 (P_7) were crossed in 2008/2009 season in a half diallel pattern. In 2009/ 2010 season, the 7 parents and their 21 F_1 crosses were grown under two different water regimes, i.e. normal irrigation (plants gave 5 irrigations during growth season) and water stress (plants gave 3 irrigations where the 2nd and 4th irrigations were prevented during vegetative and anthesis stages, respectively). A field experiment was devoted for each irrigation treatment and laid out in a randomized complete blocks design with three replicates. Performance, phenotypic correlation coefficient and path coefficient were evaluated for grain yield/ plant and its contributors under target environments. The results revealed that wheat genotypes greatly differed in there responses under both irrigation treatments for the studied traits. Drought caused great reduction in grain yield and its contributors, i.e. flag leaf area, plant height, spike length, number of spikes/ plant, number of spikelets/spike, number of kernels/ spike and 1000-kernel weight as well as days to heading and relative water content. The genotypes; P_2, P_3, P_4, P_7, $P_1 \times P_4$, $P_2 \times P_7$, $P_4 \times P_7$ and $P_6 \times P_7$ gave the highest values for the most traits under both water regimes. At the same time, the parents P_2, P_6, P_1 and P_3 and the crosses; $P_1 \times P_2$, $P_1 \times P_4$, $P_1 \times P_6$, $P_2 \times P_3$, $P_2 \times P_5$, $P_3 \times P_6$, $P_4 \times P_6$, $P_4 \times P_7$ and $P_5 \times P_7$ were the best drought tolerant according to their drought susceptibility index. Significant and positive phenotypic correlation coefficients were found between grain yield/ plant and each of flag leaf area, relative water content, number of kernels/ spike, 1000-kernel weight and number of spikes/ plant under the two levels of irrigations. Results of path coefficient analysis illustrated that flag leaf area, relative water content under both water regimes followed by number of spikes/ plant under drought treatment proved to be the major contributors in grain yield variation. Thus, these traits should be considered as selection criteria in wheat breeding programs for yield improvement under the target treatments.

Key words: Wheat · *Triticum aestivum* · Water regimes · Drought tolerance · Correlation · Path coefficient

INTRODUCTION

Improving wheat grain yield is one of the most important national goals in Egypt to face the increasing population demands. Therefore, great efforts have been made to minimize the gab between wheat production and local consumption by growing cultivars of high yield and application of the proper agronomic practices as well as extending the acreage of wheat especially in Egyptian desert to increase the total production. But because of shortage of irrigation water, drought is considered the most limiting factor affecting wheat productivity when grown in desert regions. Therefore, plant breeding research must be oriented for the developing of new wheat genotypes that use less water without affecting its yield potentiality. Previous studies indicated that expose wheat plants to water deficient during different growth stages led to decreased growth, yield and yield components of wheat [1- 5]. Hence, correlation and path coefficient studies help wheat breeders to determine the traits which could be used as a selection criteria and their relative importance in yield variation under normal irrigation and drought conditions. El-Sabbagh *et al.* [2],Tammam *et al.* [3], Belay *et al.* [6] and El-Marakby *et al.* [7]; found that yield was positively and significantly correlated with yield attributes such as flag leaf area, number of spikes/plant, number of spikelets/ spike, number of kernels/spike and 1000-kernel weight. However, El-Hawary [1], El-Shouny *et al.* [8], Dokuyucu and Akkaya [9], Tammam *et al.* [10], El-Marakby *et al.* [11] and Salama

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et al. [12] reported that the greatest positive direct effects on grain yield was expressed by number of spikes/plant, number of spikelets/spike, number of kernels/spike, 1000-kernel weight and flag leaf area.

The objective of this investigation was to study performance and association of grain yield with its related traits and to identify the most contributing traits in grain yield variation which may be used as selection criteria in wheat improvement programmes in 7 parents half diallel crosses under two irrigation regimes.

MATERIALS AND METHODS

The field work of this study was conducted at the Experimental Farm of the Faculty of Agriculture, Ain Shams University at Shalakan, El-kalubia Governorate, Egypt. Seven bread wheat genotypes representing a wide range of genetic variability were used during the two successive growing seasons; 2008/2009 and 2009/2010. Name and pedigree of the seven parental genotypes are presented in preceding paper published by Saleh [13]. In 2008/2009 season, all possible crosses without reciprocals, were made among the seven parents to produce 21 F_1 hybrids. In 2009/2010 season, the parents and their respective F_1 crosses were grown under two different water regimes, i.e. normal irrigation (plants gave 5 irrigations during growth season) and water stress (plants gave 3 irrigations where the 2nd and 4th irrigations were prevented during vegetative and anthesis stages, respectively). A field experiment was devoted for each irrigation treatment and each experiment was designed in a randomized complete blocks with three replications. Each parent and hybrid was sown in three rows in each replicate and row was 3 m long. Plants spaced 15 cm within row and the rows were 25 cm apart and one plant left per hill. The irrigation treatments began when wheat plants were 30 days old after sowing. An approximately constant amount of water was given in each irrigation of the two irrigation treatments. Sowing date was on November 17th and the preceding summer crop was maize. The physical and chemical properties of soil experimental site showed that the soil is clay in texture with pH (7.98 and 7.98), EC (2.39 and 2.88 dSm^{-1}). The other cultural practices were followed as recommended for wheat production in the region. Data were collected on ten random competitive plants of each parent and F_1 hybrid from each replicate to determine number of days to heading, flag leaf area (cm^2), relative water content% [14], plant height (cm), spike length (cm), number of spikes/plant, number of spikelets/spike, number of kernels/spike, 1000-kernel weight (g) and grain yield/ plant (g). The drought susceptibility index (DSI) was computed to characterize the relative stress resistance of each genotype. The susceptibility index was calculated independently using the original data for grain yield/ plant using a generalized formula described by Fischer and Maurer [15] as follows:

$$DSI = S\ (1-Yd/\ Yp)/\ D$$

Where:

S = An index of drought susceptibility
Yd = Performance of a genotype under drought stress
Yp = Performance of the same genotype under normal irrigation
D = Drought intensity = 1-(mean Yd of all genotypes/ mean Yp of all genotypes).

Statistical analysis for a randomized complete blocks design was made for each water regime as well as combined analysis over irrigation treatments according to Gomez and Gomez [16]. Phenotypic correlation coefficient was computed for different pairs of traits under both water regimes. However, partitioning correlation coefficient into direct and indirect effects at phenotypic level was made by determining path coefficients under different environments using method utilized by Dewey and Lu [17].

RESULTS AND DISCUSSION

Analysis of Variance, Mean Performance and Susceptibility Index: The analyses of variance for normal irrigation and drought conditions as well as their combined data for all studied characters are presented in Table 1. Mean squares due to irrigation treatments were significant for all the studied traits, indicating overall differences between the two irrigation treatments. The mean squares due to genotypes (parents and F_1 hybrids) and their interactions with irrigation treatments (I x G) were significant for all the studied traits except plant height, spike length, number of spikelets/spike and number of spikes/plant for genotypes x irrigation treatments interaction, indicating the presence of wide diversity between genotypes and inconsistence their performance under the two irrigation treatments for the most studied traits. Similar results were previously drawn by El-Hawary [1], El-Sabbagh *et al.* [2], Tammim *et al.* [3], Abd El-Aty and El- Borhamy [4], El-Hosary *et al.* [5] and Abd El-Moneim [18].

Table 1: Mean squares of combined analysis of variance over two irrigation treatments (I) for the characters studied in bread wheat genotypes (G)

Traits	I	G	IG	Error
Days to heading	680.02*	39.96**	7.62**	1.39
Flag leaf area	3055.10**	163.29**	53.62**	1.66
Relative water content	5326.32**	256.23**	78.22**	0.49
Plant height	1639.44*	75.01**	5.59	6.71
Spike length	16.17*	4.91**	0.13	0.22
No. of spikelets/spike	113.64**	6.48**	0.75	0.64
No. of spikes/plant	110.66*	5.30**	0.63	0.73
No. of kernels/spike	668.29**	119.95**	29.41**	1.76
1000- kernel weight	499.53**	37.51**	12.44**	1.79
Grain yield/plant	787.80**	14.91**	5.61**	0.73

*and** denote significant differences at 0.05 and 0.01of probability levels, respectively

Table 2: Mean performance of parents and their F_1 crosses for all the studied traits under normal irrigation (I_1), drought conditions (I_2) and their combined data and drought susceptibility index

	Days to heading			Flag leaf area (cm^2)			Relative water content%		
Genotypes (G)	I_1	I_2	Combined	I_1	I_2	Combined	I_1	I_2	Combined
P_1 (Giza 168)	87.00	80.33	83.67	39.16	31.48	35.32	48.41	41.14	44.78
P_2 (Cham 6)	92.00	91.00	91.50	46.61	34.33	40.47	72.20	58.16	65.18
P_3 (Line 1)	84.33	83.00	83.67	43.56	31.83	37.70	69.15	56.26	62.70
P_4 (Line 2)	92.00	89.67	90.83	47.28	34.00	40.64	69.27	59.23	64.25
P_5 (Sakha 94)	92.33	92.00	92.17	28.33	22.13	25.23	64.36	40.17	52.26
P_6 (IB 18)	90.00	86.33	88.17	37.22	30.83	34.03	56.23	37.45	46.84
P_7 (Maryout 5)	86.00	83.33	84.67	52.29	33.00	42.65	51.45	31.15	41.30
Parents mean	89.09	86.52	87.81	42.06	31.09	36.58	61.58	46.22	53.90
$P_1 \times P_2$	88.67	80.67	84.67	35.52	39.00	37.26	55.26	53.13	54.19
$P_1 \times P_3$	85.00	83.33	84.17	45.18	29.40	37.29	56.21	46.14	51.17
$P_1 \times P_4$	88.33	83.67	86.00	45.03	42.18	43.60	58.34	49.21	53.78
$P_1 \times P_5$	87.67	84.00	85.83	42.50	36.17	39.33	54.38	53.49	53.94
$P_1 \times P_6$	87.33	84.33	85.83	32.27	31.33	31.8	53.14	41.20	47.17
$P_1 \times P_7$	88.67	82.67	85.67	44.00	25.28	34.64	50.38	47.16	48.77
$P_2 \times P_3$	87.00	81.00	84.00	41.50	28.33	34.92	50.27	48.11	49.19
$P_2 \times P_4$	88.00	83.00	85.50	45.45	33.67	39.56	55.22	48.29	51.76
$P_2 \times P_5$	89.67	86.00	87.83	34.62	22.79	28.70	51.23	46.16	48.70
$P_2 \times P_6$	90.67	83.33	87.00	41.98	29.02	35.50	67.28	46.26	56.77
$P_2 \times P_7$	82.67	81.33	82.00	48.08	39.33	43.71	56.36	51.25	53.80
$P_3 \times P_4$	85.33	81.00	83.17	35.33	30.83	33.08	53.24	48.35	50.80
$P_3 \times P_5$	87.67	86.00	86.83	40.67	26.50	33.58	58.49	48.23	53.36
$P_3 \times P_6$	88.33	80.67	84.50	33.00	29.47	31.23	53.54	46.24	49.89
$P_3 \times P_7$	83.00	81.00	82.00	37.33	33.67	35.50	51.27	52.23	51.75
$P_4 \times P_5$	89.33	85.00	87.17	37.08	23.46	30.27	62.25	41.26	51.75
$P_4 \times P_6$	88.67	84.33	86.50	37.83	29.00	33.42	60.28	43.35	51.82
$P_4 \times P_7$	91.00	86.33	88.67	43.78	37.33	40.56	76.13	53.25	64.69
$P_5 \times P_6$	88.67	80.67	84.67	26.58	20.83	23.71	63.38	46.50	54.94
$P_5 \times P_7$	87.33	82.00	84.67	37.33	30.00	33.67	62.35	48.24	55.29
$P_6 \times P_7$	85.67	83.67	84.67	40.67	46.18	43.42	78.12	61.24	69.68
Crosses mean	87.56	83.05	85.30	39.32	31.61	35.46	58.43	48.54	53.49
General mean	87.94	83.92	85.93	40.01	31.48	35.74	59.22	47.96	53.59
LSD 0.05									
I	-	-	2.66	-	-	1.29	-	-	0.54
G	1.74	2.11	1.35	2.17	2.04	1.47	0.41	1.57	0.80
IG	-	-	1.91	-	-	2.08	-	-	1.13

Table 2: Cont.

	Plant height (cm)			Spike length (cm)			No. of spikelets/spike		
Genotypes (G)	I_1	I_2	Combined	I_1	I_2	Combined	I_1	I_2	Combined
P_4 (Giza 168)	87.67	81.33	84.5	11.72	10.72	11.22	22.22	21.22	21.72
P_2 (Cham 6)	76.39	72.00	74.19	8.78	7.95	8.36	20.33	19.06	19.69
P_3 (Line 1)	87.22	79.78	83.50	9.50	9.17	9.33	19.78	18.55	19.16
P_4 (Line 2)	84.00	80.56	82.28	11.56	10.50	11.03	23.00	21.89	22.44
P_5 (Sakha 94)	90.17	84.33	87.25	10.39	9.78	10.08	22.33	20.45	21.39
P_6 (IB 18)	84.39	81.39	82.89	10.83	10.61	10.72	21.67	20.67	21.17
P_7 (Maryout 5)	94.00	88.83	91.42	12.64	11.73	12.19	23.22	21.89	22.56
Parents mean	86.26	81.17	83.72	10.77	10.07	10.42	21.79	20.53	21.16
$P_1 \times P_2$	95.56	87.39	91.47	11.06	10.50	10.78	22.56	21.22	21.89
$P_1 \times P_3$	90.17	86.44	88.31	10.61	10.28	10.44	21.33	20.31	20.82
$P_1 \times P_4$	89.22	83.28	86.25	11.58	11.33	11.45	23.06	21.22	22.14
$P_1 \times P_5$	87.28	81.67	84.47	10.61	10.33	10.47	21.83	19.89	20.86
$P_1 \times P_6$	81.22	79.44	80.33	11.22	10.44	10.83	21.89	20.78	21.33
$P_1 \times P_7$	89.56	84.61	87.08	11.33	11.11	11.22	23.00	21.31	22.15
$P_2 \times P_3$	88.00	81.22	84.61	9.11	8.61	8.86	20.00	18.33	19.16
$P_2 \times P_4$	88.50	81.56	85.03	9.89	9.06	9.47	21.83	19.00	20.41
$P_2 \times P_5$	87.67	82.78	85.22	9.64	8.82	9.23	22.45	18.89	20.67
$P_2 \times P_6$	88.11	80.39	84.25	10.14	9.66	9.90	21.39	20.00	20.69
$P_2 \times P_7$	89.83	82.50	86.17	10.22	9.83	10.03	21.89	19.78	20.83
$P_3 \times P_4$	88.78	81.44	85.11	10.17	9.61	9.89	21.00	18.17	19.58
$P_3 \times P_5$	89.11	81.61	85.36	9.89	8.84	9.36	21.78	19.11	20.44
$P_3 \times P_6$	87.72	80.78	84.25	10.11	9.61	9.86	20.66	19.89	20.28
$P_3 \times P_7$	90.72	81.94	86.33	10.78	10.37	10.57	22.11	19.78	20.94
$P_4 \times P_5$	89.56	83.89	86.72	10.60	9.96	10.28	22.11	20.34	21.22
$P_4 \times P_6$	82.61	75.33	78.97	10.71	10.17	10.44	22.28	20.66	21.47
$P_4 \times P_7$	93.78	85.00	89.39	12.44	11.05	11.75	23.50	22.94	23.22
$P_5 \times P_6$	90.67	81.67	86.17	10.62	9.99	10.30	21.89	20.22	21.06
$P_5 \times P_7$	93.22	83.72	88.47	10.83	10.17	10.50	22.22	20.55	21.39
$P_6 \times P_7$	89.50	84.78	87.14	12.00	11.44	11.72	23.33	22.50	22.91
Crosses mean	89.09	82.45	85.77	10.65	10.06	10.35	22.01	20.23	21.12
General mean	88.38	82.13	85.26	10.68	10.06	10.37	21.95	20.31	21.13
LSD 0.05									
I	-	-	4.52	-	-	0.59	-	-	0.94
G	5.02	3.29	2.96	0.79	0.73	0.53	1.33	1.29	0.91
IG	-	-	Ns	-	-	ns	-	-	ns

Table 2: Cont.

	No. of spikes/plant			No. of kernels/spike			1000-kernel weight (g)		
Genotypes (G)	I_1	I_2	Combined	I_1	I_2	Combined	I_1	I_2	Combined
P_4 (Giza 168)	6.61	6.11	6.36	55.33	51.67	53.5	46.92	42.37	44.64
P_2 (Cham 6)	10.56	9.39	9.97	60.78	53.39	57.08	54.67	47.21	50.94
P_3 (Line 1)	9.17	7.05	8.11	63.33	53.67	58.50	50.96	49.56	50.26
P_4 (Line 2)	9.06	7.94	8.50	56.28	57.83	57.06	52.73	49.81	51.27
P_5 (Sakha 94)	7.94	6.95	7.45	58.89	48.33	53.61	46.00	43.26	44.63
P_6 (IB 18)	6.94	6.28	6.61	54.00	50.61	52.31	45.70	40.67	43.19
P_7 (Maryout 5)	6.28	4.50	5.39	60.07	52.39	56.23	51.65	47.67	49.66
Parents mean	8.08	6.89	7.48	58.38	52.56	55.47	49.80	45.79	47.80
$P_1 \times P_2$	7.17	6.28	6.72	52.95	54.89	53.92	46.22	49.31	47.77
$P_1 \times P_3$	8.33	5.33	6.83	59.00	49.17	54.08	51.35	42.25	46.80
$P_1 \times P_4$	6.94	6.39	6.67	65.44	56.67	61.06	53.95	48.00	50.97
$P_1 \times P_5$	8.28	6.89	7.58	56.67	55.44	56.06	52.45	49.87	51.16
$P_1 \times P_6$	6.95	5.39	6.17	49.06	43.94	46.50	46.87	45.28	46.08
$P_1 \times P_7$	6.89	4.78	5.83	53.00	51.28	52.14	49.93	46.00	47.96
$P_2 \times P_3$	8.45	6.28	7.36	45.00	45.11	45.06	48.66	45.73	47.19
$P_2 \times P_4$	9.28	7.06	8.17	57.22	54.28	55.75	53.14	51.32	52.23

Table 2: Cont

P_2 x P_5	8.44	6.28	7.36	54.39	45.83	50.11	45.56	44.15	44.86
P_2x P_6	7.89	6.39	7.14	46.56	52.33	49.44	48.78	45.95	47.36
P_2 x P_7	8.78	6.83	7.80	57.17	55.22	56.19	50.66	49.00	49.83
P_3 x P_4	7.78	5.78	6.78	44.28	45.44	44.86	44.24	46.80	45.52
P_3 x P_5	7.83	5.22	6.53	56.00	50.55	53.28	50.07	46.54	48.30
P_3 x P_6	7.44	5.67	6.55	53.00	46.34	49.67	49.15	43.67	46.41
P_3 x P_7	7.39	5.00	6.20	52.33	52.22	52.28	47.77	45.41	46.59
P_4 x P_5	7.78	6.83	7.31	47.00	45.11	46.06	52.18	41.75	46.97
P_4 x P_6	7.39	6.39	6.89	46.22	44.50	45.36	47.27	43.96	45.61
P_4 x P_7	8.56	7.17	7.86	56.17	55.72	55.94	54.21	47.70	50.95
P_5 x P_6	7.17	5.22	6.20	59.06	46.72	52.89	47.37	44.66	46.01
P_5 x P_7	7.28	5.11	6.20	53.11	45.89	49.5	50.14	48.23	49.19
P_6 x P_7	8.11	6.72	7.42	61.28	57.33	59.31	52.87	48.78	50.83
Crosses mean	7.82	6.05	6.93	53.57	50.19	51.88	49.66	46.40	48.03
General mean	7.88	6.26	7.07	54.77	50.78	52.78	49.70	46.25	47.97
LSD 0.05									
I	-	-	1.13	-	-	0.41	-	-	0.74
G	1.34	1.46	0.98	1.61	2.62	1.52	2.00	2.37	1.53
IG	-	-	Ns	-	-	2.15	-	-	2.16

Table 2: Cont

Genotypes (G)	Grain yield/plant (g)			Drought susceptibility index
	I_1	I_2	Combined	
P_4 (Giza 168)	12.33	9.20	10.77	0.80
P_2 (Cham 6)	15.09	12.45	13.77	0.57
P_3 (Line 1)	15.26	11.11	13.19	0.87
P_4 (Line 2)	16.27	11.25	13.76	0.98
P_5 (Sakha 94)	14.28	10.09	12.19	0.92
P_6 (IB 18)	12.15	9.61	10.88	0.66
P_7 (Maryout 5)	14.00	9.16	11.58	1.10
Parents mean	14.20	10.41	12.31	0.84
P_1 x P_2	13.45	11.20	12.32	0.53
P_1 x P_3	16.13	8.21	12.17	1.58
P_1 x P_4	14.06	11.06	12.56	0.69
P_1 x P_5	15.15	10.17	12.66	1.05
P_1 x P_6	12.32	9.75	11.04	0.66
P_1 x P_7	11.61	8.10	9.85	0.97
P_2 x P_3	10.61	8.11	9.36	0.73
P_2 x P_4	15.64	10.64	13.14	1.03
P_2 x P_5	11.76	9.26	10.51	0.69
P_2x P_6	14.31	10.31	12.31	0.9
P_2 x P_7	17.72	10.76	14.24	1.26
P_3 x P_4	12.39	7.78	10.09	1.18
P_3 x P_5	15.77	5.61	10.69	2.06
P_3 x P_6	9.73	7.39	8.56	0.75
P_3 x P_7	14.46	7.05	10.76	1.64
P_4 x P_5	15.72	9.92	12.82	1.19
P_4 x P_6	13.10	10.18	11.64	0.69
P_4 x P_7	15.53	11.75	13.64	0.79
P_5 x P_6	12.53	8.26	10.4	1.09
P_5 x P_7	11.38	8.57	9.98	0.78
P_6 x P_7	17.36	11.94	14.65	0.99
Crosses mean	13.84	9.33	11.59	1.01
General mean	13.93	9.60	11.77	0.97
LSD 0.05				
I	-	-	1.28	-
G	1.42	1.38	0.98	0.36
IG	-	-	1.39	-

The mean values of the studied genotypes for grain yield/ plant and some of agronomic traits under each of normal irrigation and drought conditions and their combined data are shown in Table 2. The results revealed that wheat genotypes greatly differed in their response under the two different water regimes for the studied traits. However, water stress caused significantly reduction for all studied traits compared with normal irrigation. Number of days to heading ranged from 82.67 days (P_2 x P_7) to 92.33 days (P_5) and from 80.33 days (P_1) to 92.00 days (P_5) under normal irrigation and drought conditions, respectively. The parent (P_3) and the two crosses, P_2 x P_7 and P_3 x P_7 under normal irrigation and the parent (P_1) and the three crosses; P_1 x P_2, P_3 x P_6 and P_5 x P_6 under drought conditions were the earliest genotypes. With respect to flag leaf area, it ranged from 26.58 cm^2 (P_5 x P_6) to 52.29 cm^2 (P_7) and from 20.83 cm^2 (P_5 x P_6) to 46.18 cm^2 (P_6 x P_7) under normal irrigation and drought conditions, respectively. The parent (P_7) and the cross P_2 x P_7 under normal irrigation and the three parents; P_2, P_4 and P_7 and the cross P_6 x P_7 under drought conditions gave the highest mean values for this trait. Relative water content ranged from 48.41% (P_1) to 78.12% (P_6 x P_7) and from 31.15% (P_7) to 61.24% (P_6 x P_7) under both water regimes, respectively. The parent (P_2) and the cross (P_6 x P_7) under normal irrigation and the two parents P_2 and P_4 and the cross P_6 x P_7 under drought conditions had the highest mean values for this trait. For plant height, it ranged from 76.39 cm (P_2) to 95.56 cm (P_1 x P_2) and from 72.00 cm (P_2) to 88.83 cm (P_7) under normal irrigation and drought conditions, respectively. The two parents; P_5 and P_7 and the three crosses; P_1 x P_2, P_4 x P_7 and P_5 x P_7 under normal irrigation and the parent P_7 and the three crosses; P_1 x P_2, P_1 x P_3 and P_4 x P_7 under drought conditions were the tallest genotypes. Concerning spike length, it ranged from 8.78 cm (P_2) to 12.64 cm (P_7) and from 7.95 cm (P_2) to 11.73 cm (P_7) under normal irrigation and drought conditions, respectively. The parent (P_7) and the two crosses; P_4 x P_7 and P_6 x P_7 under normal irrigation and the parent (P_7) and the four crosses; P_1 x P_4, P_1 x P_7, P_4 x P_7 and P_6 x P_7 under drought conditions had the tallest spike.

Regarding, the number of spikelets/spike, it ranged from 19.78 spikelets (P_3) to 23.50 spikelets (P_4 x P_7) and from 18.17 spikelets (P_3 x P_4) to 22.94 spikelets (P_4 x P_7) under normal irrigation and drought conditions, respectively. The two parents P_4 and P_7 and the four crosses; P_1 x P_4, P_1 x P_7, P_4 x P_7 and P_6 x P_7 under normal irrigation and the parents; P_1, P_4 and P_7 and the two crosses; P_4 x P_7 and P_6 x P_7 under drought conditions recoded the highest values for number of spikelets/ spike. With respect to number of spikes/plant, it ranged from 6.28 spikes (P_7) to 10.56 spikes (P_2) and from 4.5 spikes (P_7) to (P_2) 9.39 spikes under normal irrigation and drought conditions, respectively. The three parents; P_2, P_3 and P_4 and the three crosses; P_2 x P_4, P_2 x P_7 and P_4 x P_7 under normal irrigation and the parent (P_2) and the two crosses; P_2 x P_4 and P_4 x P_7 under drought conditions gave the highest values of number of spikes/ plant. For number of kernels/spike, it ranged from 45.00 kernels (P_2 x P_3) to 65.44 kernels (P_1 x P_4) and from 43.94 kernels (P_1 x P_6) to 57.83 kernels (P_4) under normal irrigation and drought conditions, respectively. The parent (P_3) and the cross P_1 x P_4 under normal irrigation and the parent (P_4) and the three crosses; P_1 x P_4, P_4 x P_7 and P_6 x P_7 under drought conditions showed the highest values of number of kernels/spike. Concerning 1000-kernel weight, it ranged from 44.24 g (P_3 x P_4) to 54.67 g (P_2) and from 41.75 g (P_4 x P_5) to 49.87 g (P_1 x P_5) under normal irrigation and drought conditions, respectively. The two parents, P_2 and P_4 and the three crosses; P_1 x P_4, P_2 x P_4 and P_4 x P_7 under normal irrigation and the two parents; P_3 and P_4 and the three crosses; P_1 x P_2, P_1 x P_5 and P_2 x P_7 under drought conditions were the best for this trait.

Regarding grain yield/ plant, it ranged from 9.73 g (P_3 x P_6) to 17.72 g (P_2 x P_7) and from 5.61 g (P_3 x P_5) to 12.45 g (P_2) under normal irrigation and drought conditions, respectively. The two parents; P_3 and P_4 and the two crosses; P_2 x $P_7$and P_6 x P_7 under normal irrigation and the three parents; P_2, P_3 and P_4 and the four crosses; P_1 x P_2, P_1 x P_4, P_4 x P_7 and P_6 x P_7 under drought conditions showed the highest grain yield/plant. Effects of water stress on wheat grain yield and its components has been studied by Wardlaw [19] who stated that when photosynthesis is limited under stress, grain filling in wheat largely depends upon translocation of stored assimilates; however, water stress also reduce translocation by decreasing vein loading of assimilates in leaves. Generally, the parents; P_2, P_3, P_4 and P_7 and the crosses, P_1 x P_4, P_2 x P_7, P_4 x P_7 and P_6 x P_7 exhibited the best performance under normal irrigation and drought conditions for the most studied traits. Thus these genotypes can be used in breeding programs for improvement wheat grain yield especially under drought conditions. Drought susceptibility index (DSI) is the value that measures drought sensitivity and can be used to

Table 3: Values of simple phenotypic correlation coefficients estimated between different pairs of traits recorded under normal irrigation (N) and drought (D) conditions

Traits		2	3	4	5	6	7	8	9	10
1- Grain yield/plant	N	-0.14	0.50**	0.53**	0.44*	0.59**	0.04	0.13	0.23	0.49**
	D	0.39*	0.55**	0.39*	0.56**	0.41*	-0.15	0.14	0.36	0.76**
2- Days to heading	N		-0.18	0.36	-0.04	0.07	-0.29	-0.02	0.18	0.16
	D		-0.12	0.08	0.15	-0.06	-0.27	-0.19	0.13	0.59**
3 -Flag leaf area	N			0.11	0.33	0.71**	-0.03	0.16	0.10	0.34
	D			0.52**	0.74**	0.60**	0.10	0.40*	0.38*	0.30
4- Relative water content	N				0.33	0.49**	-0.12	0.08	0.11	0.49**
	D				0.55**	0.62**	-0.25	-0.19	-0.04	0.53**
5- No. of kernels/spike	N					0.52**	0.09	0.19	0.21	0.21
	D					0.63**	0.17	0.33	0.40*	0.41*
6- 1000-kernel weight	N						-0.04	0.16	0.16	0.47*
	D						0.05	0.01	0.02	0.28
7- Plant height	N							0.41*	0.41*	-0.40*
	D							0.59**	0.44*	-0.51**
8- Spike length	N								0.83**	-0.58**
	D								0.85**	-0.39*
9- No. of spikelets/spike	N									-0.41*
	D									-0.07
10-No.of spikes/plant	-									0.00

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

differentiate the overall genotypes tolerance. Drought susceptibility index values (Table 3) varied between parental genotypes and their respective hybrids for grain yield/ plant. The parental genotypes varied from 0.57 (P_2) to 1.10 (P_7). The hybrids varied from 0.53 (P_1 x P_2) to 2.06 (P_3 x P_5). The best drought tolerant parents were P_2, P_6, P_1 and P_3 whereas, the crosses; P_1 x P_2, P_1 x P_4, P_1 x P_6, P_2 x P_3, P_2 x P_5, P_3 x P_6, P_4 x P_6, P_4 x P_7 and P_5 x P_7 were the best drought tolerant hybrids and the others were sensitive.

Phenotypic Correlation Coefficient: In order to detected the suitable plant characters that can be used by breeders as criteria for selection under the two different water regimes, i.e. normal irrigation and drought conditions, the phenotypic correlation among various characters was estimated for genotypes (parents and F_1 hybrids) as shown in Table 3. Positive and significant correlation was found between grain yield/plant and each of flag leaf area, relative water content, number of kernels/spike, 1000-kernel weight and number of spikes/ plant under normal and drought treatments and days to heading under drought conditions, indicating that the breeder can utilize such correlated response to obtain high grain yield genotypes through selection for one or more of these traits in segregating generations. Similar results were obtained by El-Sabbagh *et al.* [2], Tammam *et al.* [3], El-Marakby *et al.* [7], Tammam *et al.* [10], El-Marakby *et al.* [11] and Khalil *et al.* [20] who found one or more positive significant correlation coefficient between grain yield and each of days to heading, flag leaf area, no. of spikes/plant, no. of kernels/ spike and 1000-kernel weight. Other inter-character correlations revealed those days to heading was significantly and positively correlated with number of spikes/plant under drought conditions. Flag leaf area gave positive and significant correlations with 1000-kernel weight under normal irrigation and the relative water content, number of kernels/spike, 1000-kernel weight, spike length and number of spikelets/spike under drought conditions. Regarding relative water content, positive and significant correlation coefficient were obtained with each of 1000-kernel weight and number of spikes/plant under two levels of irrigation and number of kernels/spike under drought conditions. Number of kernels/spike exhibited positive and significant correlation coefficient with 1000-kernel weight under both water regimes and number of spikelets/spike and number of spikes/plant under drought conditions.1000-kernel weight showed positive and significant correlation with number of spikes/plant under normal irrigation. Plant height exhibited positive and significant correlation coefficient with spike length and number of spikelets/spike under the two irrigation treatments, while it gave negative and significant correlation with number of spikes/plant under two levels of irrigation. Spike length gave positive and significant correlation coefficient with number of spikelets/spike under both levels of irrigation,

Table 4: Phenotypic path coefficient of grain yield / plant and its contributing characters under normal (I_1) irrigation and drought conditions (I_2) in bread wheat

Source of variation	I_1	I_2
Flag leaf area vs. grain yield / plant		
Direct effect	0.345	0.345
Indirect effect vs. relative water content	0.039	-0.167
Indirect effect vs. no. of kernels/spike	0.057	0.064
Indirect effect vs. 1000-kernel weight	0.005	0.082
Indirect effect vs. no. of spikes/spike	0.054	0.226
Total	0.500	0.550
Relative water content vs. grain yield / plant		
Direct effect	0.353	-0.321
Indirect effect vs. flag leaf area	0.038	0.179
Indirect effect vs. no. of kernels/spike	0.057	0.047
Indirect effect vs. 1000-kernel weight	0.004	0.085
Indirect effect vs. no. of spikes/spike	0.078	0.399
Total	0.530	0.390
No. of kernels/spike vs. grain yield / plant		
Direct effect	0.172	0.086
Indirect effect vs. flag leaf area	0.114	0.255
Indirect effect vs. relative water content	0.117	-0.176
Indirect effect vs. 1000-kernel weight	0.004	0.086
Indirect effect vs. no. of spikes/spike	0.034	0.309
Total	0.440	0.560
1000-krenel weight vs. grain yield / plant		
Direct effect	0.008	0.137
Indirect effect vs. flag leaf area	0.245	0.207
Indirect effect vs. relative water content	0.173	-0.199
Indirect effect vs. no. of kernels/spike	0.090	0.054
Indirect effect vs. no. of spikes/spike	0.075	0.211
Total	0.590	0.410
No. of spikes/plant vs. grain yield / plant		
Direct effect	0.160	0.753
Indirect effect vs. flag leaf area	0.117	0.104
Indirect effect vs. relative water content	0.173	-0.170
Indirect effect vs. no. of kernels/spike	0.036	0.035
Indirect effect vs. 1000-kernel weight	0.004	0.038
Total	0.490	0.760

while it gave negative and significant correlation between numbers of spikes/plant under the two irrigation treatments. However, number of spikelets/ spike showed negative and significant correlation coefficient with number of spikes/ plant under normal irrigation. Similar results were obtained by El-Sabbagh *et al.* [2], Tammam *et al.* [3], El-Marakby *et al.* [7], Tammam *et al.* [10] and Khalil *et al.* [20] who found significant positive correlation, while El-Shouny *et al.* [8], Abd El-Majeed *et al.* [21] and Seleem and Hendawy [22] found significant negative correlation between different pairs of the studied traits. The rest cases of correlations were insignificant.

Path Coefficient Analysis: The traits of flag leaf area, relative water content, number of kernels/spike, 1000-kernel weight and number of spikes/plant which exhibited positive significant correlation with grain yield/plant were used in path coefficient analysis to detect the relative importance of each trait to grain yield/plant variation at phenotypic level under two different water regimes, i.e. normal irrigation and drought conditions. The direct and indirect effects of the five yield attributes are shown in Table 4. The data revealed that the direct effect of flag leaf area on grain yield/plant (0.345) was positive and moderate under both water regimes. The indirect effects of flag leaf are via number of kernels/spike and 1000-kernel weights were low under the two irrigation treatments. Also, the indirect effects via relative water content and no. of spikes/ plant were low (0.057) and moderate (0.226) under normal and drought treatments, respectively. The direct effect of relative water content was positive and high (0.353) for grain yield/plant under normal irrigation treatment, while it was negative and moderate (-0.321) under drought treatment. The indirect effects of this trait

Table 5: Phenotypic components (direct and joint effects) in percent of grain yield/plant variation under normal irrigation (I_1) and drought conditions (I_2) in bread wheat

	I_1		I_2	
Source of variation	C.D	RI%	C.D	RI%
Flag leaf area (X1)	0.119	11.90	0.119	6.24
Relative water content (X2)	0.125	12.46	0.102	5.37
No. of kernels/spike (X3)	0.030	2.96	0.007	0.39
1000-kernel weight (X4)	0.000	0.00	0.018	0.97
No. of spikes/spike (X5)	0.026	2.56	0.566	29.63
(X1) x (X2)	0.026	2.63	-0.115	6.02
(X1) x (X3)	0.039	3.89	0.044	2.30
(X1) x (X4)	0.003	0.34	0.056	2.95
(X1) x (X5)	0.037	3.71	0.154	8.05
(X2) x (X3)	0.041	4.06	-0.030	1.59
(X2) x (X4)	0.002	0.24	-0.054	2.83
(X2) x (X5)	0.055	5.54	-0.255	13.37
(X3) x (X4)	0.001	0.13	0.015	0.77
(X3) x (X5)	0.012	1.16	0.053	2.78
(X4) x (X5)	0.001	0.11	0.056	2.96
Residual	0.483	48.32	0.263	13.80
Total	1.000	100.0	1.000	100.00

C.D: coefficient of determination, RI%: Relative importance

were low via no. of kernels/spike and 1000-kernel weight under two levels of irrigation. Also, the indirect effects via flag leaf area and no. of spikes/plant were low under normal irrigation, while it were moderate and high under drought treatment for flag leaf area and no. of spikes/ plant, respectively.

Number of kernels/spike showed positive and moderate direct effect (0.172) for grain yield/ plant under normal irrigation, while it was relatively low under drought treatment. The indirect effects of number of kernels/spike via 1000-kernel weight were low under both water regimes. Also, the indirect effects via flag leaf area, relative water content and number of spikes/plant were low under normal irrigation. Meantime, the indirect effects of this trait were moderate via flag leaf area, relative water content and number of spikes/plant under drought treatment. The direct effect of 1000-kernel weight was positive and low (0.008) under normal irrigation, while it was moderate (0.137) under drought conditions. The indirect effects of this trait via flag leaf area and relative water content were moderate under both water regimes and via number of spikes/plant under drought conditions. However, the indirect effects of this trait via number of kernels/ spike were low under both water regimes and via number of spikes/plant under normal irrigation. Number of spikes/plant showed positive and moderate direct effects (0.160) for grain yield/plant under normal irrigation, while it was high (0.753) under drought conditions. The indirect effects of number of spikes/ plant via flag leaf area, number of kernels/spike and 1000-kernel weight were low under the two irrigation treatments while it was moderate for relative water content under both water regimes.

The components of the total grain yield variation determined directly and jointly by each factor are presented in Table 5. Under the normal irrigation treatment, the main sources of plant yield variation in order of importance were the direct effect of relative water content (12.46%) and its joint effects with each of no. of spikes/plant (5.54%) and no. of kernels/spike (4.06%) and the direct of flag leaf area (11.9%). Small effects ranging from 2.56% (the direct effect of number of spikes/ plant) to 3.89% (the joint effect of flag leaf area with number of kernels/ spike). The total effect of five traits and their interaction amounted to 51.68% of the whole yield variation, while the residual effect amounted to 48.32%. Under the drought treatment, the main sources of plant yield variation in order of importance were the direct effect of number of spikes/plant (29.63%) and its joint effect with relative water content (13.37%) and flag leaf area (8.05%) as well as the direct effect of flag leaf area (6.24%) and relative water content (5.37%). Small effects ranging from 1.59% (the joint effect of relative water content with number of kernels/spike) to 2.96% (the joint effect of 1000-kernel weight with number of spikes/plant). The total effect of five traits and their interaction amounted to 86.2% of the whole yield variation while residual effect amounted to 13.80%. Similar results were obtained by El-Sabbagh *et al.* [2], Tammam *et al.* [3], El-Marakby *et al.* [7], Tammam *et al.* [10], Salama *et al.* [12] and Khalil *et al.* [20].

From the above mentioned results, it is noticed that flag leaf area and relative water content under both water regimes followed by number of spikes/plant under drought treatment proved to be the major grain yield contributors. Thus the breeders should take into consideration these traits as selection criteria for wheat yield improvement under the target environments especially that they were positively and significantly correlated with grain yield/plant.

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