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Inheritance of Grain Yield per Plant, Flag Leaf Width, and Length in an 8 x 8 Diallel Cross Population of Bread Wheat (*T. aestivum* L.)

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Abstract: The inheritance of grain yield per plant, flag leaf width, and flag leaf length was studied applying Jinks-Hayman diallel analysis in an 8 x 8 wheat cross population involving the bread wheat (*T. aestivum* L.) genotypes Cumhuriyet, Kaşifbey, Ziyabey, Marmara, Basribey, Malabadi, Yüreğir, and Seri-82. The crosses were made by hand, without reciprocals, in field conditions from March to May 2001, and the field experiment was conducted during the October 2002 to June 2003 growing season. The analysis of data showed that the additive variance component (D) was significant for flag leaf width ($P < 0.01$). The dominance variance component (H_1) was significant for flag leaf width and grain yield per plant. The dominance level variance component (h^2) and corrected dominance variance component (H_2) were significant for all 3 traits studied ($P < 0.01$). The Wr/Vr graphs indicated overdominance for grain yield per plant and flag leaf width, while partial dominance was inferred for flag leaf length. Flag leaf length was significantly and positively correlated with flag leaf width ($r = 0.803$). Yüreğir x Malabadi crosses should be considered for maximizing photosynthetic area of the leaf.

Key Words: *T. aestivum* L., gene action, heritability, flag leaf, diallel analyses

8 x 8 Diallel Ekmeklik Buğday (*T. aestivum* L.) Melez Populasyonlarında Bitki Başına Dane Verimi, Bayrak Yaprak Uzunluğu ve Genişliğinin Kalıtımı

Özet: Jinks-Hayman tipi analiz metodu uygulanmasıyla 8 x 8 diallel ekmeklik buğday melez populasyonunda bitki başına dane verimi, bayrak yaprak uzunluğu ve genişliğinin kalıtımı araştırılmıştır. Araştırmada Ege Bölgesinde yaygın olarak yetiştirilen sekiz ekmeklik buğday çeşidi olarak Cumhuriyet, Kaşifbey, Ziyabey, Marmara, Basribey, Malabadi, Yüreğir ve Seri-82 kullanılmıştır. Denemedeki melezleme işlemleri 2001 Mart-Mayıs aylarında; tarla denemeleri ise Ekim 2002 - Temmuz 2003 tarihleri arasında yapılmıştır. Verilerin analiz edilmesi neticesinde bayrak yaprak genişliği için eklemeli varyans komponenti (D), bayrak yaprak genişliği ve bitki başına tane verimi bakımından dominantlık varyans komponentinin (H_1) önemli olduğu tespit edildi. Dominantlık düzeyi (h^2) ve düzeltilmiş dominantlık değerleri (H_2) üzerinde çalışılan üç özellik içinde önemli bulunmuştur. ($P < 0.01$). Wr/Vr grafiği bakımından incelendiğinde bitki başına dane verimi ve bayrak yaprak genişliği karakterleri aşırı dominantlık değerleri gösterirken bayrak yaprak boyu karakteri kısmi dominantlık özelliği göstermişlerdir.Bayrak yaprak uzunluğu bayrak yaprak genişliği ile pozitif ve önemli korelatif ilişkiye sahip sahip olduğu bulunmuştur ($r = 0.803$). Yüreğir ve Malabadi genotiplerinin melez kombinasyonunun maksimum bayrak yaprak alanı için en uygun kombinasyon olduğu tespit edilmiştir.

Anahtar Sözcükler: Buğday, *T. aestivum* L., gen etkileri, kalıtım, bayrak yaprağı, diallel analiz

Introduction

According to the TUİK (2004), Turkey has 9.3 million hectares of wheat (7.2 million hectares of *Triticum aestivum*; 2.1 million hectares of *Triticum durum*), widely cultivated in many parts of central and coastal Turkey. Improved grain yield is the ultimate aim for cereal breeders. Yield increase may be effectively tackled on the basis of the performance of yield components and other closely associated characters (Sharma et al., 2003a). The leaves, being the site of photosynthetic activity, appear to have an obvious relationship to the plant's grain yield ability. Compared to other leaves, the flag leaf contributes the most photosynthetic assimilates in wheat; therefore, it assumes the greatest importance in terms of grain yield

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(Lupton, 1973). The flag leaf makes a major contribution towards the grain yield of cereals. Physiological studies of wheat have indicated that flag leaf contribution towards grain weight accounts for 41%-43% of dry matter in the kernel at maturity and is the major photosynthetic site during the grain filling stage (Athwal, 1968; Berdhal et al., 1972; Ibrahim and Elenein, 1977). Wheat grain yield is the end product of the interaction of a large number of physiological and biochemical process in the plants and, therefore, it is genetically complex. Since the flag leaf plays a predominant role, its size is likely to be important. Leaves, being the major site of photosynthetic activity, appear to have an obvious relationship with the plant grain yield ability. As mentioned by Monyo and Whittington (1973), flag leaf area can be an indicator of grain yield in wheat.

Previous genetic studies of the inheritance of flag leaf traits were mostly based on diallel analysis (Hsu and Walton, 1970; Jain and Sing, 1976; Ilyhchenko, 1977; Bariga, 1980), which does not provide estimates of different non-allelic interactions, and can inflate the measure of additive and dominance components. To breed a physiologically efficient and productive wheat genotype, knowledge of the different epistatic gene actions operating in the inheritance of the physiological traits, like flag leaf area, would be helpful (Sharma et al., 2003b).

The possibility of selecting promising crosses in early (F_1 and F_2) generations, especially of those showing potential for transgressive segregation, may reduce the amount of work and speed up the process of breeding (Busch et al., 1974). Jinks (1956), Crumpacker and Allard (1962), and Whitehouse et al. (1958) have proposed tests to attain this goal. According to Lupton (1961) and Busch et al. (1974), the use of later (F_4 and F_5) generations in the evaluation of crosses for breeding purposes is advised.

The aims of this study were to investigate the genetic make-up of some bread wheat cultivars by crossing them in a diallel manner for grain yield per plant, flag leaf width, and flag leaf length, and to select the most promising genotypes to be used as examined characters among some commercial wheat genotypes grown in the Aegean region of Turkey.

Materials and Methods

The parents used in the crosses were Cumhuriyet (1), Kaşifbey (2), Ziyabey (3), Marmara (4), Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8). These parents are widely used in the wheat production area of western Turkey. Mean values for grain yield per plant, flag leaf length, and flag leaf width of the 8 wheat genotypes are shown in Table 1. The crosses were made by hand, without reciprocals, in field conditions from March to May 2001 and the field experiment was conducted during the October 2002 to June 2003 growing season. The 8 parents and 28 F_1 progenies were grown at Bornova, İzmir, Turkey. The seed of each entry was sown in a plot, which consisted of single 1-m rows (one per entry) spaced 30 cm apart, with an intra row spacing of 10 cm between plants. Standard agronomic and plant protection treatments were used for the duration of the experiment. At maturity, 5 plants were randomly selected from each genotype of replication. Data were recorded on grain yield per plant, flag leaf length, and flag leaf width. The measurements were grain yield per plant: total weight of kernels per plant; flag leaf length: from the beginning of the ligula to the end of the tip of the leaf; and flag leaf width: the widest part of the flag leaf. The experiment utilized a randomized complete block design with 3 replications.

Data obtained from 28 F_1 progeny and 8 parents were subjected to basic analysis of variance (Steel and Torrie, 1985). Graphical analysis of gene action and determination of genetic components of variation were also conducted, according to Hayman (1954) and Jinks (1954). Diallel analysis was performed with the PopGen statistical package (Özcan and Açıkgöz, 1999). The validity of the assumptions for diallel analysis was tested with the regression coefficient of Wr/Vr.

Results and Discussion

Phenotypic correlation coefficients among characters in wheat are given in Table 2. Flag leaf length was significantly and positively correlated with flag leaf width ($r = 0.803$), and positively with grain yield per plant ($r = 0.123$). Flag leaf width was positively correlated with grain yield per plant ($r = 0.244$).

Estimates of genetic variance components, environmental variance, direction of dominance, and magnitude of dominance ($\bar{F} - \bar{P}$) in the population of half

Table 1. Mean values of genotypes and crosses of some agricultural characteristics of the 8 wheat bread genotypes used in diallel analyses.

Genotypes	Flag Leaf Length (cm)	Flag Leaf Width (cm)	Grain Yield Per Plant (g)
Parents			
Cumhuriyet	25.40	2.03	6.90
Kaşifbey	24.33	1.92	4.40
Ziyabey	24.90	1.96	7.30
Marmara	24.60	1.93	3.83
Basribey	22.46	1.95	4.63
Malabadi	25.40	2.04	1.10
Yüreğir	29.05	2.24	3.73
Seri-82	23.86	1.96	5.43
Mean	25.40	2.03	6.90
Crosses			
1 x 2	34.00	2.49	8.03
1 x 3	30.73	2.32	13.36
1 x 4	31.26	2.34	15.30
1 x 5	32.73	2.33	10.70
1 x 6	29.33	2.32	7.53
1 x 7	33.85	2.43	10.20
1 x 8	31.86	2.42	9.80
2 x 3	28.60	2.38	17.33
2 x 4	30.60	2.39	8.30
2 x 5	29.60	2.29	14.26
2 x 6	28.73	2.31	6.90
2 x 7	31.55	2.44	12.16
2 x 8	27.43	2.14	7.66
3 x 4	29.33	2.28	11.50
3 x 5	27.13	2.38	19.20
3 x 6	30.10	2.49	15.16
3 x 7	33.20	2.49	16.33
3 x 8	28.71	2.24	9.03
4 x 5	26.13	2.14	12.63
4 x 6	29.78	2.32	14.86
4 x 7	31.33	2.32	14.03
4 x 8	26.60	2.13	12.40
5 x 6	29.43	2.33	14.03
5 x 7	30.60	2.32	12.20
5 x 8	29.80	2.26	14.80
6 x 7	29.46	2.45	11.10
6 x 8	29.73	2.43	9.63
7 x 8	31.00	2.46	21.73
Mean	30.10	2.35	12.50
LSD (%)	3.76	0.224	9.71
CV (0.05)	7.52	5.8	47.6

diallel crosses of the 8 wheat genotypes are given in Table 3, which shows the additive variance component (*D*) was significant for flag leaf width, indicating successful selection could be practiced for this trait. The *F* parameter had a negative value (–2.133), suggesting the character may be under the influence of recessive genes. The dominance variance component (H_1) was significant for flag leaf width and grain yield per plant. The corrected dominance variance component (H_2) was significant for flag leaf width, flag leaf length, and grain yield per plant. The dominance variance (H_1) was larger than the corrected dominance variance (H_2). Being larger than H_2, H_1 shows that positive beneficial and negative deleterious alleles do not have the same ratios (Hayman 1954; Mather and Jinks, 1971). The dominance level variance component (h^2) was significant for all 3 traits studied. Finally, the environmental variance component (*E*) was significant for grain yield per plant and flag leaf width.

Among the genetic components of variation dependant upon both additive and dominance effects (*F*), or dominance effects (H_1, H_2, and h^2), flag leaf width and grain yield per plan traits were significant, while flag leaf length traits for H_1 were insignificant. However, the relative magnitude of the numerical values of *F, H_1*, and H_2, and their non-significance (5% probability level) do not necessarily imply their absence (Hayman, 1954). The pertinent ratios were calculated and are given in Table 4.

Ratios between parameters of genetic variance components, heritability, correlation coefficients between Wr/Vr values, and parent means in the population of half diallel crosses of the 8 wheat genotypes are provided in Table 4.

Based on these estimates being valid, the following statements can be made:

1) On average, dominance $(H_1/D)^{0.5}$ was 7.508 for grain yield per plant, 3.086 for flag leaf length, and 3.169 for flag leaf width. These values point out that there is an overdominance for the 3 traits;

2) The genes with positive and negative effects were, on average, in equal proportions ($H_2/4H_1 = 0.25$) in the parents, for all 3 traits studied;

3) The dominance-recessive ratio (*KD/KR*) is consistent with the distribution course of the genes. Proportions of dominant and recessive genes in the parents could be indicated for grain yield per plant, flag

Table 2. Correlations among the traits examined in an 8 x 8 diallel cross population of bread wheat.

Traits	Flag leaf length	Flag leaf width	Grain yield per plant
Flag leaf length	-	0.803**	0.123
Flag leaf width	-	-	0.244
Grain yield per plant	-	-	-

* and ** significant at the 0.05 and 0.01 probability level, respectively

Table 3. Estimates of genetic variance components, environmental variance, direction of dominance, and magnitude of dominance ($\bar{F} - \bar{P}$) in the population of half diallel crosses of 8 wheat genotypes.

Parameters and ratios	Grain yield per plant	Flag leaf length	Flag leaf width
D	2501 ± 20.760	3.291± 6.970	0.010** ± 0.007
F	–2133 ± 49.053	–0.072 ± 16.469	–0.003 ± 0.016
H_1	140,959**± 47.723	31.353± 16.022	0.104** ± 0.015
H_2	122,537** ± 41.519	29.899*± 13.939	0.099** ± 0.013
h^2	136,009** ± 27.844	79.698** ± 9.348	0.349** ± 0.009
D-H_1	14,164 ± 6.920	2.398 ± 2.323	0.010** ± 0.002
E	–138,459** ± 40.948	–28.062 ± 13.748	–0.094** ± 0.013
$\bar{F} - \bar{P}$	7.73	5.09	0.33

* and ** significant at the 5% and 1% level, respectively.

Table 4. Ratios between parameters of genetic variance components, heritabilities, correlation coefficients between Wr/Vr, and values and parent means in the population of half diallel crosses of 8 wheat genotypes.

Parameters and ratios	Grain yield per plant	Flag leaf length	Flag leaf width
(H1/D)0.5	7.508	3.086	3.169
H2/(4H1)	0.217	0.238	0.238
KD/KR	0.892	0.993	0.925
K= h2/ H2	1.110	2.666	3.517
H (Narrow sense)	0.012	0.074	0.066
H (Broad sense)	0.449	0.501	0.480
R(Wr + Vr), Yr	0.223	–0.751**	–0.766**

* and ** significant at the 5% and 1% level, respectively.

leaf length, and flag leaf width (*KD/KR* = 0.892 = 1; 0.993 = 1 and 0.925 = 1, respectively);

4) The traits, namely grain yield per plant, flag leaf length, and flag leaf width, were controlled, possibly by polygenic control of genes ($h^2/H_2 = 1$), 3 groups of genes ($h^2/H_2 = 3$), and 4 groups of genes ($h^2/H_2 = 4$), respectively;

5) For flag leaf length and flag leaf width, the genes with positive effects were more often dominant than recessive [r(Wr + Vr), Yr < 0], whereas for grain yield per plant, they were recessive [r(Wr + Vr), Yr > 0];

6) The heritability of the traits were 0.012 H (narrow sense) and 0.449 *H* (broad sense) for grain yield per plant, 0.074 *H* (narrow sense) and 0.501 *H* (broad sense) for flag leaf length, and 0.066 *H* (narrow sense) and 0.480 *H* (broad sense) for flag leaf width;

7) The negative r value between parents' values with Wr/Vr indicates that the direction of dominance can vary according to the parents.

The inheritance of grain yield per plant can be obtained from the Wr/Vr graph (Figure 1). Overdominance can be inferred from this graph since the regression line cuts the Wr axis below the origin. As shown by Walia et al. (1993), Sajid (1995), and Chowdhry (2002), these results are in agreement with our findings for grain yield per plant; however, partial dominance for grain yield per plant has been reported (Yıldırım, 1977; Subhani et al., 1997; Sener et al, 2000; Riaz and Chowdhry, 2003). It can be concluded that Cumhuriyet (1), Kaşifbey (2) and Marmara (4) genotypes carry the dominant genes, while the Ziyabey (3) genotype carries the recessive genes. Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8) genotypes seem to have dominant and recessive genes in more or less equal proportions for grain yield per plant.

Flag leaf is of utmost importance in cereals like wheat, because it provides the maximum amount of photosynthesis assimilates to be stored in the grains. A greater flag leaf area will eventually help to increase photosynthetic efficiency by increasing the production of photosynthesis, which is then translocated into grains increasing their weight. Therefore, flag leaf area has a direct relationship to grain yield (Riaz and Chowdhry, 2003).

Information about the inheritance of flag leaf width can be seen from the Wr/Vr graph (Figure 2). Overdominance can be inferred from this graph since the regression line cuts the Wr axis below the origin. It can be concluded that for flag leaf width, Malabadi (6) and Yüreğir (7) genotypes carry the dominant genes, while Kaşifbey (2) and Seri-82 (8) genotypes carry recessive genes. Cumhuriyet (1), Marmara (4), Ziyabey (3), and Basribey (5) genotypes seem to have dominant and recessive genes in more or less equal proportions for flag leaf width.

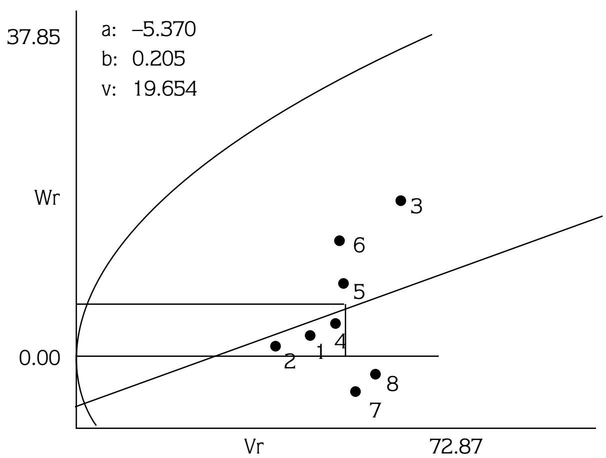

Figure 1. Wr/Vr graph of grain yield per plant. The points of Wr/Vr intercepts refer to Cumhuriyet (1), Kaşifbey (2), Ziyabey (3), Marmara (4), Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8) arrays.

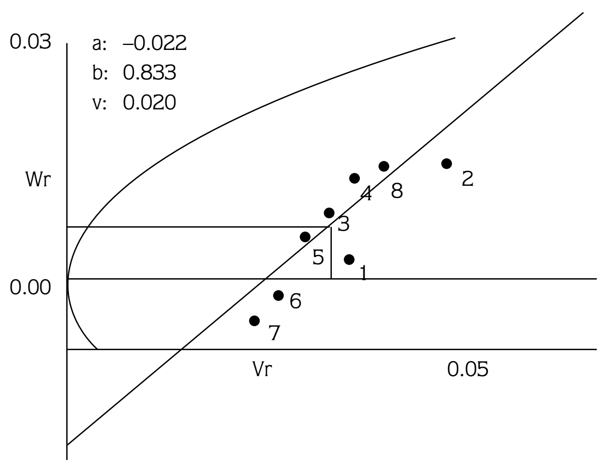

Figure 2. Wr/Vr graph for flag leaf width. The points of Wr/Vr intercepts refer to Cumhuriyet (1), Kaşifbey (2), Ziyabey (3), Marmara (4), Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8) arrays.

The Wr/Vr graph indicates that partial dominance was responsible for the expression of flag leaf length since the regression line cuts the Wr axis above the origin (Figure 3). Overdominant gene action for flag leaf area was also reported by Iqbal et al. (1991), Sajid (1995), and Chowdhry et al. (1999); however, additive gene action with partial dominance was indicated by Subham (1997), and Mahmood and Chowdhry (1999). It can be concluded that Malabadi (6) and Yüreğir (7) genotypes carry the dominant genes, while Kaşifbey (2), Seri-82 (8), Ziyabey (3), Marmara (4), Cumhuriyet (1), and Basribey (5) genotypes seem to have dominant and recessive genes in more or less equal proportions for flag leaf length. Yıldırım (1977) and Nazeer et al. (2004) reported similar results, which agree with the results of the present study. Earlier studies used different cultivars, so the similarity of results indicates that our study used new cultivars identified to have the same kind of gene action as previously identified. This study and earlier studies indicate that flag leaf length has a common genetic control mechanism; hence the results are not specific to these 8 cultivars.

The Wr/Vr graphs (Figures 1-3) provide information regarding the overall genetic situation concerning the individual array of crosses and, implicitly, their parents. Thus, the Wr/Vr graph for grain yield per plant (Figure 1) shows that the dominance is a slight overdominance. The genotype Ziyabey (3) has predominantly recessive genes, whereas Cumhuriyet (1), Kaşifbey (2), and Marmara (4) genotypes have slightly dominant genes. Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8) genotypes seem to have dominant and recessive genes in more or less equal proportions. Because high yield appeared to be controlled predominantly by recessive genes, the selection of high yielding homozygous lines from the Cumhuriyet (1) x Ziyabey (3) genotypes could be used fairly rapidly.

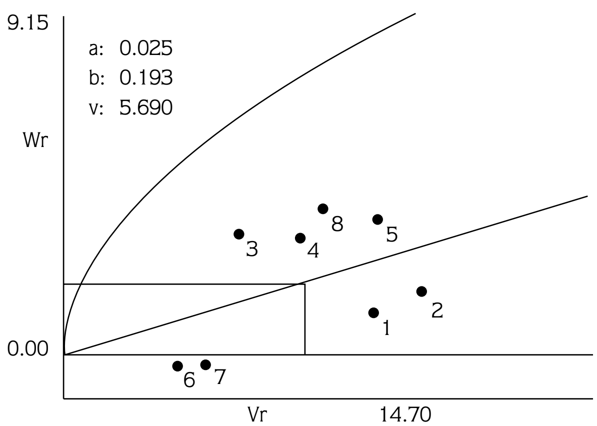

Figure 3. Wr/Vr graph for flag leaf length. The points of Wr/Vr intercepts refer to Cumhuriyet (1), Kaşifbey (2), Ziyabey (3), Marmara (4), Basribey (5), Malabadi (6), Yüreğir (7), and Seri-82 (8) arrays.

For flag leaf width (Figure 2) and for flag leaf length (Figure 3), the graphs show a slight partial dominance. For flag leaf width, the genotypes Malabadi (6) and Yüreğir (7) appear to have dominant genes, while Kaşifbey (2) and Seri-82 (8) appear to have recessive genes. For flag leaf length, the genotypes Cumhuriyet (1), Ziyabey (3), Marmara (4), and Basribey (5), and for flag leaf width, Cumhuriyet (1), Kaşifbey (2), Seri-82 (8), Ziyabey (3), Marmara (4), and Basribey (5) seem to have dominant and recessive genes in more or less equal proportions. High flag leaf length was found to be controlled by both dominant and recessive genes, with a slight preponderance of dominance. Consequently, selection for flag leaf length and flag leaf width in the progeny of Yüreğir (7) x Malabadi (6) genotypes would involve the combination of dominant genes having positive effects on these traits. Thus, the analysis of data shows that Yüreğir (7) x Malabadi (6) genotypes should be considered for maximizing leaf photosynthetic area.

Offspring obtained from the crosses have been growing in field conditions in İzmir. They are at the F_3 stage at the time of writing and selection of the promised cross lines will begin in the next few years. The selection will be made considering grain yield and photosynthesis efficiency.

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