Research Article
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Ekin
Journal of Crop Breeding and Genetics
10(2):77-84, 2024
Ekin International biannual peer-reviewed journal

Changes for Grain Yield and Spike Characters in Early Segregating Generations of Bread Wheat Crosses

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Citation:
Göçmen Balaban D., Balkan A., Bilgin O., Başer İ., 2024. Changes for Grain Yield and Spike Characters in Early Segregating Generations of Bread Wheat Crosses. Ekin J. 10(2):77-84.

Received: 25.02.2024 ***Accepted: 16.03.2024*** ***Published Online: 30.07.2024*** ***Printed: 31.07.2024***

ABSTRACT

The study was carried out to evaluate 20 bread wheat cross populations in F_2, F_3 and F_4 segregating generations, and to determine promising cross combinations with high performance for spike characteristics and grain yield. The five parents of the crosses were also evaluated along with the populations over the years. The ranges of mean value across populations were 8.66-10.94 cm for spike length, 41.08-54.96 number of grains per spike, 2.07-2.50 number of grains per spikelet, 1.89-2.46 g for grain weight per spike, 1.89-2.43 for spike density, 69.8-75.85% for spike index and 3592-5478 kg ha^{-1} for grain yield on average. These ranges were larger for all traits than the across generations indicating that there is sufficient variation for spike traits in the populations studied. Considering the statistical significance among the generations for the investigated spike traits, selection will be more efficient in as early generation as possible for the number of grains per spike, the number of grains per spikelets. Though it is not statistically significant the highest spike length and spike index values were obtained in the F_2 generation means that it may be appropriate to select in early generation for these traits keeping in mid the hybrid vigor may be affecting the traits of interest. It was concluded that it would be more appropriate to make the selection for the remaining spike characters after the F_2 generation. Among the parents used in crosses, Sana, Pehlivan and Krasunia cultivars showed their high performance in spike characteristics, and it might be plausible to use them as parents in wheat breeding studies to increase yield through spike characteristics. The Sana/Flamura 85, Sana/Krasunia, Pehlivan/Sana, Bezostaja1/Krasunia and Krasunia/Pehlivan were noted as the most promising crosses for spike characteristics.

Keywords: Bread wheat, reciprocal hybrids, spike characteristics, variation, generation

Introduction

A significant increase in the production of cereals, which are the most important crop plants, in the next decades, is of critical importance due to the increasing global population. This is particularly difficult as it is anticipated that key manageable resources, which are important components of crop production, will not increase (Connor and Mínguez, 2012) and available land will likely decrease (Albajes, et al., 2013).

Among the most important crops, wheat is one of the most critical for ensuring the nutrition of the world population: because it is the most widely grown crop in the world and accounts for 30% of global cereal production and 45% of grain nutrition (Charmet, 2011), and is the primary source of protein for the world population, representing 20% of daily intake for developing countries (Braun et al., 2010). It is considered to be a situation that can only be achieved by recovering high rates of genetic gains, but that cannot be easily achieved as there is evidence that genetic gains in yield are much lower than required recently (Reynolds et al., 2012). The actual rate of wheat production in recent years has increased by only 0.5% per year, far less than the 1.4% required to deal with the growing human population (Ray et al., 2013). Therefore, improved wheat production should be provided by further increasing the grain yield per area. The possibility of accelerating the breeding process will increase with the genetic variation information available for traits determining yield in early generations (Reynolds and Borloug, 2006).

Wheat is one of the plants that plays the most critical role in food the world population. Wheat is the most widely grown plant in the world due to its adaptability. Wheat provides 30% of global grain production and 45% of grain nutrition (Charmet , 2011) and in developing countries, it is the primary source of protein in the world's population, accounting for 20% of the daily intake (Braun et al., 2010). These high rates can be achieved by recovering genetic gains, and there is evidence that increases in wheat yield have been low in recent years, and it is considered that the food needed for nutrition in the future cannot be provided by such an increase (Reynolds et al., 2012). It shows that wheat production has increased by 0.5% in recent years, which is well below the 1.4% increase needed by the increasing world population (Ray et al., 2013). In order to meet the food needs, wheat production must be increased by further increasing the grain yield per unit area. Accelerating the breeding process with genetic diversity information for the traits that determine yield in early generations will increase the probability of increasing yield (Reynolds and Borloug, 2006).

Grain weight per spike, considered the final yield component, is the end point in the development of many components that occur in the early growth stages. Since the grain weight per spike has a direct effect on the harvest index, it makes an important contribution to yield formation. It directly reflects the efficient use of nutrients and their transport to productive parts of the plant (Borojevich, 1983). It was stated that grain yield is influenced by spike characters like spike length, a number of grains per spike and spikelet, grain weight per spike, spike density and spike index. For the improvement of wheat yield, these attributes must be improved for selection so that the yield of the wheat can be increased because these have a strong association with the grain yield (Ahmed et al., 2023). Qu et al. (2009) reported that grain yield was improved with the increasing number of grain spikelets because of the increased spikelet number. Grain yield, which is the primary characteristic considered in wheat breeding, is a complex trait that is controlled by many genes and is highly affected by environmental conditions (Shi et al., 2009; Öztürk et al., 2023). The yield, the final product of many processes, is determined directly and multilaterally by the yield components such as productive spikes per unit area, the number of grains per unit area and the total kernel number per unit area that is the product and grain crop per ear (Arbuzova et al., 2010). Wheat spike characters are a key determinant of multiple grain yield components and a detailed examination of spike traits is beneficial to explain wheat grain yield and the effects of differing agronomy and genetics (Zhou et al., 2021).

Analysis of breeding history also revealed wheat grain yield improvement in the last century was highly associated with an increase in grain number per unit area, which is largely determined by the grain number per spike (Hawkesford et al., 2013). Wheat grain number per spike is determined by the combination of the number of spikelets per spike and the number of grains per spikelet and each wheat spikelet has more than one grain. This makes the wheat spikelet one of the most essential grain yield components (Wolde et al., 2019). Other characteristics that affect the total number of grains are considered as the number of fertile tillers per plant, the number of spikelets per spike and the number of fertile flowers per spikelet.

A combination of length and density, a spike is a source of assimilation considered an essential trait of the yield. Spikes are green and functional with the awns (Sharma and Subehi, 2003). In wheat, all parts of the ear, such as the awn, glume, lemma, palea, pericarp and even peduncle, are capable of photosynthesis, and a significant portion of assimilates are obtained from the photosynthesis of these organs (Wang et al., 2001). Especially the awn plays an important role in the grain-filling stages and contributes to large grain and high grain yield in awn wheat varieties (Li et al., 2006). Various results have been obtained on the contribution of a spike to grain yield as an organ that regulates photosynthesis and respiration in many wheat varieties. It has been reported that it contributes 10-76% (Wang et al., 2001) and approximately 22-45% (Maydup et al., 2010), and these rates are higher than any flag leaf or other leaves.

In this direction, it was aimed to determine appropriate promising bread wheat cross combinations and F_2, F_3 and F_4 generations for grain yield and spike characters at F_2, F_3 and F_4 generations in Tekirdağ ecological condition.

Materials and Methods

Twenty bread wheat population and 5 five bread wheat varieties, which are the parents of the populations were used as genetic material in the study (Table 1). No selection was made in the F_2, F_3 and F_4 generations.

The study was conducted in the experimental area of Namık Kemal University Faculty of Agriculture, Department of Field Crops during three growing seasons using randomized complete block design with four replicates. The trials consist of 4 m^2 (20 cm- spaced 4 rows, 5 m long) plots. Seeding density was 500 seeds per m^2. The sowing time was at the end of October each year, and a total of 160 kg ha^{-1} N fertilization was applied in the sowing, tillering and booting stages divided equally into three. Weeds were chemically controlled.

In this study, grain yield spike length, number of grain per spike, grain weight per spike, number of grain per spikelet, spike density and spike index were measured in the spike of 10 plants in three consecutive segregating populations (F_2, F_3 and $F_{4)}$. The spike density, grains/spikelets and spike index were calculated as:

$$SD=\frac{\text{Spikelets/spike}}{\text{Spike length}}$$

$$G/SL=\frac{\text{Grains/spike}}{\text{Spikelets/spike}}$$

$$SI=\frac{\text{Grain weight/spike}}{\text{Spike weight}}$$

Combined analyses of variance (ANOVA) across generations for grain yield and some spike traits were performed. The "MSTAT version 3.00/EM" package program is used for statistical analysis. The differences among means for parents and populations for each year were determined by Duncan's New Multiple Range Test.

Results and Discussion

The results of combined analyses of variance (ANOVA) including three consecutive generations for each traits indicated that there were highly significant differences among populations means. However, the mean differences between the generation averages were not significant for spike length, grain weight per spike and spike index. The results of the significance test performed to determine the differences between populations and generation averages for each trait examined are shown in Table 2.

The important difference between populations for traits indicates the presence of significant variation between populations in which traits are studied and allow breeders to improve these traits through breeding. The grain yield which is the most important economic trait in wheat improvement is a complex quantitative trait controlled by multiple genes and is highly influenced by environmental conditions (Shi et al., 2009). Since non-genetic effects are large (Bernardo, 2003), early generation selection is expected to be ineffective for grain yield. But, screening of segregating populations can give us ideas for future evaluations.

Spike length: Average spike length values in hybrid combinations varied between 8.66-10.94 cm, and between 9.70-10.41 cm in F_2, F_3 and F_4 segregation progeny. Population 17 showed maximum spike length (10.94 cm), followed by population 16 (10.92 cm), and populations 19 and 9 (10.82 and 10.68 cm). The lowest ear length population 1 (8.66 cm) was obtained. Considering the mean values for spike length in hybrid combinations, combinations 17, 16, 18, 9, 15, 14, 6 and 4 were determined as promising.

Number of grains per spike: The number of grains per ear in the hybrid combinations varied in a wide range between 41.08-54.96, and population 16 took the first place in terms of the number of grains per head with 54.96. Population 14 was ranked with the number of grains in 52.89 spikes and populations 7 and 8 were ranked later with the number of grains in 52.64 and 49.98 spikes. The lowest number of grains per spike was obtained in the number 1 combination with 41.12. When the average grain-per-head performance in hybrid combinations is evaluated, combinations 16, 7, 8, 9, 6, 3, 4, 13 and 17 are the most promising ones.

Number of grains per spikelet: The ranges of average values across hybrid combinations were 2.07-2.50 number of grains per spikelet. Segregation generations have been determined as 1.95-2.48 number of grains per spikelet. Population 7 showed the maximum length of a spike (2.50 no). Populations 16, 20 and 8 had a higher number of grains per spikelet (2.44 no) while populations 9 and 4 had a medium number of grains per spikelet (2.42 and 2.38 no). The minimum number of grains per spikelet was revealed by populations 1 and 19 (2.07 no). When the mean performance of average values cross populations was evaluated, the promising cross combinations were numbered combinations of 16, 7, 8, 20, 9, 4, 10 and 6 for the number of grains per spikelet.

Grain weight per spike: The ranges of average values across hybrid combinations were 1.89-2.46 g for grain weight per spike. When the values of the properties examined in the F_2, F_3 and F_4 segregation generations were examined, they changed according to the generations. These values in segregation generations have been determined as 2.04-2.19 g for grain weight per spike. Population 9 showed maximum grain weight per spike (2.46 g). Population 16 had (2.30 g) grain weight per spike while populations 19 and 6 had the medium grain weight per spike (2.29 and 2.28 g). The minimum grain weight per spike was revealed by population 11 (1.89 g). When the mean performance of average values cross populations was evaluated, the promising cross combinations were numbered combinations of 5, 16, 14, 6 and 7 for grain weight per spike.

Spike density: Spike density is an agronomical important character of wheat. In addition, an optimized spike structure is a key basis for high yields. The spike is an important part of the wheat plant. Cultivating wheat varieties with longer spike lengths (SL) and higher spike density (SD) could increase yield (Faris et al., 2014; Li et al., 2016). The spike density values in the parents and populations used in the study varied between 1.93-2.43 and between 1.93-2.29 in hybrid combinations. While the highest spike density in hybrid combinations was between 2.29 and 7, this value was lower than the parent number 22. In terms of spike density, the combinations 2.26 and 2.25 and 10 and 20 are listed later. The lowest spike length was obtained in the hybrid combination numbered 1.93 and 15, followed by the hybrid number 18 with a spike density value of 1.89. In terms of spike density, the combinations numbered 7.10, 20 and 12 are the most promising, and as the generations progressed, the spike density increased.

Spike index: One of the potential traits to increase grain weight is the spike harvest index, a major component of grain weight, calculated as the ratio of grain weight to spike dry weight (Pradhan et al., 2019). The genetic basis of the spike index is not clearly understood yet and there is little agreement in the literature regarding the effect, phenotypic variability and genotype by environment interaction (GEI) for the spike index of wheat. The spike index value in the examined parents and populations varied between 69.83-75.85%. In terms of the spike index value in 20 hybrid combinations, the combination numbered 17 with 75.85% was in first place, followed by the hybrid combinations numbered 14 and 6 with 75.25% and 75.01. The lowest spike index is 69.83% in hybrid number 20. According to the data obtained, combinations 17, 14 and 6 are the most suitable combinations in terms of spike index.

Grain yield: The highest value in terms of grain yield was obtained in the parent Sana, number 14, 7, 15, 1, 2 and 8 populations were the superior hybrid combinations. On the other hand, populations 3 and 18 give the lowest performance in terms of grain yield.

When the mean performance of average values of cross combinations evaluated, the promising cross combinations were of 14, 7, 12, 9, 11 and 13 for spike density and 14, 6, 5, 7, 13 and 20 for spike index. These results indicate that 19, 2, 7, 13, 6, 14, 4 and 16 combinations may be promising for spike properties. Pradhan et al. (2019) explained that the spike harvest index is an important spike trait since it shows the main components of the grain number and grain weight in wheat, respectively. Islam et al., (1985) stated inclusion of kernel weight in a selection index with grain per spike or spikelet might have been profitable. Bhatta et al., (2019) reported that the spike harvest index value of genotypes varied between 25 and 91%.

Spike index and grain yield were increased from generation F_2 to F_4 for, there were decreases in spike length, the number of grains per spike and spikelet and spike density. Various results have been reported for the selection of yield and yield components in segregation generations. It has been explained that plant characters carrying the desired gene or allele combinations can be easily identified and selected in early generations, preferably in F_1, before reaching homozygosity in late generations (Cristina and Hall, 1995). Sing and Singh, (1997) reported that selection may be effective for seed weight in early-generation F_2, whereas early-generation selections for harvest index, grain yield and dry matter weight are ineffective in common wheat. Rasmussen (1987) explained that delaying selection to a later generation, such as F_4, can lead to the loss of such desired gene combinations. Islam et al., (1985) pointed out that the selection for the grain number per spikelet or grain number per spike may be more effective than for weight per grain and yield *per se* in the F_2 generation.

Current study shows that the highest variation in spike length, number of grains per spike, grain weight per spike and spike index is in the F_2 generation, and as a result, selection can be started in this generation, at the same time, keeping in mind hybrid effect was still effective in this generation. While the highest variation for the number of grains per spike is in the F_3 generation, the fact that the highest variation for the spike density and grain yield per hectare is in the F_4 generation shows that it is advisable to perform the selection for these characteristics in the F_3-F_4 generations.

Conclusions

It was concluded from the present research that populations showed highly significant variations for all the traits. Based on the results of this study, crosses of (Sana/Flamura 85), (Sana/Krasunia), (Krasunia/Pehlivan), (Pehlivan/Sana) and (Bezostaja1/Krasunia) were the best-performing populations for grain yield and spike traits indicating selected populations from these crosses can be used to improve these traits in breeding. Among the parents used in crosses, Sana, Pehlivan and Krasunia varieties showed high performance for spike characters indicating that it may be appropriate to use them as parents to improve the spike characteristics in subsequent breeding studies. Based on the statistical significance between generations for the traits seems that selection will be more efficient in generation for the number of grains per spike and spikelets. Although it is statistically insignificant, the fact that the highest spike length and spike index values were obtained in the F_2 generation means that it may be appropriate to select in the very early generation for these traits. It was concluded that it would be more appropriate to make the selection for the remaining spike characters after the F_2 generation.

Conflict of interest

The authors declare that there is no conflict of interests regarding the publication of this article.

Acknowledgements

This study is presented at the 2nd International Symposium for Agriculture and Food-ISAF 2015 as a poster presentation.

Table 1. Cross combinations and their parents used as genetic material.

Crosses		Parents
1. Pehlivan/Flamura 85	11. Bezostaja1/Sana	21. Flamura 85
2. Flamura 85/Pehlivan	12. Sana/Bezostaja 1	22. Sana
3. Bezostaja 1/Flamura 85	13. Krasunia/Sana	23. Krasunia
4. Flamura 85/Bezostaja 1	14. Sana/Krasunia	24. Bezostaja 1
5. Krasunia/Flamura 85	15. Pehlivan/Krasunia	25. Pehlivan
6. Flamura 85/Krasunia	16. Krasunia/Pehlivan	
7. Sana/Flamura 85	17. Bezostaja1/Krasunia	
8. Flamura 85/Sana	18. Krasunia/Bezostaja 1	
9. Pehlivan/Sana	19. Pehlivan/Bezostaja 1	
10. Sana/Pehlivan	20. Bezostaja 1/Pehlivan	

Table 2. The means of parents and populations used in the experiment for grain yield and spike characteristics.

Crosses and parents	Spike length (cm)	Number of grain per spike (no)	Number of grain per spikelet (no)	Grain weight per spike (g)	Spike density	Spike index (%)	Grain yield (kg ha^{-1})
1	8.66 d*	41.12 f	2.07 c	2.08 ab	2.05 c-g	72.07 a-d	5110 a-d
2	9.54 a-d	45.47 c-f	2.31 abc	2.13 ab	2.09 b-g	73.18 a-d	5059 a-e
3	9.12 bcd	47.16 a-f	2.28 abc	1.95 b	2.03 d-g	70.15 cd	3804 hı
4	10.10 a-d	47.10 a-f	2.38 abc	2.05 ab	2.02 efg	74.04 abc	4440 d-h
5	9.57 a-d	44.68 c-f	2.11 abc	2.04 ab	2.23 a-e	71.38 bcd	5306 ab
6	10.10 a-d	46.44 a-f	2.32 abc	2.28 ab	2.00 fg	75.01 ab	4730 b-g
7	9.41 a-d	52.64 abc	2.50 a	2.18 ab	2.29 ab	74.57 ab	5154 abc
8	9.91 a-d	49.98 a-d	2.44 abc	2.14 ab	2.11 b-f	73.43 a-d	5014 a-e
9	10.68 a	49.96 a-d	2.42 abc	2.46 a	2.02 efg	74.91 ab	4843 a-f
10	9.58 a-d	44.83 c-f	2.36 abc	2.09 ab	2.26 abc	72.68 a-d	4742 b-g
11	9.59 a-d	42.14 def	2.11 abc	1.89 b	2.21 a-e	70.02 cd	4239 f-ı
12	9.77 a-d	46.03 b-f	2.11 abc	2.21 ab	2.24 a-d	73.09 a-d	4147 ghı
13	9.82 a-d	46.84 a-f	2.25 abc	2.16 ab	2.21 a-e	74.16 abc	4888 a-f
14	10.14 a-d	52.89 abc	2.10 bc	2.24 ab	2.07 b-g	75.25 ab	5396 ab
15	10.28 abc	41.41 f	2.14 abc	1.97 b	1.93 fg	71.28 bcd	5100 a-d
16	10.92 a	54.96 a	2.44 abc	2.30 ab	2.11 b-f	73.53 a-d	4762 a-g
17	10.94 a	47.24 a-f	2.20 abc	2.16 ab	2.04 c-g	75.85 a	4007 hı
18	10.82 a	44.89 c-f	2.26 abc	2.15 ab	1.89 g	72.12 a-d	4123 ghı
19	9.83 a-d	41.08 f	2.07 c	2.29 ab	1.95 fg	71.47 bcd	4470 c-h
20	10.21 abc	41.74 e	2.44 abc	2.02 ab	2.25 abc	69.83 d	4381 e-h
PARENTS							
21	9.77 a-d	48.93 a-g	2.41 abc	2.01 b	2.08 b-g	73.74 a-d	4749 a-g
22	8.80 cd	54.12 ab	2.47 ab	2.08 ab	2.43 a	74.82 ab	5478 a
23	10.74 a	49.39 a-f	2.31 abc	2.21 ab	2.02 d-g	73.71 a-d	5071 a-e
24	10.38 ab	42.61 def	2.11 bc	1.92 b	2.06 b-g	70.13 cd	3592 ı
25	9.93 a-d	42.29 def	2.11 bc	2.06 ab	2.05 c-g	75.22 ab	5418 ab
MSE	*0.968*	*26.663*	*0.059*	*0.077*	*0.018*	*12.872*	*1897.925*
GENERATIONS							
F_2	10.41	49.17 a	2.48 a	2.19	1.94 b	74.26	4563 b
F_3	9.7	49.36 a	2.37 ab	2.15	2.11 a	72.97	4542 b
F_4	9.71	41.38 b	1.95 b	2.04	2.26 a	71.84	5059 a
MSE	*11.343*	*175.86*	*175.86*		*0.067*		*2200.253*

* The differences between the means for each trait denoted by the same letter are statistically insignificant.

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