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The Evaluation of Agronomic Traits of Durum Wheat (*Triticum durum* Desf.) Mutants

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Abstract: Genetic variability induced by mutagen treatments has maintained in the generations. The increases in variability resulted in the selection of superior mutant types for yield and yield components are used successfully in wheat breeding. The aims of the study were: (I) to select mutant lines with good yielding properties by comparing mutant lines with mother cultivars for agronomic traits in the M_4 and M_5 generations and (ii) to advance the selected lines to the following generations. The lines used in the experiment were selected from mutant populations of durum wheat cultivars (*Sofu* and Gediz-75) treated with etil-methane-sulfonate (EMS). The mutants were identified by visual screening for short straw, long spike and confirmed by measuring some characters of theoretical and practical interest in the M_2 and M_3 generations. The mutants with good yielding properties as compared to the mother cultivars were transferred to the M_4 generation. Eighteen of these lines were from cv. Gediz-75 and twelve were from cv. Sofu. The experiments were organized as a randomized complete block design with three replications. There were several mutant lines with higher or lower means than those of mother cultivars. Responses of the mutants depended on the environmental conditions. It is possible to select higher yielding mutant lines with also some important agronomic traits. Selection of high yielding mutant lines could be performed in the M_5 and these lines as a breeding material transferred in the yield experiments. Thus, number of mutant lines can be decreased considerably by early selections in the M_4 and M_5. Mutant lines with desirable characters varied with cultivars. Gdem-1, 2, 7 lines of cv. Gediz-75 and Sfem-1, 2, 3 lines of cv. *Sofu* showed a better agronomic performance than the others.

Key words: Durum wheat, mutant, breeding, yield, yield components

INTRODUCTION

The increasing economic importance of durum wheat has stimulated the breeding studies in this crop. One of the methods used in durum wheat breeding has been mutation breeding. Mutation breeding has been used successfully in several crops for breeding agronomically important traits[1]. It was also used to select some durum wheat mutants with increased agronomic performances[2]. There are about 28 registered durum wheat cultivars bred via mutation breeding techniques[3]. These cultivars are very important in durum wheat production and have a competition potential with bread wheat cultivars[4].

If desired genetic variability or a specific character is not available in a crop, then mutation breeding is a logical step[5]. The range and frequency of desirable mutants induced differs with mutagen and the genotype[6]. One of the breeding aims in durum wheat is to select high yielding genotypes. Durum wheat lines must have the best combination of spike numbers per square meter, plant height, spike length, single spike yield and maturity period for obtaining the highest yield potential. Selection based upon above yield components would result in yield increases. As a matter of fact, some mutants showed a better agronomic performance than their mother cultivars[4]. On the other hand, Knott[5] reported that although some mutant lines selected in the M_4 and M_5 generations had good agronomic traits such as earliness and shortness, they did not have any advantages in overall yield when compared to their parent cultivars.

Genetic variability in segregating generations (M_2, M_3) after mutagen applications allows to select mutant types with desirable changes. As a result, the success of mutation breeding is affected by selecting desirable mutant types for different traits. The aims of this study were: (I) to select mutant lines with good yielding properties by comparing mutant lines with mother cultivars for agronomic traits in the M_4 and M_5 generations and (ii) to advance the selected lines to the following generations.

MATERIALS AND METHODS

This study was performed in the 1998-1999 and 1999-2000 growing seasons under Kazova Plain ecological conditions in Tokat, Turkey. Average precipitation for

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this region was about 387.2 mm yr^{-1}. Amount of precipitation during the first year growing period was much lower (352.6 mm) than that the second year (425.3 mm). Soil properties of the research area were clay-loam, little alkaline, medium in calcium carbonate content, poor for available phosphorus and for organic matter, and reach for potassium.

The two durum wheat cultivars, Gediz-75 and Sofu (*Triticum durum* Desf.), were used as plant materials. Sofu cultivar is an alternative type, tall, weak straw with low yield potential and susceptible to lodging and is a native durum adapted to the conditions of Tokat region. Gediz-75 cultivar is an alternative type, medium height, strong straw, high yielding but has low "semolina" flour yield, it was registered in 1986 and adapted to the coastal regions of Turkey.

Treatment methods and mutagen used: Ethyl-methane-sulfonate (EMS) treatment was prepared as to 1 mm concentration per seed. Dry seeds were treated with 0.1, 0.2, 0.3 and 0.4 % EMS at 24°C for 8 h and washed for 6 h after treatment[7].

Selection of mutants: M_1 material grown in field was harvested as single spikes. Seeds at each M_1 spike were sown in field as spike-row progeny as M_2 generation. M_2 plants that differed from the mother cultivar or plants with desired phenotypes were harvested individually. Then, M_3 progenies from selected M_2 plants were grown[8] The mutants were identified by visual screening for short straw, long spike and confirmed by measuring some characters of theoretical and practical interest in the M_2 and M_3 generations[9]. The mutants with good yielding properties as compared to the mother cultivar were transferred to the M_4 generation. Eighteen of these lines were from cv. Gediz-75 and twelve were from cv. Sofu. Mutant lines were examined along with their mother cultivars.

Agronomic evaluation of mutant lines: Selected mutant lines were evaluated for important agronomic traits by comparing with mother cultivars at the M_4 and M_5 generations[10]. The mutant lines of each cultivar were grown under dry conditions. The design was as a randomized complete block with three replications. Each plot consisted of two rows, 2 m long. Seeds were sown 20 cm apart in rows. Sowing was performed by hand on November 10, 1998 in the first year of trial and on November 9, 1999 in the second year. Total quantity of P fertilizer (70 kg ha^{-1} P_2O_5) was applied during sowing together with half of N (totally 140 kg ha^{-1}). The rest of N was applied before the joint growth stage.

Statistical analysis: The traits studied in this research were determined in the following ways. Plant height: Main stem of plants was the distances in cm from ground level to the terminal of last spikelets. Spike length: The length of main spikes was measured in cm. Number of kernel per spike: The number of kernels in ten spikes was counted after they had been harvested and was divided by the number of spikes. Single spike yield: The kernels of ten spikes was weighed and divided by the number of spikes. 1000 kernel weight was calculated by taking 4 different samples of 100 kernel from per plot and by weighing and averaging these samples. Grain yield m^{-2} was calculated by multiplying the computed grain weight for each plot. Data were analyzed according to the experimental design with analysis of variance (ANOVA) by using the Statistical Software Package (MSTATC) computer program. The differences among mutant lines and mother cultivars means were determined by Duncan's multiple range test.

RESULTS AND DISCUSSION

Plant height: Mutant lines of cv. Gediz-75 in the M_4 and M_5 generations had the same values as compared to the mother cultivar except for Gdem-4, 7, 8, 9, 17 lines. Differences for plant heights among the lines were significant in the M_4 and M_5 generations (Table 1). The induced mutant lines with long or short plant heights indicated the potential of mutation breeding. The changes in plant height of mutants generally were similar. As a result, plant height for cv. Gediz-75 was affected more frequently by genotypes than by environment.

Sofu mutant lines had a lower plant height when compared with the mother cultivar in both generations, but the decreases in plant height for Sfem-7 and Sfem-10 were significant in the M_5 (Table 2). The reduced plant height in the M_4 and M_5 generations indicated the successful of selection in the segregating generations. Selection of mutants for plant height provides better results in the M_5. Borojevic[11] reported that induced variability in the plant height has been stable in the M_5 and maintained later generations. Thus, since Sofu cultivar characterized by tall culm and high susceptibility to lodging, short culm mutants associated with relevant agronomic characteristics can be selected. However, both mutants and mother cultivar in the M_4 and M_5 generations did not lodge, thereby cannot tested for resistant to lodging of lines. The average plant height in the M_5 generation was higher than that in the M_4 generation (Table 2). The increases in the plant height could be originated from longer vegetative growth period in the second year of trial.

Table 1: Yield components and grain yield of mutant lines and Gediz-75

Mutant lines and Gediz-75	Plant height (cm)		Spike lenght (cm)		Number of kernels per spike		Single spike yield (g)		1000-kernel weight (g)		Grain yield (g m^{-2})	
	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5
Gdem-1	75.7bc*	76.3a-e*	7.8d*	6.3	51.7	36.3	2.38	2.05	52.6a**	54.8bcd**	276.7a*	129.5ab**
Gdem-2	79.3a-c	77.3a-e	9.1bcd	6.6	56.0	44.0	2.63	2.39	41.3b	55.2abc	215.2ab	158.4a
Gdem-3	86.9a	85.0a	9.5bc	6.6	60.3	36.7	2.56	2.21	47.5ab	48.8e	165.9bcd	139.2ab
Gdem-4	81.0a-c	76.0b-e	10.4ab	6.1	68.7	43.7	2.85	2.44	36.9b	49.9cde	141.7cd	153.2a
Gdem-5	85.0ab	83.0a-c	8.9bcd	5.2	48.7	34.0	2.24	1.69	38.9b	49.3de	197.3bcd	108.1ab
Gdem-6	88.0a	84.0ab	9.5bc	6.7	53.3	43.0	2.51	2.48	40.6b	55.8ab	199.2bcd	114.0ab
Gdem-7	83.0ab	77.0a-e	11.2a	6.5	56.7	38.7	3.14	2.16	38.1b	54.4bcde	209.2abc	110.5ab
Gdem-8	84.3ab	78.0a-e	9.1bcd	6.5	52.3	38.7	2.54	2.15	46.9ab	56.3ab	199.9bcd	100.4ab
Gdem-9	78.0a-c	82.5a-d	9.3bcd	6.8	57.3	43.7	2.56	2.64	42.5ab	60.9a	217.7ab	111.6ab
Gdem-10	78.0a-c	81.0a-d	9.1bcd	6.8	60.7	34.7	2.77	2.39	40.2b	57.7ab	232.2ab	118.0ab
Gdem-11	78.3a-c	80.3a-d	9.6bc	7.0	66.0	41.7	2.53	2.37	40.5b	55.2abc	200.0bcd	158.8a
Gdem-12	82.7ab	85.0a	10.2abc	7.2	54.0	37.7	2.22	2.25	40.5b	53.0bcde	200.0bcd	80.9b
Gdem-13	74.7bc	70.4e	9.2bcd	5.9	46.7	36.3	1.94	2.09	37.3b	57.1ab	173.3bcd	126.5ab
Gdem-14	81.2a-c	82.7a-d	9.7bc	7.1	58.7	42.0	2.97	2.41	41.2b	55.9ab	182.4bcd	128.8ab
Gdem-15	76.2bc	75.0c-e	9.1bcd	6.9	40.3	44.7	1.59	2.25	41.5b	53.7bcde	224.6ab	137.2ab
Gdem-16	76.3bc	74.0de	9.1bcd	6.7	61.0	41.0	2.62	2.34	36.4b	53.8bcde	213.5ab	156.0a
Gdem-17	82.3a-c	79.3a-d	9.0bcd	7.0	52.7	39.7	2.58	1.71	45.7ab	55.9ab	171.1bcd	117.6ab
Gdem-18	72.0c	77.2a-e	9.2bcd	6.7	54.0	41.7	2.31	2.23	38.6b	51.9bcde	137.1d	106.2ab
Gediz-75	81.0a-c	81.7a-d	8.8cd	6.6	54.7	36.3	2.76	2.42	42.3ab	57.5ab	200.3bcd	106.5ab
Mean	80.2	79.2	9.4	6.6	55.5	39.7	2.51	2.25	41.5	54.6	197.7	124.3
C.V.(%)	6.5	5.7	8.3	10.6	14.3	10.5	16.2	12.4	10.4	4.2	14.2	14.1

Table 2: Yield components and grain yield of mutant lines and Sofu

Mutant lines and Sofu	Plant height (cm)		Spike lenght (cm)		Number of kernels per spike		Single spike yield (g)		1000-kernel weight (g)		Grain yield (g m^{-2})	
	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5	M_4	M_5
Sfem-1	115.0	135.7abc**	10.0ab**	8.0a**	51.0a**	42.7	3.18a**	3.10a*	44.6bc**	68.9ab**	144.2bc**	193.2abc*
Sfem-2	120.0	144.3a	8.7bc	6.8b	37.7abc	33.7	2.22abc	2.34abc	46.0abc	67.6ab	225.3ab	256.3a
Sfem-3	109.0	138.0abc	8.3c	7.0ab	24.7c	33.0	1.35c	1.98bc	51.5a	60.4c	261.9a	186.2abc
Sfem-4	110.7	152.0a	9.2abc	7.2ab	43.7ab	37.3	2.41abc	2.63abc	50.3ab	68.2ab	198.0abc	211.6ab
Sfem-5	119.0	136.7abc	8.4c	6.8b	32.7bc	38.7	1.55bc	2.52abc	45.9abc	66.1ab	149.4bc	173.0bc
Sfem-6	131.0	141.7ab	9.3abc	7.4ab	38.3abc	29.0	2.17abc	2.49abc	49.9ab	67.9ab	174.4abc	154.9bc
Sfem-7	120.0	123.3bc	9.0bc	6.7b	43.0ab	33.2	1.91bc	1.77c	43.0cd	54.5d	125.8bc	159.9bc
Sfem-8	116.7	138.0abc	8.5c	6.9b	36.0abc	35.3	1.85bc	2.85ab	48.6abc	65.8abc	116.0c	175.3abc
Sfem-9	130.9	134.7abc	10.5a	6.5b	48.3a	41.0	2.66ab	2.84ab	48.7abc	65.2abc	124.5bc	144.5bc
Sfem-10	113.0	122.7c	9.3abc	6.3b	46.3ab	31.0	2.48ab	2.04bc	38.0d	63.0bc	174.7abc	122.4c
Sfem-11	125.3	138.3abc	9.4abc	6.8b	41.0ab	33.0	2.19abc	2.24abc	48.3abc	69.8a	215.8abc	126.9c
Sfem-12	112.7	144.7a	9.0bc	7.4ab	33.0bc	40.0	1.85bc	2.87ab	52.2a	67.1ab	200.8abc	214.3ab
Sofu	126.3	144.7a	9.5abc	7.1ab	41.0ab	34.4	2.11abc	2.45abc	52.2a	66.7ab	171.4abc	138.9bc
Mean	119.2	138.1	9.2	7.0	39.7	35.6	2.15	2.47	47.6	65.5	175.5	173.6
C.V.(%)	7.5	5.2	5.9	6.0	14.6	15.8	15.7	14.3	5.5	3.4	14.7	16.7

*,** indicates significance at 0.05 and 0.01 respectively. Different letters in the same column indicate significant difference

Spike length: Mean spike lengths in the M_4 were different ($p<0.05$ and $p<0.01$) among lines of cv. Gediz-75 (Table 1). Spike lengths of the mutant lines were higher than that of the mother cultivar except for the Gdem-1 line, but only the Gdem-4 and 7 had significant differences. Longer spikes of the mutant lines could be due to the selection performed in the M_3 for longer spike length. On the contrary, mean values of the mutant lines were close to the values of the mother cultivars in the M_5 generation and differences were not significant. However, the presence of mutant lines with longer spikes in the M_4 and M_5 generations indicates that selection for spike length could be effective. Similarly, Minocha et al.[12] obtained important genetic advances for spike length in the M_5 generation. Gdem-4, 12 and 14 lines with longer spike had lower yields in the M_4 generation whereas Gdem-7 exhibited yield stability in both generations. Borojevic[11] determined that some mutant lines with long spikes had weaker agronomic traits and higher sterility. In addition, mutants for spike length had no response to conditions in the M_5, but their yields enhanced. These results indicated that potential of yield didn't depend on only one character.

Differences for spike length in both generations were found significant among lines of Sofu ($p<0.01$). Mutant lines generally had lower spike lengths as compared to mother cultivar, but they were not statistically different (Table 2). However, Sfem-1 in both generations gave the highest values, but also its grain yield was high in the M_5. As a matter of fact, the positive correlation between the spike length and yield[13] promotes the selection of long spiked lines in breeding studies.

The average spike length of both cultivars in the M_5 was lower than that in M_4 (Tables 1 and 2). Decreased spike lengths could be low temperature effect during spike development.

The number of kernels per spike: Differences in the number of kernels per spike of mutant lines and Gediz-75 had no significant differences in the M_4 and M_5 generations (Table 1). There were several mutant lines with higher or lower means than that of mother cultivar in both generations, and distinctions among means were smaller in the M_5 generation when compared to the M_4 generation. The shortening of spike lengths could be resulted in the decreases in the numbers of kernel. This was influenced by selection of the normal and best spikes of the M_2 and M_3 generations as the parents for further generations. When selection ceased, the mean values declined in the M_4 and were at the mean level of the Gediz-75 in the M_5. In addition, grain yield of the mutant lines with high number of kernels per spike was lower or higher than that of mother cultivar in the M_4 generation whereas it was generally high in the M_5 generation.

Differences ($p<0.01$) among the lines of cv. Sofu for the number of kernels per spike were found in the M_4 whereas no significant differences were in the next generation (Table 2). Among mutant lines, Sfem-1 and 9 had the highest means in the both generations increasing their chances for selection in the following generations. Sfem-1, 7 and 9 lines had lower grain yield although their number of kernels per spike was higher than that of mother cultivar in the M_4 generation. However, the mutant lines with higher numbers of kernel per spike also had higher grain yields than that of Sofu in the M_5 generation. In addition, single spike yields of the mutant lines with high number of kernels per spike were high. Some other researchers also reported the positive correlation between the number of kernels per spike and single spike yield[14].

The number of kernels per spike in the M_5 generation was found lower than that in the M_4 (Tables 1 and 2). Growing conditions such as temperature and precipitation also influenced the numbers of kernel formed per spike.

Single spike yield: Single spike yields of the mutant lines of cv. Gediz-75 were between 1.59 and 3.14 g in the M_4 while it changed from 1.69 to 2.64 g in the M_5 and differences among the mutant lines were not significant (Table 1). Single spike yields of the mutant lines were generally determined to be lower than that of the mother cultivar, therefore selection based on this trait would not be useful in cv. Gediz-75. In addition, there was no relationship between single spike yield and grain yield of mutant lines. Single spike yield in the M_4 was found 2.51 g whereas it was decreased to 2.25 g in the M_5 (Table 1). Not enough accumulation of dry matter after anthesis in lines with low numbers of kernel decreased the single spike yield.

Mutant lines of cv. Sofu for single spike yield had significant differences in the both generations ($p<0.01$ for the M_4, $p<0.05$ for the M_5). These data indicated that differences for spike development and grain set between mutant lines and mother cultivar (Table 2). Marked reductions in single spike yield of Sfem-3 and 7 were observed in the M_4 and M_5. However, Sfem-4 and 6 lines had not only high single spike yields but also high grain yield in both generations. In addition, Sfem-1 with an increased yield performance showed a substantial improvement for single spike yield. Because, single spike yield that is one of main yield components may be genetically manipulated to permit maximum yield stability under adverse conditions. Single spike yield in the M_5 increased although the number of kernels per spike was decreased (Table 2). This could be depended on the high increases in the 1000-kernel weights of lines. Because, single spike yield was affected by numbers of kernel per spike along with 1000-kernel weight[13].

1000-kernel weight: Significant differences ($p<0.01$) among the lines of cv. Gediz-75 for 1000-kernel weight were observed in both generations. The means of the mutant lines in the M_4 were generally lower although they didn't differ from that of mother cultivar (Table 1). Gdem-1 had not only the highest 1000 kernel weight but also the highest grain yield. In the M_5, 1000-kernel weights of Gdem-3, 4, 5 were significantly reduced as compared to Gediz-75. However, Gdem-9 in both generations had higher 1000-kernel weight and grain yield. Mutant lines generally exhibited grain yields higher than that of Gediz-75 although their 1000-kernel weight values were low. Yıldırım[15] concluded that as 1000-kernel weight increased, grain yield decreased in wheat mutants, so it would be feasible to decrease 1000-kernel weight in acceptable limits by selection.

The mutant lines in the M_4 generation had lower means than that of *Sofu* and means of Sfem-1, 7 and 10 were decreased significantly (Table 2). Sfem-3 had high 1000-kernel weight and produced the highest yield, it is important for improving yielding ability. Six mutant lines in the M_5 generation had higher means, but they were not statistically different from Sofu. Some mutants with high or low values showed high grain yields. This indicates that in determining the grain yield in this generation, 1000-kernel weight values could not be an important criteria. Crowley *et al.*[16] also reported that yields of mutants with low or high 1000-kernel weight similar to mother cultivar. There was generally a positive relation between 1000-kernel weight and grain yield, but 1000-kernel weight would not affect grain yield in one direction.

More kernels per spike of lines in the first year of trial caused the shriveling in the kernels. In addition, since the water requirements of plant cannot be obtained during the grain-filling period due to low precipitation in the M_4, 1000-kernel weight was reduced.

Grain yield (g m^{-2}): Grain yields of the mutant lines of cv. Gediz-75 were determined to be 137.1-276.7 g m^{-2} and 80.9-158.8 g m^{-2} in the M_4 and M_5 generations, respectively, and differences were significant $p< 0.05$ for the M_4 and $p< 0.01$ for the M_5 (Table 1). In the M_4 generation, 11 out of 18 mutant lines had lower grain yields than that of mother cultivar. It was seen that mutation generally caused decreases in grain yield, but seven mutants in both generations had higher grain yields. Grain yields of Gdem-2 were high values in both generations. High grain yields of some mutants throughout generations indicated that the variability induced in the M_2 and M_3 was maintained. Also, large differences between generations were obtained for some lines. The average increase in yield of mutant lines with higher values in relation to control was found 11.7 % in the M_4 and this value in the M_5 enhanced to 17.3 %. Gaul *et al.*[8] also reported that in their study going on from the M_5 up to M_9 generation, it was possible to select a mutant having a yield potential % 10 higher than the mother cultivar. The average grain yield (124.3 g m^{-2}) reduced highly in the M_5 (Table 1). In the second year of trial, low fertile tiller of lines (not given) negatively affected the grain yield although increases in 1000-kernel weight were observed.

Grain yields of the mutant lines of cv. Sofu were 116.0-261.9 g m^{-2} in the M_4 and 122.4 –256.3 g m^{-2} in the M_5 generation (Table 2). Differences were significant $p<0.01$ for the M_4 and $p<0.05$ for the M_5. There were more mutant lines with higher yields than that of mother cultivar in the M_5 generation when compared with the M_4. Sfem-2, 3, 4, 6, 12 in both generations had higher yields than that of Sofu, but the increases were not significant except for Sfem-2. Besides, Sfem-2 had greater yield stability than those of other lines in the subsequent generations. The average increase in yield of mutant lines increased from 15.8 % in the M_4 to 23.7 % in the M_5. Selection of high yielding mutant lines could be performed in the M_5 and these lines as a breeding material transferred in the yield experiments. Thus, number of mutant lines can be decreased considerably by early selections in the M_4 and M_5. There were also increases in spike length, the numbers of kernel per spike, single spike yield, 1000-kernel weight of the mutant lines with higher yields than that of mother cultivar. This result could be an indication of successful selections for these traits as well as yield. On the other hand, Knott[5] reported that 54 wheat mutant lines selected in the M_4 and M_5 generations had some usable agronomic characteristics such as earliness and shortness, but they didn't have a considerable advantage over their parents. In spite of high annual precipitation, low temperatures during early vegetative stage resulted in decreasing in performances of lines in the M_5 (Table 2). So, grain yield (173.6 g m^{-2}) decreased slightly based on fertile tiller although the increases in single spike yield and 1000-kernel weight was obtained.

There were several mutant lines with higher or lower means than those of mother cultivars. Responses of the mutants depended on the environmental conditions. It is possible to select higher yielding mutant lines with also some other important agronomic traits. Mutant lines with desirable characters varied with cultivars. Selection of high yielding mutant lines could be performed in the M_5 and these lines as a breeding material transferred in the yield experiments. Thus, number of mutant lines can be decreased considerably by early selections in the M_4 and M_5. Gdem-1, 2, 7 lines of cv. Gediz-75 and Sfem-1, 2, 3 lines of cv. Sofu showed a better agronomic performance than the others. In addition, some mutant lines with short plant height and long spikes can be also valuable breeding sources.

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