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Investigation of Mutants Induced in Durum Wheat (*Triticum durum* Desf.) for Yield and Some Agronomic and Quality Traits

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Abstract: The aim of the study was to select mutant lines having a better agronomic potential than the mother variety Sofu of durum wheat (*Triticum durum* Desf.) in the M_6 and M_7 generations. The seeds were either irradiated with γ rays at Cobalt 60 (^{60}Co) or treated with Ethyl-Methane-Sulfonate (EMS). Selection of mutants was carried out in the segregating (M_2, M_3) generations. Mutants were first tested for yield and other agronomic characteristics in the M_4 and M_5 generations. Twelve selected mutants and the mother variety Sofu were examined in the M_6 and M_7 generations for yield and quality characteristics. The experiments were organized in a Randomized Complete Block Design with 3 replications. Results revealed that any of these mutants could be used directly as new varieties. However, Sfga-7 showed yield stability across different environments, but the increases were not significant compared with Sofu. Sfga-5 had percentages of yellowberry kernels close to those of Sofu in both generations. This line with its high quality is a promising parent candidate for quality breeding. Therefore, more information on the new years and locations would greatly facilitate the evaluation of these lines. In addition, the utilization of the reduced plant height of Sfga-8 by crossing to the Sofu or other varieties could give rise to new lines whose agronomic features could be superior to those of both parents.

Key words: Durum wheat, mutant, grain yield, yellowberry kernel, lodging

INTRODUCTION

Durum wheat (*Triticum durum* Desf.) is a crop adapted to the semi-arid region of Turkey. Generally, durum wheat production is restricted to marginal lands, leaving the best lands for the high yielding bread wheat varieties. In the recent years, Turkey has become an importer of durum wheat. To meet the increasing demand for durum wheat, Turkey has to expand the area under cultivation, develop more productive varieties or improve the agronomic techniques.

The increased economic importance of durum wheat stimulated efforts towards the genetic improvement of this crop using methods such as hybridization and mutagenesis. The breeders were led to improve high yielding varieties that could compete with the bread wheat varieties in yielding ability. For proper expression of genetic yield potential, any new durum wheat must also have the proper combination of disease resistance, plant height, straw strength and the maturity. Mutation breeding was developed to obtain diverse and valuable materials. If the desired genetic variability or a specific character is not available in a crop, then mutation breeding is a logical step[1]. The main goals of mutation breeding in durum wheat have been: reducing plant height, modifying tillering habit, maintaining or improving grain size and quality. Mutant lines having yield stability and high values of both yield and quality characters could be used for durum wheat improvement[2]. Recently, 28 durum wheat varieties worldwide have been released by using mutagens[3]. The mutants induced in durum wheat have potential not only for direct release but also hybridization program. The hybridization works between mutants resulted finally in the obtention of new varieties[4,5]. The improvement of new varieties have had a great impact on durum wheat production and have competed with bread wheat varieties[6].

Genetic variability produced in the M_2 and M_3 generation after mutagen applications allows the selection of mutant types with desirable changes. The performance of uniform $M_{4\text{-}5}$ line may be evaluated in replicated tests for the character under selection of important agronomic characters. The best mutants have been tested for release as varieties or for use as parent form generation M_6 to M_9. The ail of the study was to select mutant lines having a better agronomic potential than the mother variety Sofu in the M_6 and M_7 generations.

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MATERIALS AND METHODS

This research was conducted in the 2000-2001 and 2001-2002 growing seasons at the Kazova Plain in Tokat, Turkey. The experimental soils were slightly alkaline (pH = 7.2-7.9), medium in calcium carbonate content (8.8-10.9%), poor in organic matter (1.48-1.81%) content and in P content (41.2-34.4 kg ha^{-1} P_2O_5) and high in K content (796.0-376.0 kg ha^{-1} K_2O). Long term average precipitation for this region was 387.2 per year. The amount of precipitation in the first year growing period was much lower (225.5 mm) than that in the second year (399.0 mm).

As plant materials, mutants derived from the Sofu variety of durum wheat (*Triticum durum* Desf.) were used. Sofu is an alternative type, tall, weak straw with low yield potential and susceptible to lodging and was adapted to the Tokat region.

Dry seeds, equilibrated at 11% water content, were irradiated at the Nuclear Research and Training Center, Ankara, Turkey, with 50 and 100 Gy (Gy = Gray; 1 Gray = 10 krad) gamma rays at a Cobalt 60 (^{60}Co) source as a physical mutagen[7]. Seeds without presoaking were also treated with 0.1, 0.2, 0.3 and 0.4% doses of Ethyl-Methane-Sulfonate (EMS) at 24°C for 8 h and were washed for 6 h after treatment[8].

M_1 plants grown after mutagenic treatments were propagated based on the spike progeny method. The M_2 seeds obtained from each spike were sown to rows. The M_1 and M_2 generations were grown in Tokat-Kazova in 1996 and 1997. Selection of mutants was carried out in the M_2 and M_3 generations. M_2 plants showing a difference from the control and plants with desired phenotypes were harvested individually. Then M_3 progeny from selected M_2 plants according to the pedigree selection procedure were grown[9]. The mutants were identified by visual screening for short straw and earliness and were confirmed by measuring single spike yield and single plant grain yield in the M_2 and M_3 generations[10]. Population sizes of M_1 to M_3 are given in Table 1.

The mutants with good yielding properties compared with the mother variety were transferred to the M_4 generation. Twenty-one lines were examined along with Sofu. Description of the mutants and evaluation of their practical values were first tested for other important agronomic characteristics in the M_4 and M_5 generations[11]. The M_4 and M_5 generation tests were performed in the 1998-1999 and 1999-2000 growing seasons under Kazova Plain ecological conditions in Tokat. Selected mutant lines were evaluated for heading period, plant height, spike length, the number of kernels per spike, single spike yield, 1000 kernel weight and grain yield traits by comparison with Sofu. Twelve desirable mutant lines from the M_5 generation were examined for release as varieties in the M_6 and M_7 trials. Seven of these (Sfem-1, Sfem-2, Sfem-3, Sfem-5, Sfem-7, Sfem-8 and Sfem-12) originated from the population treated with EMS and the remaining mutant lines (Sfga-3, Sfga-5, Sfga-7, Sfga-8 and Sfga-9) were induced by gamma-irradiation. In addition, Sofu was used as the mother variety.

Table 1: Population sizes in the M_1, M_2 and M_3 generations

Doses	M_1 spikes (No.)	M_2 plants (No.)	Sampling M_2 plants (No.)	Growing lines in M_3 (No.)
Control (%)	47	1268	100	20
EMS 0.1	110	2974	100	25
EMS 0.2	110	3006	100	25
EMS 0.3	110	2981	100	25
EMS 0.4	100	2678	100	25
Control (Gy)	16	456	50	10
Gama 50	115	3166	100	25
Gama 100	13	354	50	20

The experiments were organized in a Randomized Complete Block Design with 3 replications. Each plot consisted of four 3.0 m long rows. Seeds were sown 20 cm apart in rows with a density of 400 plants m^{-2}.

Sowing was performed by hand on November 7, 2000, in the first year of the trial and on November 2, 2001, in the second year. The total quantity of P fertilizer (60 kg P_2O_5 ha^{-1}) was applied during sowing together with half of the N (totally 120 kg N ha^{-1}). The rest of the N was applied before the joint growth stage. After removing a 0.5 m area from the beginning of each row, a 1.6 m^2 of plot was harvested. The observations and measurements were obtained from 10 spikes. Harvesting was performed by hand on July 8, 2001, in the first year of the trial and on July 12, 2002, in the second year.

Heading period was determined as day between the emergence of plants date and the heading date of 75% of the plants in the plot. The degree of lodging was measured according to an index scale from 0, entirely erect, to 5, completely lodged: Lodging measurements were taken at heading and at maturity[12]. Data were analyzed with ANOVA using MSTATC (Statistical Software Package). The comparison of the lines means was performed using the Duncan's test.

RESULTS AND DISCUSSION

Agronomic characteristics: Among the mutants, Sfga-8 had the longest heading period in both generations (Table 2). Similarly, in some mutant lines, heading dates were mostly delayed[2]. Other mutants for earliness had the same values as Sofu. However, some lines exhibited heading period not significantly lower than that of Sofu. In general, breeders have tended to select plants with short life cycles that could reach maturity before severe water deficits occurred[13]. However, frequency of early heading mutants appears to be lower than that of mutants with a late heading

Table 2: Heading period, number of spikes per square meter, plant height and lodging index values of mutant lines and Sofu in the M_6 and M_7 generations

Mutants and Sofu	Heading period (day)		Number of spikes (m^{-2})		Plant height (cm)		Lodging index†	
	M_6	M_7	M_6	M_7	M_6	M_7	M_6	M_7
Sfem-1	185.0 b	201.7 cd	191.7 bc	351.7	116.4 abc	146.9 a	0.0	5.0 a
Sfem-2	185.0 b	201.3 d	201.7 bc	376.7	124.4 a	150.8 a	0.0	5.0 a
Sfem-3	185.7 b	203.0 ab	235.0 bc	401.7	116.8 abc	145.9 a	0.0	5.0 a
Sfem-5	186.0 ab	202.7 abc	188.3 bc	373.3	120.1 ab	152.3 a	0.0	5.0 a
Sfem-7	185.3 b	201.7 cd	143.3 c	350.0	110.7 bc	152.0 a	0.0	5.0 a
Sfem-8	185.7 b	202.0 bcd	210.0 bc	355.0	108.8 c	150.8 a	0.0	5.0 a
Sfem-12	185.3 b	202.3 a-d	188.3 bc	353.3	123.1 a	153.2 a	0.0	5.0 a
Sfga-3	184.7 b	202.3 a-d	166.7 bc	338.3	113.6 abc	151.0 a	0.0	5.0 a
Sfga-5	185.3 b	202.7 abc	220.0 bc	353.3	122.7 a	152.7 a	0.0	5.0 a
Sfga-7	184.7 b	202.0 bcd	206.7 bc	330.0	116.9 abc	147.8 a	0.0	5.0 a
Sfga-8	187.0 a	203.3 a	370.0 a	500.0	76.2 d	127.5 b	0.0	2.3 b
Sfga-9	184.7 b	202.0 bcd	248.3 b	416.7	115.7 abc	148.5 a	0.0	5.0 a
Sofu	185.3 b	202.3 a-d	200.0 bc	413.3	123.1 a	150.3 a	0.0	4.7 a
Mean	185.4	202.3	213.1	377.9	114.5	148.4		4.8
Blocks	**	*	**	NS	**	**		NS
Lines	**	**	**	NS	**	**		**
Error								
CV%	0.3	0.3	16.5	16.0	3.8	2.3		9.3

*,** indicate significance at 0.05 and 0.01 respectively, NS indicates not significant
Different letter(s) in the same column indicate a significant difference, (†) 0 = no lodging, 5 = maximum lodging

Table 3: Test weight, grain yield and yellowberry kernel percentage values of mutant lines and Sofu in the M_6 and M_7 generations

Mutants and Sofu	Test weight (kg)		Grain yield (kg ha^{-1})		Yellowberry kernel (%)	
	M_6	M_7	M_6	M_7	M_6	M_7
Sfem-1	78.4 abc	73.6	2198 abc	4249 abc	3.1 ef	36.0 cde
Sfem-2	79.3 ab	73.5	2566 ab	3870 bc	4.3 e-f	48.0 abc
Sfem-3	78.7 abc	71.4	2685 a	3750 bc	1.7 f	41.9 b-e
Sfem-5	77.4 cde	74.1	1904 abc	4347 ab	2.9 ef	47.3 a-d
Sfem-7	74.9 f	72.7	804 e	3737 bc	7.8 a-d	45.3 a-e
Sfem-8	77.5 cde	73.6	1551 cd	3465 bc	6.6 b-e	53.6 ab
Sfem-12	79.2 ab	69.7	2314 abc	3425 bc	3.5 ef	30.9 de
Sfga-3	77.7 bcd	68.6	1814 bc	3127 c	9.0 ab	54.3 ab
Sfga-5	78.7 abc	71.5	1975 abc	3827 bc	4.4 c-f	29.9 e
Sfga-7	79.3 ab	71.2	2226 abc	5031 a	11.4 a	60.0 a
Sfga-8	76.3 def	74.6	901 de	3655 bc	8.4 abc	39.3 b-e
Sfga-9	76.0 ef	69.4	2321 abc	3257 bc	5.4 b-f	34.1 cde
Sofu	79.8 a	74.5	1941 abc	4008 abc	4.0 def	36.3 cde
Mean	77.9	72.2	1939	3827	5.6	42.8
Blocks	NS	NS	NS	NS	NS	NS
Lines	**	NS	**	**	**	**
Error						
CV%	0.8	3.4	15.9	11.3	29.3	15.2

** indicates significance at 0.01, NS indicates not significant, Different letter(s) in the same column indicate a significant difference

period[14]. In addition, the genotype of the original variety greatly affects the occurrence of early heading mutants in wheat[15].

Only Sfga-8 had a higher number of spikes per square meter than that of Sofu in M_6 (Table 2). This mutant could be more resistant to drought conditions in the first year. Siddiqui *et al.*[16] also explained that Mutant-154 exhibited drought tolerance and produced the highest yields. However, although Sfga-8 in both generations had the highest numbers of spikes per square meter, its grain yields were low (Table 3). The reasons for the differences in the numbers of spikes per square meter in different mutants are not fully understood. They may, however, be due to differences in the number of plants per square meter, tillering capacity and tolerance of genotypes to abiotic stress conditions. Al-Ubaidi *et al.*[17] also found that significant differences among mutants for number of spikes per square meter and grain yield. The mutant lines with a better tillering capacity could be more resistant to the drought conditions and have a more efficient water use capacity. Therefore, yield reduction under adverse conditions may be minimized by selecting these lines[6,16].

Sfga-8 significantly had a shorter height in both generations (Table 2) and more lodging resistant than those of both other mutants and Sofu in M_7 (Table 2). Al-Ubaidi *et al.*[17] reported that SI x IX-22 line with the highest plant height reduction had the highest lodging resistance. The other researchers also selected short straw mutants[6,18]. All mutants and Sofu in the M_6 generation did not lodge, thereby could not make comparison among lines for lodging index (Table 2). Most of the short culm mutants show detrimental changes in other agronomical relevant characteristics. Sfga-8 also showed slightly lateness in both generations and reduction in the yield compared to Sofu. Similarly, reduced plant heights associated with late maturity in some wheat mutants has been determined by Filev [19]. However, Amri *et al.*[20] reported that the possibility of developing mutants from landraces that combine good grain quality and good agronomic traits such as earliness and short stature.

Six mutants in the M_6 generation exhibited a test weight significantly lower than that of Sofu (Table 3). The other mutants had the similar values to Sofu. The reductions in accumulation of dry matter could be due to drought and high temperature during vegetation period. In M_7, test weights under more favorable conditions decreased with kernel deformation, especially shriveling together with increases in the number of kernels per spike. The reason for shriveling could be lodging in lines. Environment plays roles in major kernel characteristics like test weight, 1000-kernel weight.

Grain yield: Seven mutants had grain yields higher than that of Sofu, but the differences were not statistically significant in M_6 (Table 3). Sfem-3 gave the highest grain yield due to high number of kernels per spike. In addition, Sfem-7 and Sfga-8 had a marked reduction. These mutants could have been negatively affected by adverse conditions. In the M_7 generation, mutants exhibited similar grain yields to Sofu. Three of twelve tested mutants outyielded the Sofu, but not statistically significant. Decreases in yield potential of mutants may be accompanied by lodging (Table 2). Lodging resistance clearly was crucial for wheat varieties under more favorable conditions, because lodging limited grain yield. The average grain yield (1939 kg ha^{-1}) in M_6 was lower than that in M_7 (3827 kg ha^{-1}). Responses of the mutants depended on the environmental conditions, which varied during the generations. The assessment of the changes in yield components of mutants that outyielded their Sofu was difficult due to genotype and environment interactions[6]. In the first year of the trial, the low number of spikes per square meter negatively affected the grain yield. The increase in grain yield in the M_7 generation depended on the number of spikes per square meter.

Yellowberry kernel percentage: Yellowberry kernel percentages of Sfga-3 and Sfga-7 in both generations were significantly higher than those of Sofu whereas some mutants had lower percentages of yellowberry kernels, but decreases were not statistically important (Table 3). The genotypes with the lower percentages of yellowberry kernel result in increasing quality. Because, the cultivars with low percentages of yellowberry kernels, when milled, produced higher semolina[21]. Sfga-5 had percentages of yellowberry kernels similar to those of Sofu in M_7 (Table 3). This line with its high quality seems an ideal type for selection. Heavy annual precipitation in M_7 resulted in a higher accumulation of dry matter. Therefore, the percentages of yellowberry kernels (42.8%) increased. Ryan *et al.*[21] determined that the responses for quality characters of genotypes clearly varied with growing conditions.

Promising mutants: Based on the results of this study, Sfga-7, Sfga-5 and Sfga-8 lines had better agronomic features than did others. Sfga-7 showed yield stability across different environments, but the increases were not significant compared with Sofu. In addition, this line had not a good grain quality due to higher percentages of yellowberry kernels. Therefore, it was possible to produce high yields, but not suitable for high semolina flour yield. Sfga-5 had percentages of yellowberry kernels close to those of Sofu in both generations. This line with its high quality is a promising parent candidate for quality breeding. Sfga-8 with short straw had a higher lodging resistance. However, it had a slightly long heading period and not resistant to drought conditions.

Results revealed that any of these mutants could be used directly as new varieties. However, Sfga-7 showed yield stability across different environments, but the increases were not significant compared with Sofu. Sfga-5 had percentages of yellowberry kernels close to those of Sofu in both generations. This line with its high quality is a promising parent candidate for quality breeding. Therefore, more information on the new years and locations would greatly facilitate the evaluation of these lines. The utilization of the reduced plant height of Sfga-8 by crossing to the mother variety Sofu or other varieties could give rise to new lines whose agronomic features could be superior to those of both parents.

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