

Improvement of Grain Yield and Yield Associated Traits in Bread Wheat (*Triticum aestivum L.*) Genotypes Through Mutation Breeding Using Gamma Irradiation

Ekmeklik Buğday (*Triticum aestivum L.*) Genotiplerinde Tane Verimi ve Verimle İlişkili Özelliklerin Gamma Işını Kullanılarak Mutasyon İslahı ile Geliştirilmesi

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Abstract


The present research was conducted to evaluate the M1, M2, M3 and M4 bread wheat (*Triticum aestivum L.*) mutant populations for yield and yield related traits during 2010-11, 2011-12, 2012-13 and 2013-14 at Tekirdağ ecological conditions. Three wheat genotypes were treated with different levels of gamma rays (100 Gy, 200 Gy, 300 Gy, 400 Gy, 500 Gy and Control). The mutated plants were evaluated along with parental lines (control) for grain yield (GY) and its contributing traits such as plant height (PH), spike length (SL), the number of spikelets per spike (NSPS), the number of grains per spike (NGPS), grain weight per spike (GWPS), harvest index (HI) and thousand grain weight (TGW) under field conditions. The results obtained from the present study showed that the genotypes significantly and variably differed in their response for various traits at different gamma rays doses. The traits such as PH, TGW and grain yield (GY) showed generally reduction with higher gamma irradiation doses as compared to low doses, while mutagenic treatments shifted the mean values mostly towards the negative direction in the other yield components. But, the negative or positive shifts were not unidirectional or equally effective for all the traits. These findings suggested that the variability could be induced through the use of gamma irradiations in bread wheat. Some of the traits showed improvement due to the induced mutations could be used in future wheat breeding programs. The differences in mean values and the nature of variability observed in M2 indicated a possible preference of selection in M3 generation.


Keywords: Bread wheat (*Triticum aestivum L.*), mutation, population, grain yield


Öz


Bu araştırma, M1, M2, M3 ve M4 ekmeklik buğday mutant populasyonlarını verim ve verime etkili özellikler bakımından değerlendirmek için 2010-11, 2011-12, 2012-13 ve 2013-14 yıllarında Tekirdağ ekolojik koşullarında yürütülmüştür. Üç buğday genotipine farklı dozlarda gamma ışını (Kontrol, 100 Gy, 200 Gy, 300 Gy, 400 Gy ve 500 Gy) uygulanmıştır. Mutant bitkiler anaçları (kontrol) ile birlikte tane verimi (TV) ve bitki boyu (BB), başak uzunluğu (BAU), başakta başakçık sayısı (BABS), başakta tane sayısı (BATS), başakta tane ağırlığı (BATA), hasat indeksi (HI) ve bin tane ağırlığı (BTA) gibi verime etkili özellikler bakımından tarla koşullarında değerlendirilmiştir. Çalışmadan elde edilen sonuçlar, genotiplerin çeşitli özellikler için farklı gamma ışını dozlarına yanıtlarının önemli ve değişken bir şekilde farklı olduğunu göstermiştir. Bitki boyu, bin tane ağırlığı ve tane verimi gibi özellikler düşük dozlarla karşılaştırıldığında yüksek gamma ışını dozlarında genellikle azalma gösterirken, mutagen uygulamaları diğer verim unsurlarında ortalama değerleri çoğunlukla negatif yöne doğru kaydırmıştır. Ancak, negatif ya da pozitif yöndeki kaymalar tüm özellikler için tek yönde ya da eşit derecede etkili olmamıştır. Bu bulgular, buğdayda gamma ışınları kullanılarak varyabilenin oluşturulabileceğini göstermiştir. Oluşturulan mutasyonlara bağlı olarak gelişme gösteren bazı özellikler gelecekte buğday ıslahı çalışmalarında kullanılabilir. M2'de gözlenen varyabilite ve ortalama değerlerdeki farklar M3 generasyonunda seleksiyonun mümkün olabileceğini göstermiştir.


Anahtar Kelimeler: Ekmeklik buğday (*Triticum aestivum L.*), mutasyon, populasyon, tane verimi


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Due to the increasing of global population together with a growing demand for meat and dairy products, a substantial increase of grain production in the next decades is critical. This is particularly challenging as the basic manageable resources for crop growth and yield (water, nutrients) will not increase (Connor and Minguez, 2012) and the land available for crop production is likely to decline (Albajes et al., 2013). Among the major crops, wheat is one of the most critical for warranting human nourishment: it is the most widely crop grown globally and is the primary source of protein for the world population, representing c. 20% of the daily intake for developing countries (Braun et al., 2010). In order to maintain balance between demands and supply alternative ways and means to further raise wheat yield must be found (Chand, 2009). The grain yield, a complex polygenic trait is highly affected by environmental stresses (Sial et al., 2010), itself is determined by yield component traits, which besides the number of spikes per unit area are characteristics of the spikes and kernels. Previous studies suggest that the number of grains is much more plastic than the seed morphology, and yield in the wheat therefore appears to be more related to grain number than to grain weight (Fischer, 2011). Consequently, wheat yield improvements appear to have been realized mainly through an increase in the grain number rather than through the size of grains (Calderini et al., 1995). A promising approach to continue improving yield levels in the wheat is therefore the targeted exploitation of genetic variation for yield component traits such as the PH, SL, NSPS, NGPS, GWPS, TGW and HI.

Mutagenesis and hybridization are generally the most commonly used breeding methods to develop new superior varieties. Mutation breeding has some advantages compared to cross breeding. When comparing mutation and hybridization; the occurrence of even a few desirable mutation in high yielding varieties has the great advantage of becoming homozygous and expressing its superiority within a couple of generations after induction in M_2 or M_3 as compared to F_6 or F_7 generations in case of hybridization (Chakraborty and Paul, 2013). Mutation breeding has become an appropriate option to improve plant traits when conventional breeding does not work, or the desired traits were recessive, or improving another character in an established plant variety, or improving one or two main character(s) (Ahloowalia and Maluszynski, 2001; van Harten, 1998). In addition, mutagenesis is able to isolate mutant with multiple traits, as compared to transgenes where only line can be introduced, it's the major advantage of induce mutations (Louali et al., 2015). Mutation breeding can be applied to improve a specific character without changing other characters and it is possible to improve a single line without causing an important disturbance in the genome. Furthermore, it may create a new character that was not belong to parental plants. The mutants developed in the wheat have a great potential for direct release and for inclusion in hybridization breeding programs (Sakin et al., 2005). The released mutant cultivars in different crops had great economic impact on agriculture and food productions and added billion of dollars in the economy of many countries (Jain, 2006). More than 3000 varieties of different crops have been officially released by mutation breeding technique. Mutation induction with radiation has been the most frequently used method to develop direct mutant varieties, accounting for about 90% of obtained varieties (64% with gamma-rays, 22% with X-rays) (Ahloowalia et al., 2004). Gamma ray mutagen was effective in broadening genetic variability and increasing means of the wheat cultivars for the GY and its components, helping plant breeders to practice an efficient selection in the M_2 and next mutated generations (Khanna et al., 1986; Al-Naggar et al., 2007). Mutant populations have now been created for many cereal crops, including rice (Suzuki et al., 2008), durum wheat (Başer et al. 1997; Sakin and Yildirim, 2004) and the bread wheat (Slade et al., 2005). The present work envisages providing information on the effects of gamma rays with regard to the PH, SL, NSPS, NGPS, GWPS, TGW, HI and GY of M_1 , M_2 , M_3 and M_4 populations in the bread wheat genotypes.

Materials and Methods

Plant material

Three bread wheat (*Triticum aestivum* L.) genotypes, Bezostaja 1 (tall, mid-early, awnless, superior in flour quality for bread making, but inferior in lodging resistance and yield capacity), Kate A-I (tall, mid-early, awnless and inferior in flour quality for bread making, lodging and disease resistance and superior in yield capacity) and IBWSN4 (tall, early, awned and inferior in flour quality for bread making, disease resistance and superior in lodging and yield capacity), were used as the experimental material.

Gamma irradiation

The moisture contents of seeds of wheat genotypes (*Triticum aestivum* L.) used in the study were 11.4% for Bezostaja 1, 11.7% for Kate A-I and 12.0% for IBWSN4. The grains for each genotype were divided into six groups (A, B, C, D, E and F), each of which contained 2000 grains. Group A was kept un-irradiated (Control), while the other groups were irradiated with various levels of gamma ray (100, 200, 300, 400 and 500 Gy). Gamma treatment was obtained from $^{60}\text{Cobalt}$, Ob-Servo Sanguis Co-60 Research Irradiator with isotope model, while the dose

rate was 2.190 kGy h⁻¹ in before the 2009-2010 growing season sowing at the Turkish Atomic Energy Authority, Sarayköy Nuclear Research and Training Center, Ankara, Turkey. The unit for the absorbed dose of radiation energy is the gray (Gy), which is equivalent to 1 J Kg⁻¹ and 100 rads. Right after irradiation, the experiment was set up using a total of 15 M₀ combination seeds together with the un-irradiated (Control) in the experimental field of the Field Crops Department of the Faculty of Agriculture of Tekirdağ Namık Kemal University during the growing season of 2009-2010. The experiment was carried out in a randomized complete block design (RCBD) with 3 replicates. Plots were sown on Nov.15, 2010 by hand at the rate of 350 seeds per m² and were 2 m in length x 1.0 m wide, with 6 rows 0.2 m apart. 20.20.0 composed fertilizer was used which include 50 kg ha⁻¹ pure nitrogen (N) and 50 kg ha⁻¹ pure phosphor (P₂O₅) was with the sowing. In addition to this, 60 kg ha⁻¹ pure N as urea fertilizer (46% N) at the tillering stage and 50 kg ha⁻¹ pure N as ammonium nitrate fertilizer (33% N) at the stem elongation stage were also given. The plots were kept free of weeds by hand hoeing when necessary. The remaining seeds were sown in the greenhouse in order to guarantee the work. The seeds obtained from the harvested plants in M₁ generation were sown in 2011-12 (M₂), 2012-13 (M₃) and 2013-14 (M₄) growing seasons as 20 cm row distance in 5 meters of 6-row parcels with 4 replicates and as 400 seeds in each row.

Data Collection

To study the effect of gamma irradiation doses on yield and yield related characters such as the PH-cm, SL-cm, NSPS-no, NGPS-no, GWPS-g, HI-%, TGW-g and GY-kg da⁻¹ were investigated in the M₁, M₂, M₃ and M₄ generations of the studied genotypes.

Statistical analyses

The data thus collected on yield and some yield components was subjected to analysis of statistical manipulation as outlined by Steel and Torrie (1980). The statistical analysis concerned mainly as a comparison between data of the control and that of the corresponding population using two groups t-test (means) and one tail F-ratio (variances).

Results and Discussion

Analysis of variance for the experiment with six treatments (gamma rays) and three genotypes for eight traits viz., PH, SL, NSPS, NGPS, GWPS, HI, TGW and GY were carried out in the M₁, M₂, M₃ and M₄ generations for testing the significance of variance among the treatments for each trait through ‘F’ test (Table 1).

The ‘F’ test indicated that variances due to genotypes were highly significant for all the characters which provided the evidence for the significant genetic variability for heading among the varieties.

The analysis of variance results for the treatments (which means the gamma radiation doses), indicated that the traits out of HI in the M₂, PH, GWPS and HI in the M₃ and NGPS in the M₄ under study were highly significant at (p<0.01) probability level. Whereas, significant for the NSPS and TGW in the M₁, for the PH and TGW in the M₂, for the TGW in the M₄, at (p<0.05) probability level.

Table 1. Significances of variance components for 8 traits in the bread wheat mutated populations of M₁, M₂, M₃ and M₄

Traits	Replication d.f.= 2				Treatments d.f.= 5				Genotype d.f.= 2				Treatment x genotype d.f.= 10			
	M ₁	M ₂	M ₃	M ₄	M ₁	M ₂	M ₃	M ₄	M ₁	M ₂	M ₃	M ₄	M ₁	M ₂	M ₃	M ₄
PH (cm)	ns	*	ns	**	**	*	ns	**	**	**	**	**	**	ns	ns	**
SL(cm)	ns	ns	ns	*	**	**	**	**	**	*	**	*	**	**	**	ns
NSPS (no)	ns	ns	ns	**	*	**	**	ns	**	**	**	**	*	*	**	**
NGPS (no)	ns	ns	ns	ns	**	**	**	**	**	**	**	**	*	**	**	**
GWPS (g)	ns	ns	ns	ns	**	**	ns	**	*	**	**	**	**	ns	**	**
HI (%)	ns	ns	ns	ns	**	ns	ns	**	**	**	**	**	**	*	**	**
TGW (g)	ns	*	ns	ns	*	*	**	*	**	**	**	**	**	**	*	**
GY (kg da ⁻¹)	ns	ns	ns	ns	**	**	**	**	**	**	**	**	ns	**	ns	*

d.f.: degree of freedom, ns: non-significant, *: significance at 5% level, **: significance at 1% level.

Mean values at 100, 200, 300, 400 and 500 Gy of gamma rays and its controls in tested three genotypes for the investigated characters during the M₁, M₂, M₃ and M₄ generations are presented in Tables 2-4. However, the response was non-conventional; following results explore the findings of present investigation.

The PH is widely used as an index in determining the biological effects of various physical mutagens. In the present investigation, it was observed that all the gamma rays treatments were non-equally effective in shifting the mean values significantly towards reduced height.

Among genotypes, Bezostajal genotype was the least affected by gamma irradiation, while IBWSN4 showed high response to gamma irradiations. However, the maximum reduction of the PH was happened in the M₁ generation of all the varieties for gamma rays 500 Gy (Tables 2-4). The grains irradiated with low dose (100 Gy) of gamma radiation surpassed the other four-irradiation doses and the control in the PH, while, high gamma irradiation doses caused high reduction in the PH for 4 mutated generations of the three genotypes.

Table 2. Mean performance and significances of the M₁, M₂, M₃ and M₄ generations of Bezostaja 1

Generation	Gamma doses (Gy)	PH (cm)	SL (cm)	NSPS (no)	NGPS (no)	GWPS (g)	HI (%)	TGW (g)	GY (kgda ⁻¹)
M ₁	Control	114.6	10.2	21.3	28.5	1.103	32.68	42.5	330.0
	100	108.1**	10.4	21.1	24.1**	0.797**	31.35	38.8**	329.7
	200	115.2	10.6	21.5	33.9**	1.270**	31.04*	39.8**	318.0
	300	92.4**	10.3	20.3**	27.0*	1.153	31.97	38.7**	348.7*
	400	102.7**	10.6	19.9**	33.3**	1.303**	33.98	40.0**	264.0**
	500	99.2**	10.7	21.3	34.5**	1.330**	34.14	39.9**	264.3**
M ₂	Control	104.3	10.5	20.6	34.6	1.440	30.61	37.8	525.0
	100	107.8	10.6	20.7	40.6**	1.580*	29.62	37.6	406.3**
	200	99.9*	10.5	20.9	33.2	1.463	32.73	36.2**	472.0*
	300	102.9	10.1**	21.5**	34.4	1.200**	35.97	35.3**	453.0*
	400	99.8*	10.3**	21.4**	36.9*	1.240**	34.95	38.6	441.0**
	500	97.3**	10.6	20.8	43.3**	1.650**	33.08	38.3	403.0**
M ₃	Control	118.9	10.0	20.3	31.8	1.047	28.88	35.6	579.3
	100	119.8	10.1	20.2	32.8	1.077	31.28**	35.6	528.7*
	200	115.9*	10.2	20.6	31.4	1.100	30.73*	32.7**	569.3
	300	116.9*	11.1**	22.4**	43.7**	1.387**	31.02**	31.9**	482.0**
	400	118.1	10.9**	21.6**	40.5**	1.263**	30.89*	32.4**	534.3
	500	119.0	11.5**	21.5**	41.7**	1.400**	32.31**	31.8**	498.3**
M ₄	Control	110.7	9.2	22.7	47.9	1.697	36.15	44.6	604.7
	100	105.8	9.4	22.6	40.7**	1.887	42.33	47.0*	588.3
	200	102.0	10.3**	23.7	48.1	2.283*	43.10	48.1**	651.7*
	300	111.0	10.5**	22.9	41.8**	1.923	42.83	47.8*	587.0
	400	86.1**	10.7**	22.7	43.4**	2.103*	42.70	45.9*	625.0
	500	110.2	10.4**	22.7	43.3**	2.070	37.28	44.1	622.0

* and **statistically significant differences from control at %5 and %1 level.

The stimulatory effect of gamma irradiation at low doses was reported by several researchers such as Farag and El-Khawaga (2013) and Shubhra et al. (2013). The irradiation of seeds with high doses of gamma rays disturbs the synthesis of protein, hormone balance, leaf gas-exchange, water exchange and enzyme activity which may be the possible causes of adverse effects of gamma radiations on the PH in the present investigation.

The SL and NSPS are the most important yield components, as they determine the ultimate GY (Siddiqui et al., 1979). The highest SL in the four evaluated generations (M₁, M₂, M₃ and M₄) were 11.5 cm for IBWSN4, 11.3 cm for IBWSN4, 11.5 cm for Bezostajal and 11.1 cm for Kate A-1 were shown in genotypes derived from irradiation with 500 Gy and 400 Gy gamma ray dose. These present results also shows co-linearity with the studies of Bano et al. (2017) in which they observed significant increase of spike length in nearly all the radiation doses. The highest NSPS in the four evaluated generations (M₁, M₂, M₃ and M₄) were 21.5 for Bezostajal, 23.1 for IBWSN4, 22.7 for IBWSN4 and 23.7 for Bezostajal were shown in genotypes derived from irradiation with 200, 500, 500, 200 Gy gamma ray doses, respectively. Gamma radiation resource displayed positive effects upon these traits. The increase was however non-significant in 100 Gy and 200 Gy. Every additional after 200 Gy dose of

radiation progressively increased the NSPS and SL. In such treatments it is difficult to select desirable plants with respect to the SL and NSPS. These results are similar to those of [Mohammad et al. \(2004\)](#) and [Githinji and BIRTHIA \(2015\)](#), who also reported highly significant differences for the SL in the bread wheat.

The NGPS and GWPS are a reliable measure of yielding ability ([Borojevic and Borojevic, 1972](#)). In addition, they were the most sensitive traits to mutagenic action, and were suggested as criteria for investigating the action of gamma rays ([Rachovska and Dimova, 2000](#)).

Concerning to the NGPS, it was significantly altered mutated populations of studied genotypes from that of the controls. In comparison between the controls and irradiation treatments, NGPS was significantly increased in the four evaluated generations of IBWSN4 and Bezostaja1, while it reduced in M_1 , M_2 , M_3 and M_4 of Kate A-1. However, these shifts were not unidirectional.

Table 3. Mean performance and significances of the M_1 , M_2 , M_3 and M_4 generations of IBWSN4

Generation	Gamma doses	PH (cm)	SL (cm)	NSPS (no)	NGPS (no)	GWPS (g)	HI (%)	TGW (g)	GY (kg da ⁻¹)
M_1	Control	103.4	9.1	21.5	38.1	1.113	30.36	33.2	407.0
	100	99.5**	9.5**	20.6*	34.9*	1.020**	31.48	34.7	420.7
	200	106.6	9.8**	21.5	39.8*	1.123	32.36*	36.9**	394.3
	300	102.1	10.2**	19.9**	41.1*	1.850**	39.10**	37.8**	373.3**
	400	100.0*	10.5**	22.6*	39.7*	1.253**	40.14**	41.8**	310.0**
	500	72.0**	11.5**	20.6	33.3*	1.323*	35.72**	42.8**	227.7**
M_2	Control	87.1	9.0	19.9	48.5	1.677	36.00	33.4	594.3
	100	90.5**	9.3**	21.5**	52.5**	1.957**	38.21**	36.4*	446.7**
	200	89.4*	10.2**	21.9**	53.4**	1.940**	38.19**	36.6**	494.3**
	300	84.9	10.2**	21.9**	45.7	1.493**	36.32**	36.5*	463.0**
	400	85.7	10.3**	21.5**	47.5	1.777*	36.98**	37.4**	544.0**
	500	82.9**	11.3**	23.1**	55.7**	2.090**	36.14**	38.0**	402.7**
M_3	Control	102.8	9.1	20.6	41.9	1.237	36.06	31.4	721.0
	100	104.6**	9.5**	21.3**	43.1*	1.360**	37.60**	29.3**	685.7**
	200	103.8**	9.8**	21.8**	50.3**	1.583**	38.70**	28.6**	678.3**
	300	99.6**	10.1**	22.1**	45.6**	1.417**	38.58**	28.8**	681.3**
	400	100.1**	10.4**	22.7**	45.7**	1.193	36.84	27.3**	660.0**
	500	98.2**	11.1**	22.7**	51.1**	1.577**	35.68	28.7**	574.3**
M_4	Control	91.5	9.6	21.5	48.9	2.407	41.51	43.0	735.7
	100	100.2**	10.4*	21.2	48.9	2.250	42.00	43.8	709.3
	200	89.8**	10.4*	22.3	55.5**	2.787*	42.11	43.8	788.0*
	300	92.0	10.5**	21.9	47.4	2.250	42.34	43.5	696.3
	400	95.0**	10.8**	22.9*	47.9	2.137	42.54	43.1	734.7
	500	91.4	10.8**	23.5*	49.5	2.790*	42.45	44.0	575.0**

* and **statistically significant differences from control at 5% and 1% level.

The highest NGPS was counted in IBWSN 4 (41.1 no for M_1 at 300 Gy, 55.7 no for 500 Gy in M_2 , 51.1 no for 500 Gy in M_3 and 55.5 no for 200 Gy in M_4). These results collaborate with those of [Ahmad et al. \(2011\)](#) who found a highly significant difference ($p \leq 0.01$) in mixed genotypes showing diverse types of the wheat genotypes. This could be attributed to the different genetic makeup of the three wheat genotypes or be the rearrangement of the genes on the same or other chromosomes. In case of GWPS, in comparison between controls and irradiation treatments, grains weight per spike was significantly increased in the four evaluated generations of IBWSN4 and Bezostaja1, while it reduced in M_1 , M_2 , M_3 and M_4 of Kate A-1. However, these deviations were not systematic as that of NGPS. The highest GWPS was weighted in IBWSN 4 (1.850 g for M_1 at 500 Gy, 2.090 g for 500 Gy in M_2 , 1.583 g for 200 Gy in M_3 and 2.790 g for 500 Gy in M_4). The results also concur with those of [Sobieh and Ragab \(2000\)](#) who explained although they are not regular in the M_2 generation, there is an increase in the grain weight increases with increasing mutation doses.

Table 4. Mean performance and significances of the M₁, M₂, M₃ and M₄ generations of Kate A-1

Generation	Gamma doses	PH (cm)	SL (cm)	NSPS (no)	NGPS (no)	GWPS (g)	HI (%)	TGW (g)	GY (kg da ⁻¹)
M ₁	Control	117.8	9.4	19.3	30.7	1.043	32.47	36.1	427.3
	100	114.0*	9.9**	19.0	30.9	0.870*	24.26**	35.1*	412.3
	200	113.6 **	9.7	18.4**	37.5**	1.237**	34.02 **	35.8	382.0**
	300	103.3**	10.5**	18.1**	33.9	1.200*	34.90 **	36.1	429.3
	400	105.4**	10.5**	20.3**	35.8**	1.250**	31.91	35.0*	362.3**
	500	79.9**	9.6	18.9*	24.7**	0.987	25.32 **	33.0*	195.7**
M ₂	Control	95.9	9.9	19.3	40.2	1.467	35.84	34.5	561.3
	100	95.1	9.8	19.5	40.8	1.480	36.73	33.9	488.7**
	200	88.1**	10.1	19.7	42.6*	1.280*	36.74	33.4	507.7**
	300	89.5**	10.3**	19.5	36.4**	1.317	36.56	33.5	467.7**
	400	87.6**	10.3**	18.6*	34.3**	1.417	36.41	33.1	402.3**
	500	83.3**	10.7**	19.0	35.7**	1.370	35.53	34.4	354.7**
M ₃	Control	116.5	10.2	20.6	47.0	1.373	40.18	30.8	704.3
	100	113.4**	10.8*	20.6	45.8*	1.580**	38.78**	28.9**	660.7*
	200	118.3**	10.2	21.2	36.2**	1.163**	38.59**	29.4*	731.7
	300	112.5**	10.4	21.4*	41.4**	1.350	37.21**	30.3	645.3**
	400	112.3**	10.0	20.5	42.7**	1.483	38.65**	27.5**	623.0**
	500	109.4**	9.4*	19.8*	35.1**	1.200**	37.64**	29.1*	619.3**
M ₄	Control	106.9	9.0	20.2	40.7	1.763	42.34	44.7	689.7
	100	101.4*	9.7*	21.3	49.3**	2.430**	43.48	43.6	687.3
	200	107.3	10.6**	21.5	46.1**	2.613**	43.07	41.6*	695.0
	300	101.8*	10.5**	20.9	45.5**	2.167**	42.74	42.0*	708.0
	400	98.8**	11.1**	20.4	53.3**	2.160**	42.67	40.6**	633.0*
	500	82.5**	10.7**	18.9	34.9**	2.067**	41.66	44.8	618.3**

* and **statistically significant differences from control at %5 and %1 level.

The grain yield can be determined from the components of the biological (biomass) yield and harvest index (Passioura, 1977), and the potential yield of bread wheat has increased due to increases in the harvest index (Gustavo and Andrade, 1989; Curtis, 2002). The HI is considered to be associated with the PH, stem dry weight and straw yield. Reduction in the PH had the greatest effect on the stem dry weight and least on the GY. Reduction in the PH lowered the dry weight of the vegetative parts and thereby lowered the straw yield, which resulted in an increased the HI (Singh and Stoskopf, 1971). Recently, the values of HI have been increased to 40% and even 45%. However, the future purpose is to the increase HI to over 50%. Regarding to the HI, gamma irradiations shifted the mean values from the control towards positive or negative direction depending on genotype and dose, but these siftings were not consistent. Among the genotypes, it was found that the plant treated with gamma irradiated at 200-300 Gy gained the highest increase when compared with control in the Bezostaja 1 and Kate A-1 genotypes except M₂ and M₄ generations. In case of IBWSN4, out of M₄ generation, significant deviations from the controls were observed in the M₁, M₂ and M₃, indicating that the IBWSN4 is more sensitive to gamma irradiations than the other two bread wheat genotypes. These findings are supported by results of Mohammad and Abdollah (2011) who stated that harvest index were affected with different levels of irradiation.

In addition to being a very important yield component, the thousand grain weight is also considered as an important quality criterion and a feature used in the calculation of the amount of seed to be sown in the unit area. Different dose of gamma rays irradiation in three wheat varieties affected TGW differently in different genotype. The highest TGW in the four evaluated generations (M₁, M₂, M₃ and M₄) were 42.8 g for IBWSN4 (500 Gy), 38.6 for Bezostajal (400 Gy), 35.6 for Bezostajal (Control and 100 Gy) and 48.1 for Bezostajal (200 Gy), respectively. In general, gamma irradiations shifted the mean values from the control towards negative direction in all mutated generations of Bezosytajal and Kate A-1, while that of IBWSN4 was towards positive direction, indicating that the effect of irradiation was depressing with increase in irradiation doses, which is transmitted from generation to

generation (Ayub et al., 1989).

Radiation in general reduced the grain yield (Table 2, 3 and 4). In all the genotypes gamma rays displayed progressive decrease with the increase of radiation dosage in all the cases except 100 and 200 Gy treatment where the character showed some improvement over the control in M₁, M₂, M₃ and M₄. Yield is a dependent character, and is the result of all the biological processes going on during the growth and development of plant (Scarascia-Mugnozza, 1964). The general trend of reduced yield among the mutagenic treated material could be due to pleiotropic effects (Brock, 1965; Gaul, 1977) on other characters. However, the present results suggest that the lower doses of gamma rays in general and 100-200 Gy treatment in particular can be useful from breeding point of view for selecting higher yielding plants in early generations. Gamma-rays are effective in broadening genetic variability and increasing means of wheat cultivars for grain yield and its components, helping plant breeders to practice an efficient selection in the M₂ and next mutated generations (Sobieh, 2002; Al-Naggar et al., 2007). From practical breeding point of view increased variation assumes greater significance. Frey (1969) reported that mutagen derived variability for quantitative characters in crop plants is heritable and that the response to selection is good. The relative value of this source of variability for use in crop improvement, therefore, depends almost entirely upon the nature of phenotypic expression caused by the mutations induced at polygenic loci.

Conclusion

The shifts in the M₁, M₂, M₃ and M₄ generations were significantly important than that in the control for the PH, NGPS and GY, indicating that these are the most sensitive to gamma irradiation. In the ascending order, NSPS, SL, HI, TGW and GWPS were the least sensitive characters to the gamma irradiation. The results of the study showed that 200 and 300 Gy irradiation were the most beneficial doses for improving yield and its components.

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