jotaf Journal of Tekirdag Agricultural Faculty
Tekirdağ Ziraat Fakültesi Dergisi

Ocak/January 2019, 16(1)
**Başvuru/Received:** 19/10/18
**Kabul/Accepted:** 20/11/18
**DOI:** 10.33462/jotaf.472456

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**RESEARCH ARTICLE** **ARAŞTIRMA MAKALESİ**

# 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 Islahı 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 varyabilitenin oluşturulabileceğini göstermiştir. Oluşturulan mutasyonlara bağlı olarak gelişme gösteren bazı özellikler gelecekte buğday ıslahı çalışmalarında kullanılabilecektir. 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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**Citation:** Balkan, A., Bilgin, O., Başer, İ., Göçmen, D.B., Demirkan, A.K., Deviren, B. Improvement of grain yield and yield associated traits in bread wheat *(Triticum aestivum L.)* genotypes through mutation breeding Using gamma irradiation. *Tekirdağ Ziraat Fakültesi Dergisi,* 16(1), 103-111.

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 Mínguez, 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 $^{60}$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 $M_0$ 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 $m^2$ 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 ($P_2O_5$) 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 $M_1$ generation were sown in 2011-12 ($M_2$), 2012-13 ($M_3$) and 2013-14 ($M_4$) 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 $M_1$, $M_2$, $M_3$ and $M_4$ 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 $M_1$, $M_2$, $M_3$ and $M_4$ 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 $M_2$, PH, GWPS and HI in the $M_3$ and NGPS in the $M_4$ under study were highly significant at ($p<0.01$) probability level. Whereas, significant for the NSPS and TGW in the $M_1$, for the PH and TGW in the $M_2$, for the TGW in the $M_4$, at ($p<0.05$) probability level.

**Table 1. Significances of variance components for 8 traits in the bread wheat mutated populations of $M_1$, $M_2$, $M_3$ and $M_4$**

| 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 $M_1$, $M_2$, $M_3$ and $M_4$ 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, Bezostaja1 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 $M_1$ 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 $M_1$, $M_2$, $M_3$ and $M_4$ 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 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 ($M_1$, $M_2$, $M_3$ and $M_4$) were 11.5 cm for IBWSN4, 11.3 cm for IBWSN4, 11.5 cm for Bezostaja1 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 ($M_1$, $M_2$, $M_3$ and $M_4$) were 21.5 for Bezostaja1, 23.1 for IBWSN4, 22.7 for IBWSN4 and 23.7 for Bezostaja1 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 Birithia (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 $M_1$, $M_2$, $M_3$ and $M_4$ 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 $M_2$ and $M_4$ generations. In case of IBWSN4, out of $M_4$ generation, significant deviations from the controls were observed in the $M_1$, $M_2$ and $M_3$, 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 ($M_1$, $M_2$, $M_3$ and $M_4$) were 42.8 g for IBWSN4 (500 Gy), 38.6 for Bezostaja1 (400 Gy), 35.6 for Bezostaja1 (Control and 100 Gy) and 48.1 for Bezostaja1 (200 Gy), respectively. In general, gamma irradiations shifted the mean values from the control towards negative direction in all mutated generations of Bezosytaja1 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 $M_1$, $M_2$, $M_3$ and $M_4$. 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, l977) 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 $M_2$ 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 $M_1$, $M_2$, $M_3$ and $M_4$ 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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