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Use of Gamma Rays and Hybridization to Create New Drought Tolerant Wheat Genotypes

A. M. M. Al-Naggar[1*], Kh. F. Al-Azab[2], S. E. S. E. Sobieh[2] and M. M. M. Atta[1]

[1]Department of Agronomy, Faculty of Agriculture, Cairo University, Giza, Egypt.
[2]Plant Research Department, Nuclear Research Center, Atomic Energy Authority, Inshas, Egypt.

Authors' contributions

This work was carried out in collaboration between all authors. Author AMMAN designed the study, wrote the protocol, and wrote the first draft of the manuscript. Authors KFAA and SESES managed the experimental process and analyses of the study. Author MMMA managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

Selection from established high yielding pure line wheat cultivars would rarely isolate a new genotype. Inducing new genetic variation in bread wheat populations *via* gamma ray irradiation and hybridization procedures and isolating drought tolerant genotypes from derived heterogeneous populations were the aims of this study. The M_2 populations of seven irradiated wheat genotypes exhibited differences in the magnitude of phenotypic (PCV) and genotypic (GCV) coefficient of variation and heritability for studied traits under water stress (WS) and well watering (WW) conditions. The highest expected gain from selection (GA) for grain yield/plant (GYPP) was shown by Sids-4 irradiated (I) and Sakha-61 (I) under well watering (WW) and Aseel-5 (I) and Sids-4 (I) under WS conditions. The predicted GA from selection for GYPP in the F_2's of diallel crosses among six genotypes, reached a maximum of 71.6% under WS for F_2 of (As-5 x Sk-93). Selection for high GYPP and other desirable traits was practiced in the M_2 and F_2 populations under WW and WS. Progenies of these selections (53 M_3 and 109 F_3 families) and their seven parents were evaluated under WW and WS. Selection under WS was more efficient than that under WW for the use under WS. Twelve families (7 M_3's and 5 F_2's) significantly outyielded their parents by at least 15 % and reached 74.71% for SF9 (a family selected from F_2 of Sd-4 x Mr-5) under WS and

**Corresponding author: E-mail: ahmedmedhatalnaggar@gmail.com;*

therefore were considered as putative drought tolerant (DT). These DT genotypes were superior in one or more yield component traits as compared with their parents under drought stress.

Keywords: Mutations; transgressive segregation; Triticum aestivum; drought tolerance; selection gain.

1. INTRODUCTION

Wheat is one of the most important cereal crops of the world's population in more than 40 countries including Egypt. Across the last five years, the average annual consumption of wheat grains is about 14 million tons, while the average annual local production is about 8 million tons with an average grain yield of 18.0 ardab/feddan (6.43 t/ha) [1]. Therefore, the gap between annual local production and consumption of wheat grains is about 6 million tons, which are imported from Russia, France, Australia …etc. This gap could be narrowed by increasing local production of wheat *via* two ways. The first way is through vertical expansion, *i.e.*, increasing wheat production per unit area through the development of new cultivars of high yielding ability, early maturity, resistance to biotic and abiotic stresses, and the adoption of recommended cultural practices for growing these cultivars. The second way is through horizontal expansion, *i.e.,* by increasing the area cultivated with wheat. But the limiting factor for this approach in Egypt is the availability of irrigation water. Potential expansion of wheat area is only possible in the North coast and Egyptian deserts. But the soil in these areas is sandy with low water holding capacity and thus exposes wheat plants to drought stress, resulting in great losses in wheat yield and its components [2,3,4]. Using drought tolerant wheat cultivars that consume less water, and can tolerate soil water deficit could solve this problem.

Drought tolerance is the ability of a variety to remain relatively more productive than others under limited water conditions. He added that the ideal genotype for moisture stress conditions must combine a reasonably high yield potential with specific plant characters, which could buffer yield against severe moisture stress. To start a proper wheat breeding program for improving drought tolerance, the source populations should possess sufficient genetic variability amenable for selection. Unfortunately, with present distribution of improved high yielding, pure line cultivars in all of the world's wheat growing areas, selection from established cultivars would rarely isolate a new genotype [5]. Two breeding procedures, *i.e.,* mutation and hybridization are used to induce new genetic variation.

Induction of mutations could be achieved *via* physical or chemical mutagens [6]. The most important physical mutagens include X-rays, gamma-rays and fast neutrons. 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 [7,8,9,10]. In a little less than a century, mutation breeding programs resulted in developing more than 3200 crop varieties that are being grown all over the world; of which 254 mutant wheat varieties were developed by physical mutagens [11]. The mutants developed in wheat have a great potential for direct release and for inclusion in hybridization breeding programs [12]. Numerous wheat cultivars that were developed through induced mutation have been released which possess tolerance to many biotic and abiotic stresses and other improved traits. Mutants induced *via* gamma rays have been obtained in bread wheat for tolerance to drought leading to the release of 26 varieties worldwide [11].

Hybridization is the principal breeding procedure for inducing genetic variability in wheat. The chief role of hybridization is to cross diverse genotypes to create hybrid populations with wide genetic variation from which new recombinations of genes may be selected [13]. Transgressive segregation is a phenomenon specific to segregating hybrid generations and refers to the individuals that exceed parental phenotypic values for one or more characters [14]. Observations on transgressive segregants were previously explained by many researchers [15,16]. Selection from segregating generations of wheat hybrid combinations succeeded to develop new genotypes that possess adaptive traits of drought tolerance, such as early maturity [17,18,19], glaucosness [9,20], high water use efficiency [21] and high grain yield/plant under water deficit conditions [22,23].

The main objective of the present investigation was to develop new wheat genotypes (putative mutants and transgressive segregants) of high grain yield under water stress conditions. The detailed objectives were: (i) identification of the proper gamma ray dose for induction of useful mutations in seven wheat genotypes, (ii)estimation of variance components, heritability and expected genetic advance from selection in F_2 populations of diallel crosses among six wheat genotypes and in M_2 populations of seven gamma-irradiated wheat genotypes under water stress and non-stress conditions and (iii) field evaluation of selections under drought stress and estimating the actual progress from selection.

2. MATERIALS AND METHODS

This investigation was carried out during the four successive wheat growing seasons 2008 / 2009 through 2011 / 2012 at the Experimental Farm of the Plant Research Department, Nuclear Research Center, Inshas, El-Sharkyia Governorate (The latitude and longitude of the experimental site are 30° 24` N and 31° 35` E, respectively, while the altitude is 20 m above the sea level). The soil of experimental site was sandy loam.

2.1 Materials

Seven genotypes of bread wheat (*Triticum aestivum* L.), Sids-4, Sakha-61, Aseel-5, Sakha-93, Giza-168, Sahel-1 and the line Maryout-5 were used in the present study. Name, pedigree, origin and important traits of these genotypes are presented in Table 1.

2.2 Experimental Procedures

2.2.1 First season (2008/2009)

2.2.1.1 Testing radio sensitivity of the studied wheat genotypes

Fresh air-dried seeds 12 % moisture content from each of the seven wheat genotypes used in the present study were treated with nine different doses of gamma rays *i.e.* 0, 100, 150, 200, 250, 300, 350, 400 and 450; GY, 10 GY = 1 Krad, in order to indentify the proper radiation dose for useful mutation induction. Irradiation treatments were achieved by Co^{60} Gamma unit which delivered 20000 GY per hour. Exposure time was adjusted to achieve expected doses. The source of irradiation is installed at the Nuclear Research Center, Inshas, Egypt. The effect of different doses of gamma radiation doses on mean seedling height of all seven genotypes grown in three replicates in plastic containers with 120 grains per treatment was studied after 14 days of sowing. The proper dose for the induction of useful mutations in cereals is that causing 30-50% reduction in seedling growth in laboratory tests [24]. This experiment proved that the dose of 350 Gy gamma rays was the best for induction of useful mutations in the studied wheat genotypes and therefore was used in this investigation.

2.2.1.2 Making the diallel crosses

The six genotypes, viz. Sids-4 (P1), Sakha-61 (P2), the line Maryout-5 (P3), Aseel-5 (P4), Sakha-93 (P5) and Giza-168 (P6) chosen as parents for the diallel crosses were grown in 2008/2009 season at the Experimental Farm of the Plant Research Department, Nuclear Research Center, Inshas. All possible diallel crosses (excluding reciprocals) were made among the six parents, to obtain seeds of 15 F1 crosses.

2.2.2 Second season (2009/2010)

2.2.2.1 Producing M2 seeds

Seeds of each of the seven parents irradiated with the selected dose of gamma ray (350 GY) were immediately sown on 20 Nov., 2009 at the Experimental Farm of Plant Research Department, Nuclear Research Center, Inshas in separate plots to obtain M1 plants of each bulk. Each plot consisted of 30 rows; each row was 4 m long and 30 cm wide. Spaces between each two plants were 10 cm in each row. The plants were left for natural self pollination. At harvest, ten kernels were taken randomly from each M1 plant (M2 seed). The 10 M2 kernels from each plant of each bulk were blended to represent seed of the respective M2 bulk. These seeds of M2 bulks were kept for use in experiments of the third season (2010/2011). The recommend cultural practices for wheat production at Inshas were followed in M1 generation.

2.2.2.2 Producing F2 seeds

F1 seeds from each of the 15 crosses were sown in the field under well watered conditions in separate plots. The plants were left for natural self pollination. At maturity F2 seeds of each cross were separately harvested.

2.2.3 Third season (2010/2011)

2.2.3.1 Field evaluation of the 7 $M_2{}^{'}{}_s$ and 7 $P^{'}_s$

A field experiment including 7 M_2 bulks and 7 parents (14 entries) was conducted in a split-plot design with randomized complete blocks arrangement in 3 replications. Main plots were assigned to the two irrigation regimes (water-

Table 1. Pedigree and the most important traits of the studied wheat genotypes

Genotypes	Designation	Pedigree	Origin	Important trait
Sids-4 cv.	Sd-4	Maya"S"Mon"S"/CMH74.A592/3/Sakha8 X2SD10002-140sd-3sd-1sd-0sd	ARC – Egypt	Earliness
Sakha-61 cv.	Sk-61	Lina/RL4220//7c/Yr"S"CM 15430-25-55-0S-0S	ARC – Egypt	Earliness
Maryout-5 Line	Mr-5	Giza 162 // Bch's /4/ PI-ICW 79Su511Mr-38Mr-1Mr-0Mr	DRC – Egypt	High yielding and Salt tolerant
Aseel-5 cv.	As-5	BIG INC 08 104	ICARDA - Syria	Drought tolerant
Sakha-93 cv.	Sk-93	Sakha 92/ TR 810328 S8871-1S-2S-1S-0S	ARC – Egypt	High yielding
Giza-168 cv.	Gz-168	Mrl / Buc // Seri CM 930468M-0Y-0M-2Y-0B	ARC – Egypt	High yielding
Sahel-1 cv.	Sah-1	NS 732 / PIMA // VEERY "S"	ARC – Egypt	Drought tolerant

ARC = Agricultural Research Center, DRC = Desert Research Center, ICARDA = International Center for Agricultural Research in the Dry Areas, cv. = cultivar

stress and well-watering) and sub-plots were assigned to the 14 genotypes. Two irrigation treatments (starting from 21 days after sowing) were used, *viz*., irrigation every 5 days (well-watering; WW) and irrigation every 15 days (water-stress; WS). The total quantity of irrigation water for WS was 70 % of that for WW. Each sub plot consisted of 6 rows, 3 m long and 30 cm wide, with hills spaced 10 cm apart (plot size = 5.4 m^2).

2.2.3.2 Field evaluation of the 15 F_2's and their 6 parents

Asecond field evaluation experiment was conducted to evaluate 15 F_2's and their 6 parents in the same season using a split-plot design in a randomized complete blocks arrangement with 3 replications. Main plots were assigned to the two irrigation regimes (stress and non-stress) and sub-plots were assigned to the 21 genotypes. Irrigation regimes and experimental plots were similar to those used in the previous experiment.

2.2.3.3 Practicing selection

Individual plant selection, using *ca* 1 % selection intensity was practiced in the same season (2010/2011), in both experiments, *i.e*., in the 15 F_2's and 7 M_2's for grain/yield plant and some other favorable traits, such as spike length, spike weight, spikes/plant, earliness, glaucousness…*etc*., under water stress and non-stress conditions. One hundred and sixty two individual plant selections were separately harvested (53 from M_2 and 109 from F_2 populations).

<u>**2.2.4 Fourth season (2011/2012)**</u>

2.2.4.1 Field evaluation of selections and their parents

A field experiment was conducted to compare the selected individual genotypes with their parents. The experimental design used was a split-plot in a balanced lattice (13x13) arrangement with three replications. Main plots were assigned to two irrigation regimes and sub-plots were devoted to 169 genotypes (162selections + 7 parents). Each plot consisted of 4 rows, 2.25 m long and 30 cm wide; with hills spaced 10 cm apart (plot size = 2.7 m^2). Rainfall in both seasons was very light and scattered with a total precipitation of 10.3 and 13.9 mm for the two seasons, respectively, suggesting that rainfall in these seasons during the stress period was of negligible influence on disappearing the drought symptoms of experimental soil. Moreover, temperature was slightly lower in 2011/2012 season as compared with 2010/2011 season, except the 1st half of April 2011/2012, where it was higher by 5 degrees than that of 2010/2011 season.

2.3 Data Recorded

Data were recorded on days to 50% heading (DTH), days to 50% anthesis (DTA), days to 50%

physiological maturity (DTM), plant height (PH), spike length (SL), spikes/plant (SPP), grains/spike (GPS), spike weight (SW), 100-grain weight (100GW) and grain yield/plant (GYPP). Data on the latter seven traits were measured on 30 individual plants/plot for F_2's, M_2's and on 10 individual plants/ plot for F_1's and parents. Data on the 1st three traits were measured on a per plot basis.

2.3.1 Biometrical and genetic analyses

Data were subjected to the normal analysis of variance of split-plot design, for all experiments and LSD value were calculated to verify differences between means according to Snedecor and Cochran [25]. Data was further analyzed under each irrigation regime as RCBD to estimate required genetic parameters.

Genotypic (δ^2_g) and phenotypic (δ^2_{ph}) variances of each of the studied F_2 crosses were estimated separately. Phenotypic variance of each parent was considered as environmental variance, while that of the F_2 cross was considered to include both genetic (δ^2_g) and environmental (δ^2_{ph}) variances. Therefore, δ^2_g of each F_2 cross was calculated using the formula: $\delta^2_g$of F_2 = δ^2_{ph} of F_2 – (δ^2_{ph} of P_1 + δ^2_{ph} of P_2)/2. Heritability in the broad sense (h^2_b) for each F_2 was estimated as follows: h^2_b=100 (δ^2_G/δ^2_{ph}). Expected gain from selection (GA) for each F_2 was estimated using h^2_b as follows: GA =100 h^2_b k δ_{ph} / X, where k=selection differential=2.64 for 1 % selection intensity used in this study.

Genotypic and phenotypic variances of each M_2 bulk were estimated separately. Phenotypic variance (δ^2_{ph}) of untreated plants of each cultivar was considered as environmental variance (δ^2_{ph}), while that of each treated bulk was considered to include both genetic (δ^2_q) and environmental (δ^2_{ph}) variances. Therefore, δ^2_q of each M_2 bulk was calculated using the formula: {δ^2_q of M_2 = δ^2_{ph} of M_2 – (δ^2_{ph} of corresponding parent)}. The following equations were used to estimate genotypic (GCV) and phenotypic (PCV) coefficients of variations: GCV = (δ_q / x) 100, PCV = (δ_{ph} / x) 100 Where: x = Mean of the respective M_2 population (bulk). Broad-sense heritability (h_b^2) was estimated for each M_2 bulks using the following formula: h^2_b = 100 δ^2_q / δ^2_{ph}. The predicted genetic advance (GA) from selection as suggested by Singh and Chaudhury [26] was calculated in each M_2 using-1 % selection intensity as follows:

$$GA = 100\ h^2_b\ k\ \delta_{ph} / x$$

where k = selection differential = 2.64.

3. RESULTS AND DISCUSSION

3.1 Evaluation of M_2 Bulks and their Parents

3.1.1 Analysis of variance of M_2 bulks and their parents

Analysis of variance of the studied wheat genotypes treated and untreated with gamma rays (350 Gy dose) in M_2 generation under two watering regimes (well watering and water stress) using a split-plot design in RCB arrangement in 2010/2011 season showed that mean squares due to irrigation regimes (W) were significant and highly significant for all studied traits. This indicates that water deficit stress had a significant effect on all studied traits of studied wheat genotypes (M_2 bulks and their parents). Results also exhibited that mean squares due to studied wheat genotypes (G), whether were irradiated (I) or non-irradiated (NI) with gamma rays were highly significant, for all studied traits, suggesting that wheat genotypes (irradiated, I and non-irradiated, NI) used in this study were significantly different for all studied traits. Mean squares due to irradiated *vs.* non-irradiated wheat genotypes were significant at 0.05 or 0.01 levels of probability for all studied traits, except for days to maturity, spikes/plant and 100 grain weight traits, indicating that irradiation had a significant effect on most studied traits. These results confirm the previous ones reported by other investigators [8,9,10,27].

Moreover, mean squares due to genotypes X watering regimes, *i.e.,* G X W were highly significant for all studied traits, except for days to heading and days to anthesis traits, suggesting that studied wheat genotypes behaved differently under different irrigation regimes. This conclusion was confirmed by previous investigators [9,10].

Partitioning mean squares due to G X W interaction into their components indicated significant or highly significant mean squares due to I X W for five traits, namely DTA, PH, GPS, 100GW and GYPP and due to NI X W for eight traits, namely DTH, DTA, PH, spike weight (SW), SPP, GPS, 100GW and GYPP. Non-irradiated genotypes interacted with watering regimes for most studied traits (8 out of 10), while irradiated genotypes interacted with irrigation regimes for half of studied traits (5 out of 10). The genetic variation induced by irradiation of the studied wheat genotypes might have resulted in more adaptation (stability) under different environments (watering regimes) and thus less interaction between genotype and watering regime for 50% of studied traits, *viz.* DTH, DTM, spike length (SL), SW and SPP. Mean squares due to I X W *vs* NI X W interaction were significant for 5 out of 10 studied traits, namely DTH, DTA, DTM, PH and GYPP, indicating that irradiated genotypes differ from non-irradiated genotypes in their response with watering regimes for such traits, confirming that irradiated genotypes responded to watering regimes in less number of traits than non-irradiated genotypes.

3.1.2 Mean performance of M_2 bulks and their parent

Genotypic differences existed among studied wheat cultivars, either irradiated (in M_2 generation) or non-irradiated ones under both drought stress and non-stress conditions (Table 2). For the non-irradiated genotypes, the highest yielders were Sakha-61 (40.6 g) followed by Maryout-5 (37.7 g) under well watering and Aseel-5 (28.9 g) followed by Sids-4 (27.0 g) under water stress, while the lowest yielder were Sahel-1 (34.0 g) under WW and Sakha-61 (24.1 g) under WS conditions. For the irradiated genotypes (generally lower yielders than non-irradiated), the highest yielders of them were Sids-4(I) (35.0 g) under WW and Aseel-5(I) (28.1 g) under WS, while the lowest ones were Giza-168(I) (21.8 g) and Sahel-1(I) (22.0 g) under WS environment. The cultivar Aseel-5 followed by Maryout-5 proved to be the best grain yielders under water stress conditions, either with or without irradiation treatment. Under WW conditions, Sakha-61 (non-irradiated) and Sids-4 (irradiated) were the highest yielders.

The least reduction in grain yield as a result of water stress was achieved by the M_2 generation of the irradiated cultivar Aseel-5 (4.5 %) followed by Maryout-5 (7.5%). Moreover, the irradiated cultivar Sakha-61 exhibited an increase (14.5%) in grain yield due towater stress as compared to well watering. These three genotypes are of common superiority under water stress and two of them (Maryout-5 and Aseel-5) under non-stress conditions, and thus could be considered the most drought tolerant in this experiment. The superiority of these genotypes in grain yield was accompanied by superiority in spikes/plant.

Table 2. Mean performance of irradiated (I) and non- irradiated (NI) wheat genotypes in M_2 generation evaluated under water stress (WS) and well watering (WW) conditions (Inshas 2010/2011 season)

	Days to maturity			Plant height(cm)			Spikes/plant			Grain yield/plant(g)		
Genotypes	WW	WS	Ch.%	WW	WS	Ch.%	WW	WS	Ch.%	WW	WS	Ch.%
Sd-4 (NI)	120.3	117.0	2.8	95.4	88.8	6.9	8.1	6.0	26.0	34.8	27.0	22.5
Sd-4 (I)	123.3	120.3	2.4	99.9	84.8	15.1	10.7	8.4	21.3	35.0	25.4	27.3
Sk-61(NI)	124.3	120.3	3.2	82.0	83.6	-2.0	12.5	8.0	36.1	40.6	24.1	40.7
Sk-61 (I)	123.7	122.3	1.1	78.0	75.2	3.5	10.0	10.7	-7.3	22.4	25.6	-14.5
Mr-5 (NI)	125.7	122.7	2.4	96.2	92.7	3.6	7.9	7.3	7.6	37.7	28.1	25.5
Mr-5 (I)	122.7	121.3	1.1	91.7	83.8	8.6	8.1	7.8	4.0	28.6	26.4	7.5
As-5 (NI)	126.7	123.3	2.6	85.6	85.4	0.2	10.9	8.7	19.8	37.3	28.9	22.5
As-5 (I)	122.7	121.3	1.1	82.7	78.2	5.4	9.6	9.4	2.3	29.5	28.1	4.5
Sk-93 (NI)	123.7	121.3	1.9	82.0	79.4	3.2	10.0	8.4	16.3	36.7	26.9	26.7
Sk-93 (I)	123.0	122.3	0.5	76.8	71.2	7.3	8.7	7.7	11.4	25.7	23.0	10.7
Gz-168 (NI)	124.0	121.3	2.2	83.0	80.1	3.5	9.6	8.0	16.3	36.6	26.7	27.0
Gz-168 (I)	122.0	120.7	1.1	79.0	79.6	-0.7	8.1	7.3	10.2	26.2	21.8	17.0
Sah-1 (NI)	122.0	119.7	1.9	88.0	83.7	4.9	9.0	8.2	8.1	34.0	25.4	25.4
Sah-1 (I)	122.3	120.5	1.5	78.6	78.1	0.7	9.1	7.7	15.0	29.8	22.0	26.2
Aver. (NI)	123.8	120.8	2.4	87.5	84.8	3.0	9.7	7.8	19.6	36.8	26.7	27.4
Aver. (I)	122.8	121.3	1.3	83.8	78.7	6.1	9.2	8.4	8.2	28.2	24.6	12.6
LSD $_{0.05}$												
(W)	0.004			0.002			0.0002			0.016		
(G)	0.09			2.169			0.139			2.373		
(I)	0.462			1.054			0.611			1.203		
G x W	0.362			8.675			0.539			9.494		

Watering (W), G = Genotypes, Ch. = Change = 100 (WW - WS)/WW

Many studies have also indicated that there is a genotypic variation in grain yield of wheat M_2 bulks derived *via* gamma irradiation under water stress and non-stress conditions [7,8,9,10].Several workers also reported wheat genotypic differences under both drought stress and non-stress conditions in number of spikes/plant [9,28,29] and plant height [7,8,9,30].

3.1.3 Coefficients of variation of M_2's

The estimates of phenotypic (PCV) and genotypic (GCV) coefficients of variation are presented in Table 3. In general, the estimates of PCV were higher than those of GCV, and both PCV and GCV estimates were higher under WW than corresponding estimates under WS conditions in most cases.

The highest estimates of PCV and GCV were exhibited by grain yield/plant and spikes/plant, while the lowest ones were shown by 100-grain weight and spike length. The irradiated cultivar Sids-4(I) recorded the highest estimates of PCV under both WW and WS conditions and highest GCV under WW for all studied traits, including grain yield and the most important yield component, *i.e*., number of spikes/plant. The irradiated genotypes Maryout-5 and Sakha-93 under WW and WS came in the second rank (after Sids-4) for PCV estimates of SPP and GPS for Maryout-5 and SPP, GPS and GYPP for Sakha-93. These genotypes could be considered the most responsive ones to induction with more variability to a dose of 350 Gy gamma rays, especially for grain yield and spikes/plant of Sids-4 and Sakha-93 under water stress and non-stress conditions. This can help wheat breeder for increasing the efficiency of selection for drought tolerance. This conclusion was also reported by Al-Naggar et al. [9,10] on their work to develop new genetic variation in wheat drought tolerance *via* irradiation.

Recorded high estimates of PCV and GCV in wheat due to gamma ray irradiation in this study in grain yield and its component are in agreement with those reported by many investigators [10,27,31].

3.1.4 Heritability and expected selection gain in M_2's

Estimates of heritability in the broad sense (h^2_b) and expected genetic advance from selection (GA) for M_2 bulks derived from irradiated wheat cultivars under well watering and water stress conditions are presented in Tables 4. Heritability estimates in the broad sense in M_2's were, on average higher under WW than WS for the five traits PH, SPP, GPS, 100GW and GYPP. On average, the highest h^2_b estimate (61.70 and 51.45%) was shown by plant height followed by GYPP (25.21 and 24.10%) and spikes/plant (27.77 and 22.03%) under WW and WS, respectively (Table 4). On the contrary, the

Table 3. Phenotypic (PCV %) and genotypic (GCV %) coefficient of variation estimates for some studied traits of irradiated (I) bread wheat genotypes under water stress and well watering conditions (Inshas 2010/2011 season)

M_2	PCV %					GCV %				
bulk	PH	SPP	GPS	100GW	GYPP	PH	SPP	GPS	100GW	GYPP
					Under well watering					
Sd-4 (I)	5.68	25.24	13.17	5.32	28.21	4.20	18.38	6.58	2.40	13.90
Sk-61(I)	11.42	18.94	10.61	4.02	21.74	10.89	6.84	3.03	1.45	12.11
Mr-5 (I)	3.97	21.06	14.60	4.01	16.96	2.92	12.56	5.66	2.46	9.44
As-5 (I)	3.43	19.55	10.19	3.81	20.94	2.36	7.39	4.81	2.04	10.88
Sk-93 (I)	5.14	30.03	12.45	5.04	28.78	3.92	9.20	3.98	1.37	12.26
Gz-168 (I)	3.84	17.28	9.76	4.19	15.02	2.98	7.39	3.71	1.67	7.94
Sah-1 (I)	4.80	25.85	10.90	3.65	29.27	3.91	18.43	4.03	1.46	12.10
					Under water stress					
Sd-4 (I)	2.77	23.86	15.27	3.30	22.75	2.12	19.22	3.94	0.55	10.67
Sk-61(I)	4.59	18.58	12.79	3.41	18.76	3.86	7.24	3.88	0.56	7.38
Mr-5 (I)	5.62	13.33	13.74	3.09	18.96	3.34	3.09	4.73	1.54	9.62
As-5 (I)	3.79	20.95	10.11	1.98	19.98	3.02	9.51	4.38	0.60	11.28
Sk-93 (I)	5.31	21.61	11.31	2.11	24.47	4.23	9.24	3.42	0.74	9.91
Gz-168 (I)	4.16	14.90	10.60	2.54	13.98	2.54	5.10	3.67	0.95	7.15
Sah-1 (I)	4.58	12.29	12.99	2.78	14.62	2.59	5.24	4.19	2.04	8.14

PH = Plant height (cm), SPP = Spikes/plant, GPS = Grains/spike, 100GW = 100-grain weight (g), GYPP = Grain yield/plant (g) lowest average h^2_b was shown by GPS (11.13 %) under WS and (15.53 %) under WW conditions. Under WW, the highest h^2_b for GYPP (31.04%) and plant height (90.96%) were exhibited by Sakha-61(I), for SPP (53.01%) and GPS (24.99%) by Sids-4(I) and 100GW (37.56%) by Maryout-5(I). Under WS, the highest h^2_b for GYPP (31.90%) and GPS (18.80%) were shown by Aseel-5(I), PH (70.52%) by Sakha-61(I), SPP (64.87%) by Sids-4(I) and 100GW (53.92%) by Sahel-1(I).

Gamma rays were found to increase genetic variance as reflected by heritability estimates of the mutated segregating generations for grain yield and its component in wheat [9,10,27].

The average predicted genetic advance from selection (GA %) of the best 1 % in M_2 bulks was generally higher under well watering than under water stress conditions for all studied traits (Table 4). Under well watering, maximum predicted GA % from selection in M_2's was achieved from SPP (17.07 %) followed by GYPP (14.79 %). Under water stress conditions, the highest expected GA percentage was obtained from GYPP (11.84 %) and SPP (11.79 %). These two traits (GYPP, SPP) are probably therefore the most responsive ones to selection in M_2 bulks resulting from gamma irradiation treatment (350 Gy dose of gamma radiation). Few cycles of selection for high values of these traits would be enough to improve these traits either under water stress or non-stress conditions. On the contrary, 100 grain weight exhibited the lowest expected GA % estimate as a result of selection in M_2 populations of wheat cultivars under investigation derived *via* irradiation with gamma rays.

Maximum gain from selection in M_2's for high grain yield would be expected to be 18.09% from Sids-4(I) followed by 17.82% from Sakha-61(I) under non-stress and 16.83%from Aseel-5(I) followed by 13.22% from Sids-4(I) and 12.89% from Maryout-5(I) underwater stress conditions. Under WW, the best responsive M_2 populations to selection are expected to be Sids-4 (I) for GYPP, SPP and GPS Sakha-61 (I) for GYPP and PH and Sahel-1(I) for SPP. While under WS, the best responsive ones are predicted to be Sids-4(I) for SPP and GYPP, Maryout-5(I) for GYPP and Aseel-5(I) for GPS and GYPP.

Since, the efficiency of selection would depend upon the magnitude of variability that is heritable and caused by genetic factors, the higher values, therefore, of heritability accompanied by high genetic advance for the characters studied should be quite valuable. It is obvious from the previous results of this study on M_2 and M_3 bulks, that superior bulks were characterized with high heritability accompanied by high values of genetic advance for grain yield/plant and one or more yield components.

Table 4. Heritability in broad sense % (h^2_b) and expected genetic advance (GA %) from selection for some studied traits of irradiated (I) bread wheat genotypes under water stress and well watering conditions (Inshas 2010/2011 season)

M_2	h^2_b					GA %				
bulk	PH	SPP	GPS	100GW	GYPP	PH	SPP	GPS	100GW	GYPP
Under well watering										
Sd-4 (I)	54.66	53.01	24.99	20.35	24.29	8.21	35.33	8.69	2.85	18.09
Sk-61(I)	90.96	13.04	8.16	12.92	31.04	27.42	6.53	2.28	1.37	17.82
Mr-5 (I)	54.24	35.57	15.01	37.56	30.95	5.69	19.79	5.79	3.98	13.86
As-5 (I)	47.44	14.29	22.24	28.72	27.02	4.31	7.38	5.99	2.90	14.94
Sk-93 (I)	58.01	9.38	10.20	7.43	18.15	7.88	7.44	3.36	0.99	13.79
Gz-168 (I)	60.15	18.31	14.46	16.01	27.94	6.09	8.36	3.72	1.77	11.09
Sah-1 (I)	66.44	50.81	13.69	16.00	17.09	8.42	34.68	3.95	1.55	13.22
Average	61.70	27.77	15.53	19.85	25.21	9.72	17.07	4.83	2.21	14.69
Under water stress										
Sd-4 (I)	58.37	64.87	6.65	2.78	21.99	4.28	40.86	2.69	0.24	13.22
Sk-61(I)	70.52	15.17	9.19	2.70	15.48	8.55	7.44	3.11	0.24	7.67
Mr-5 (I)	35.41	5.38	11.83	24.93	25.74	5.25	1.89	4.29	2.04	12.89
As-5 (I)	63.39	20.61	18.80	9.23	31.90	6.35	11.40	5.03	0.48	16.83
Sk-93 (I)	63.38	18.29	9.12	12.25	16.41	8.90	10.44	2.73	0.69	10.61
Gz-168 (I)	37.26	11.71	11.95	13.95	26.16	4.10	4.61	3.35	0.93	9.66
Sah-1 (I)	31.84	18.18	10.39	53.92	30.99	3.86	5.90	3.56	3.95	11.96
Average	51.45	22.03	11.13	17.11	24.10	5.90	11.79	3.53	1.23	11.84

PH = Plant height (cm), SPP = Spikes/plant, GPS = Grains/spike, 100GW = 100-grain weight (g), GYPP = Grain yield/plant (g)

Genetic improvements in these M_2 bulks can therefore be achieved with care for these characters. Singh and Kumar [32] also found high heritability and high genetic advance for grain hardness and 100 grain weight in 18 mutant lines (stabilized in M_3 generation) of bread wheat derived *via* different doses of gamma rays.

Many investigators were able to induce genetic variation in the M_2 generation of wheat following irradiation [32,33,34]. Salam [34] reported that grain yield/plant, 100-grain weight and plant height showed significant increase with 7.5 krad in M_3 under drought conditions. He concluded that this probably would indicate the occurrence of drought tolerant genotypes as a result of irradiation. Moreover, Kalia et al. [35] reported that with effective mutagenesis, it was possible to induce mutations and with rigorous screening in M_2 and M_3 generations, and isolate mutant plants with higher grain yield potential, protein content, desirable quality and better rust resistance.

4. EVALUATION OF F_2 DIALLEL CROSSES

4.1 Analysis of Variance

Analysis of variance of split-plot design for studied traits of 15 F_2 cross populations under two irrigation regimes showed that mean squares due to irrigation regimes were significant for all studied traits, indicating that water stress significantly affected all studied traits of F_2 crosses. Mean squares suggested the existence of highly significant differences among studied F_2 populations for all studied characters. Such significant differences among F_2 populations in bread wheat were also recorded by Al-Naggar et al. [9]. Mean squares due to the F_2 crosses X irrigation regimes interaction were significant or highly significant for all studied characters, except for spike length and spikes/plant, which were not significant. These results suggest that the F_2 populations responded differently to the different irrigation regimes for most studied traits, supporting previous results of Al-Naggar et al. [9]

4.2 Mean Performance of F_2Diallel Crosses and their Parents

Data presented in Table 5 indicated great and highly significant differences among parents and F_2 crosses in DTM, PH and GYPP traits under well irrigation (WW). Sids-4 was the earliest parent and matured after 120 days under WW, and 117 days under WS.

Mean performance for DTM, PH and GYPP traits of 15 F_2 crosses and their parents under two irrigation regimes (WS and WW) is also presented in Table 5. Water stress caused a significant reduction in all studied traits of F_2 crosses; however such reduction was slight and ranged from 4.3 % for plant height to 11.5% for grain yield/plant and in parents from 1.9 % for DTM to 25.4 % for GYPP. Small reduction in GYPP due to water stress in F_2 populations (11.5 %) as compared to such reduction of their parents (25.4%) might be due to the more genetic heterogeneity and thus adaptability of F_2's than parents. Water stress imposed on F_2 populations caused significant earliness in DTM (8 days) and reductions of 4 cm (in PH) and 4.2 g (in GYPP) consistent with report by Al-Naggar et al. [9,10].

Results indicated significant differences among the 15 F_2 populations in all studied traits under both irrigation regimes regarding their absolute mean performances as well as relative change (reduction) were due to water stress. The earliest F_2 cross was Sd-4 X Sk-61 for DTM (120 and 118) under WW and WS, respectively. The second earliest F_2 was Sd-4 X Mr-5. The two F_2 crosses share a common parent, namely Sids-4 which was the earliest parent in both F_1 and F_2 experiments. The tallest F_2 cross was Mr-5 X As-5 (101 and 94 cm), while the shortest ones were Sk-61 X Sk-93 and As-5 X Gz-168 (85 and 83 cm) under WW and WS, respectively. For grain yield attribute under water stress conditions, the F_2 cross Sk-61 X As-5 came in the 1st rank for absolute grain yield/plant (35.9 g) under WS and for the lowest reduction due to water stress (4.4%), indicating that this cross is tolerant to drought stress and would be proper for practicing selection for high grain yield under water stress. The F_2 crosses Sk-61 X Mr-5, Sd-4 X Sk-61, and Sd-4 X Sk-93 came in the 2nd, 3rd and 4th ranks, respectively for absolute GYPP under WS. The two F_2 crosses Sd-4 X Sk-61 and Sd4 X Sk-93 showed low reduction due to water stress (8.5 and 7.3%, respectively). Under non-stress conditions, the best F_2 crosses for absolute GYPP were Sk-61 X Mr-5 (44.5 g), Mr-5 X Sk-93 (39.0 g), Mr-5 X Gz-168 (38.0 g) and Sk-61 X As-5 (37.6 g); without significant differences among the latter three F_2 crosses. Two F_2 crosses (Sk-61 X Mr-5 and Sk-61 X As-5) showed the highest absolute GYPP under both water stress and non-stress conditions. It seems that three out of the six genotypes used in the present hybrids possess desirable complementary combinations of favorable genes for high yield per plant that contribute to the superiority of the hybrid among any two of them, *i.e.*, genes at different chromosomes and/or chromosome locations for the three yield contributing traits.

4.3 Heritability and Expected Genetic Advance from Selection in F_2s

Separate estimates of phenotypic (δ^2_p) and genotypic (δ^2_g) variances, heritability in the broad sense (h^2_b) and expected genetic advance (GA%) from selection of the best 1 % based on h^2_b in each F_2 generation of the studied 15 diallel crosses for GYPP are presented in Table 6. Results of this table indicate that the F_2 crosses differ in the magnitude δ^2_p, δ^2_g, h^2_b and GA. Based on the genetic parameter estimates in this table, it could be concluded that under well watering, it is predicted that the best F_2 population is that of the cross Mr-5 X Sk-93 for selection to improve GYPP followed by Sd-4 X Sk-93, As-5 X Sk-93, Mr-5 X Gz-168 and Sk-61 X Mr-5. Under water stress, it is expected that the best responsive F_2 cross to selection is As-5 X Sk-93 for selection for high GYPP followed by Mr-5 X As-5, Sk-61 X As-5, Sd-4 X As-5 and Sk-93 X Gz-168. It is interesting to note that Sk-61 X As-5 was the highest yielding F_2 cross under WS and the most drought tolerant F_2 cross (lowest reduction in GYPP due to water stress). Moreover, the F_2 cross As-5 X Sk-93 was high yielding and tolerant to WS. These crosses are expected to release more drought tolerant transgressive segregants.

4.4 Agronomic Characterization of the Best 12 Selected M_3 and F_3 Families

The best twelve selected families (SF) included 7 M_3 families; two (SF2 from M_2 of Sakha-93 and SF3 from M_2 of Giza-168) selected under WS, and five (SF1 from M_2 of Aseel-5, SF4 and SF5 fromM_2 of Giza-168, SF6 and SF7 from M_2 of Sahel-1) selected under WW and 5 F_3 families; three (SF9, SF10 and SF11) selected under WS , from the F_2 of Sd4 X Mr5, Sk61 XAs5 and Sk61 X Sk93, respectively, and two (SF8 and SF12) selected under WW, from the F_2 of Sd4 X Sk61 and Mr5 X Sk93, respectively. Means of studied traits of the best 12 families and the 7 parental genotypes under WS and WW are presented in Table 7. On average, under WS conditions the group of the best 5 F_3 families showed the highest mean grain yield (41.2 g), while the group of 7 parents exhibited the lowest grain yield (26.6 g). Moreover, yield reduction due to water stress in the best M_3 and best F_3 groups (12.0 and 13.3% on average, respectively) was less than that of the parents group (17.1%). This means that, in this experiment, selection practiced inboth M_2 and F_2 populations was effective in producing higher yielding families under WS than the original parents and the success of the two procedures, *i.e.,* gamma-ray mutation induction and hybridization followed by transgressive segregation, in isolating new variants for higher drought tolerance. This is confirmed by Sobieh [8] and Al-Naggar et al. [9,10] for the success of mutation breeding and Al-Naggar et al. [9,19]. It is worth noting that the group of best F_3 families was, on average, earlier than the group of parents for DTH (by 5.3 days), DTA (by 3.9 days) and DTM (by 1.9 days) under WS Table 7.

Comparing all the 12 best families (Table 8), it is interesting to mention that the best families in grain yield/plant under water stress were SF9 (45.6 g), followed by SF11 (44.2 g) and SF3 (42.8 g) with a very low reduction due to water stress (6.9, 6.2 and 11.2%, respectively). It is worth noting that the best three families under WS resulted from selection for high yield under water stress conditions.

The earliest M_3 family for DTM was SF6 as compared with the earliest parents Sids-4, Sakha-61 and Aseel-5, under water stress. The best M_3 and F_3 families for grain yield/plant were characterized by high value of one or more of yield components.

Practicing selection in the F_2 generation of the studied crosses resulted in a significant superiority (selection gain) over the better parent of the corresponding cross in grain yield/plant ranging from 15.48 % for SF10 to 74.71 % for SF9 under water stress and from 32.76% for SF12 to 60.24 % for SF9 under non-stress conditions (Table 8). The SF9 selected F_3 family showed the highest selection gain under both water stress and non-stress conditions. The five selected F_3 families (SF8, SF9, SF10, SF11 and SF12) showed significant superiority in grain yield over their better parents under both stress and non-stress conditions. These superior families in grain yield are the result of transgressive segregation and may be considered promising lines having tolerance to drought conditions. Observations on transgre-ssive segregation in segregating hybrid generations were previously explained by several research workers [16]. The results from classical genetic studies have provided fairly convincing evidence for the hypotheses that transgressive segregation can result from complementary gene action [36].

Practicing selection for high grain yield in the M_2 populations derived from gamma radiation treatment of parent cultivars of wheat resulted in an actual progress over the corresponding original parent in GYPP ranging from 26.27 to 64.36% under WS for SF1 and SF3, respectively (Table 8). The SF3 selected M_3 family showed the highest selection gain followed by SF6 (62.62 % under WS). These two M_3 families showed also superiority in SPP and in DTM, *i.e*., earliness of maturity.

Superiority in grain yield of the 12 best families over the Egyptian cultivar Sids-4 reached 97.8% for SF9, 91.8% for SF11and 85.7% for SF3 under water stress. The twelve selected families should further be selfed for more generation to reach complete homozygosity to be tested for their stability under a variety of water stress conditions.

Table 5. Means of days to maturity, plant height and grain yield/plant in wheat parents and F_2's evaluated under water stress (WS) and/or well watering (WW) conditions (2010/2011 season)

	Days to maturity			Plant height (cm)			Grain yield/plant(g)		
Genotype	**WW**	**WS**	**Cha. %**	**WW**	**WS**	**Cha. %**	**WW**	**WS**	**Cha. %**
					Parents				
	2010/11			2010/11			2010/11		
Sd-4	120	117	2.8	95	89	6.3	34.8	27	22.5
Sk-61	124	120	3.2	82	84	-2.2	40.6	24.1	40.7
Mr-5	126	123	2.4	96	93	3.1	37.7	28.1	25.5
As-5	127	123	2.6	85	85	0.0	37.3	28.9	22.5
Sk-93	124	121	1.9	82	79	3.7	36.7	26.9	26.7
Gz-168	124	121	2.2	83	80	3.6	36.6	26.7	27.0
Aver. parents	122	120	1.9	88	85	3.4	37.3	25.4	25.4
					F_2 crosses				
	WW	WS		WW	WS		WW	WS	
Sd-4 X Sk-61	120	118	1.9	90	89	1.8	37.1	34.0	8.5
Sd-4 X Mr-5	123	120	2.2	94	90	4.5	35.7	28.6	19.8
Sd-4 X As-5	136	124	9.3	93	87	6.5	33.1	29.9	9.7
Sd-4 X Sk-93	129	123	4.6	89	87	2.2	36.2	33.6	7.3
Sd-4 X Gz-168	135	126	6.4	90	85	5.0	33.6	28.9	13.9
Sk-61 X Mr-5	133	123	7.3	95	92	3.3	44.5	34.8	21.8
Sk-61 X As-5	136	123	9.6	90	87	3.3	37.6	35.9	4.4
Sk-61 X Sk-93	133	124	6.8	85	83	2.8	36.7	32.3	12.1
Sk-61 X Gz-168	134	126	6.2	90	84	6.2	35.1	32.2	8.2
Mr-5 X As5	135	125	7.2	101	94	6.5	35.8	32.9	8.1
Mr-5 X Sk-93	126	121	4.2	98	94	3.6	39.0	32.6	16.5
Mr-5 X Gz-168	135	123	8.6	97	88	9.4	38.0	33.0	13.2
As-5 X Sk-93	129	124	4.1	89	86	3.5	34.8	33.1	5.0
As-5 X Gz-168	130	125	3.8	85	83	3.3	31.1	28.2	9.5
Sk-93 X Gz-168	125	121	3.7	86	84	2.8	31.8	27.3	14.2
Aver. crosses	131	123	5.7	91	87	4.3	36.0	31.8	11.5
LSD $_{0.05}$ (for F_1's and parents)									
LSD $_{0.05}$ (for F_2's and parents) (G)	1.8			3.47				2.42	
Watering (W)	0.7			2.8				0.8	
G x W	2.54			4.91				3.42	

Cha. = Change % = 100 (WW - WS) / WW

Table 6. Estimates of some genetic parameters for grain yield per plant of each F_2 cross under water stress (WS) and well watering (WW) conditions (Inshas 2010/2011season)

	Well watering (WW)				Water stress (WS)			
F_2 Cross	δ^2_p	δ^2_g	h^2_b	GA %	δ^2_p	δ^2_g	h^2_b	GA %
Sd-4XSk-61	4.5	1.3	29.6	4.5	63.6	17.0	26.8	16.7
Sd-4XMr-5	25.6	7.5	29.3	11.6	42.8	7.5	17.5	10.7
Sd-4XAs-5	27.3	9.2	33.6	14.9	62.0	16.8	27.1	18.9
Sd-4XSk-93	75.4	29.7	39.4	26.0	63.6	18.0	28.2	17.7
Sd-4XGz-168	28.0	12.3	44.0	19.5	23.6	3.3	13.9	6.2
Sk-61XMr-5	44.4	24.1	54.2	21.5	43.4	11.8	27.3	14.4
Sk-61XAs-5	24.2	8.0	33.0	11.6	83.4	41.1	49.3	33.2
Sk-61XSk-93	19.9	6.4	32.3	10.4	32.2	2.8	8.7	4.1
Sk-61XGz-168	20.1	9.9	49.0	18.9	46.5	5.2	11.2	6.2
Mr-5XAs-5	41.5	17.2	41.5	20.6	80.9	49.3	60.9	44.0
Mr-5XSk-93	116.6	81.8	70.1	52.5	48.4	13.5	27.9	16.2
Mr-5XGz-168	42.6	22.5	52.9	24.0	67.4	14.0	20.8	13.7
As-5XSk-93	36.2	18.7	51.5	24.2	149.1	109.3	73.4	71.6
As-5XGz-168	30.2	8.8	29.2	14.4	52.1	8.9	17.0	11.6
Sk-93XGz-168	40.8	13.1	32.2	17.7	56.3	14.7	26.1	18.9

H = higher limit of the range. R = higher limit – lower limit of the range

Table 7. Mean performance of the 12 best selected families (7 best M_3 and best 5 F_3 families) and their parents for studied wheat traits under water stress (WS) conditions (2011/ 2012 season)

Genotypes	DTH (day)	DTA (day)	DTM (day)	PH (cm)	SL (cm)	SW (g)	SPP (No)	GPS (No)	100GW (g)	GYPP (g)	Red. %
Best M											
SF1	95	111	141	95	13.7	3.6	11.7	75	4.4	42.1	0.0
SF2	102	112	141	96	14.1	3.3	13.3	68	4.7	42.0	2.1
SF3	91	102	135	89	14.1	3.7	11.9	74	4.3	42.8	1.2
SF4	94	103	137	87	13.7	4.0	10.1	71	4.4	39.9	0.1
SF5	93	102	137	84	13.5	3.5	11.3	65	4.6	39.3	1.9
SF6	95	105	129	101	13.4	3.7	10.9	68	4.8	40.2	3.0
SF7	98	111	139	80	13.1	3.3	11.9	64	4.8	38.2	5.3
Av. (M_3)	95.4	106.6	137.0	90.3	13.7	3.6	11.6	69.3	4.6	40.6	2.0
Best F											
SF8	89	98	131	103	13.5	3.6	10.9	67	5.0	38.2	1.6
SF9	82	92	131	97	14.3	4.1	11.2	71	5.0	45.6	.9
SF10	92	100	132	90	12.0	4.0	9.7	72	5.5	38.5	9.0
SF11	88	96	133	85	13.9	3.9	11.4	64	5.6	44.2	.2
SF12	87	99	131	85	16.3	5.0	8.0	64	5.6	39.4	2.6
Av. (F_3)	87.6	97	131.6	92	14	4.1	10.2	67.6	5.3	41.2	3.3
Parents											
Sids-4	87	95	132	96	16.2	4.3	5.3	84.0	5.0	23.1	4.6
Sakha-61	92	100	132	79	10.3	3.1	8.1	63.0	4.4	24.8	7.7
Maryout-5	95	103	138	94	14.2	3.8	6.9	76.0	4.9	26.1	3.4
Aseel-5	96	101	132	92	13.1	3.4	9.1	69.0	4.6	33.3	0.6
Sakha-93	94	101	132	81	12.2	3.2	8.7	66.0	4.4	28.2	7.0
Giza-168	95	102	136	86	12.6	3.6	7.3	65.0	4.2	26.0	5.5
Sahel-1	94	107	133	100	13.3	3.3	7.5	68.0	4.8	24.7	0.8
Av. (P)	92.9	100.9	133.5	89.9	13.1	3.5	7.6	70.1	4.6	26.6	7.1
$LSD_{0.05}$	0.67	0.58	0.56	1.08	0.13	0.08	0.13	0.90	0.07	0.80	

Red. (Reduction %) = 100(GYPP under WW - GYPP under WS)/ GYPP under WW, P = Parents, Av. = Average
F_3 = best F_3 families, M_3 = best M_3 families

Table 8. Actual progress (%) of the best selections over the original parent (from M_2's) and over the better parent (from F_2's) for DTM, SPP and GYPP under water stress (WS) and well watering (WW) conditions (2011/ 2012 season)

Best families		**DTM**		**SPP**		**GYPP**	
	Pedigree	**WW**	**WS**	**WW**	**WS**	**WW**	**WS**
Best M_3 families		Progress (%) over the original parent					
SF1	As-5-WW-PM5	6.77	7.22	21.78	28.57	25.44	26.27
SF2	Sk-93-WS-PM2	5.97	7.22	40.21	52.87	40.71	49.04
SF3	Gz-168-WS-PM2	-1.09	-0.74	53.01	63.01	56.34	64.36
SF4	Gz-168-WW-PM5	1.09	0.74	31.33	38.36	44.02	53.23
SF5	Gz-168-WW-PM6	1.09	0.74	50.6	54.79	44.66	50.92
SF6	Sh-1-WW-PM6	-2.6	-3.01	40.24	45.33	48.03	62.62
SF7	Sh-1-WW-PM7	4.83	4.51	50	58.67	44.50	54.53
Best F_3 families		Progress (%) over better parent					
SF8	Sd4XSk.61-WW-PS8	-0.37	-0.76	26.37	34.57	41.27	54.22
SF9	Sd4XMr5-WS-PS2	-1.12	-0.76	68.06	62.32	60.24	74.71
SF10	Sk61XAs5-WS-PS3	0.37	0.00	17.82	6.59	45.27	15.48
SF11	Sk61XSk93-WS-PS2	0.37	0.76	20.62	31.03	38.65	56.85
SF12	Mr5XSk93-WW-PS8	-0.75	-0.76	-2.06	-8.05	32.76	39.82

4.5 The Most Important Traits of the Best 12 Selections

SFI: It is a high yielding mutant under WS (2nd highest best M_3s) with low reduction (10.0%) due to water stress, *i.e.*, drought tolerant. It recorded the highest number of grains/spike amongst the 7 best M_3 families (Fig. 1).

SF2: It is a high yielding mutant under WS conditions; with low yield reduction due to water stress (drought tolerant). It recorded the highest number of spikes (Fig. 2) under water stress (13.3).

SF3: This mutant ranked first in grain yield/plant amongst the 7 best M_3 families under both WS and WW conditions; with low yield reduction due to water stress, *i.e.*, a drought tolerant family. It recorded the second largest number of grains/spike under WS and the longest spike (Fig. 1) and the earliest in DTH and DTM under WW and WS.

SF4: It is a high yielding mutant under both WW and WS; with low yield reduction due to water stress, *i.e.,* drought tolerant. It recorded the heaviest spike and grain (Fig. 3) under both irrigation regimes.

SF5: It is a high yielding mutant under WS conditions; with low reduction in GYPP due to water stress, *i.e.,* a drought-tolerant family.

SF6: It is a high yielding mutant under WS conditions, with low reduction in GYPP due to water stress, *i.e.,* a drought-tolerant family. It ranked the earliest amongst the best 12 families and the 7 parents. It recorded heavy grain (Fig. 3) comparable with its parent (Sh-1).

SF7: It is a high yielding M_3 family under both WW and WS conditions; with low yield reduction due to water stress. It is also characterized by the shortest plant height, the heaviest grain (Fig. 4) and the second highest in SPP (Fig. 2) amongst the 7 best selected M_3 families.

SF8: It is a transgressive segregant in the F_3 generation. It showed high GYPP under WS; with low yield reduction due to water stress. It also recorded the tallest plant (Fig. 4) and was earlier than the earliest parent.

SF9: It is a transgressive segregant in the F_3 generation. It showed the highest GYPP under WS; with the second lowest yield reduction (6.9%) due to WS, *i.e.,* the 2nd most drought tolerant F_3family. It is the earliest F_3 for DTH and DTA (Fig. 5).

SF10: It is a transgressive segregant in the F_3 generation. It recorded significantly higher yield than the best parent (Mr-5) under drought stress conditions. This family (SF10) recorded the heaviest grain (Fig. 6) under both irrigation regimes.

SF11: It is a transgressive segregant in the F_3 generation. It is the most drought tolerant selected family; since reduction in its yield due to water stress was lowest (6.2 %). Its yield under WS ranked the second highest and amongst the 5 best F_3 families. This selected family showed the heaviest grain (Fig. 6) under both WW and WS conditions.

SF12: It is a high yielding family under WS; with low yield reduction (12.6 %) due to water stress. It is characterized by the longest and heaviest spike (Fig. 7).

Fig. 1. The highest number of grains/spike for SF1 and SF3 as compared with their parents As-5 and Gz-168, respectively, and the longest spike for SF3

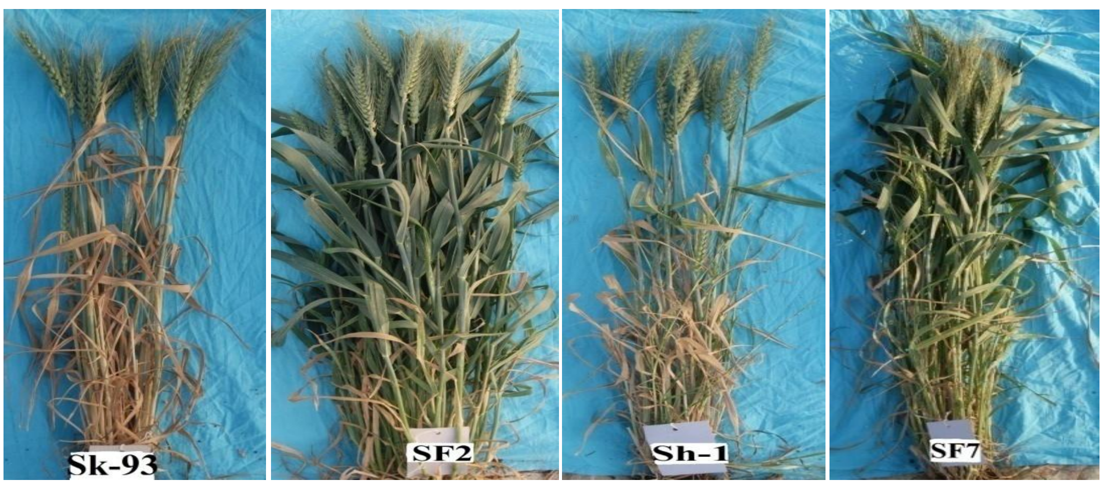

Fig. 2. The highest number of spikes for SF2 and SF7as compared with their parents Sk-93 and Sh-1, respectively

Fig. 3. The grains of SF4 and (SF6 and SF7) as compared with their parents Gz-168 and Sh-1, respectively

Fig. 4. The earliest maturity and tallest plant shown by SF8 as compared with the better parent Sids-4

Fig. 5. The earliest heading shown by SF9 as compared with the better parent Sids-4

Fig. 6. The heaviest grains shown by SF10 and SF11 as compared with the better parent Sakha-61

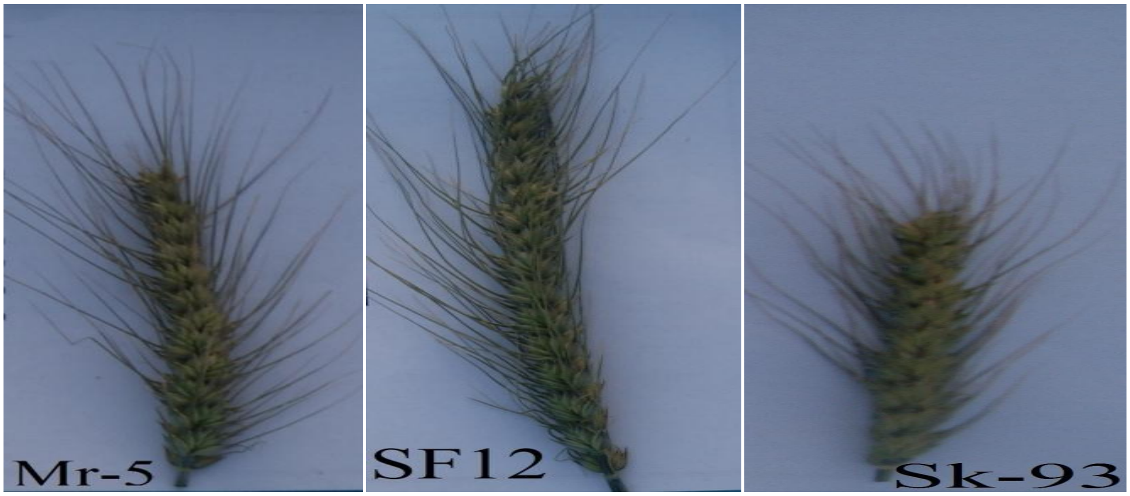

Fig. 7. The longest and heaviest spike of SF12 as compared with the better parent Maryout-5 and Sakha-93

5. CONCLUSIONS

Gamma rays and hybridization were effective in increasing genetic variability as reflected by high heritability estimates accompanied with high values of expected genetic advance from selection in the resulting heterogeneous populations for grain yield and its components in wheat. Selection practiced in both M_2 and F_2 populations was effective in producing higher yielding F_3 families under water stress (WS) than the original parents, suggesting the success of the two breeding procedures, in isolating new variants of higher drought tolerance. It is worth noting that the best F_3 families under WS resulted from selection for high yield under water stress conditions. Practicing selection for high grain yield in the M_2 and F_2 populations resulted in an actual progress over the corresponding original (better) parent in GYPP under WS ranging from 15.48 to 74.71% for SF10 and SF9, respectively. The twelve selected families should further be selfed for more generations to reach complete homozygosity to be tested for their stability under a variety of water stress conditions.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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