J. Agr. Sci. Tech. (2017) Vol. 19: 1161-1172

Response to Selection for Winter Survival and Yield in Different Populations of Synthetic Hexaploid Wheats (*Triticum dicoccum*/*Aegilops tauschii*)

N. Daskalova[1], and P. Spetsov[2*]

ABSTRACT

Pureline selection was applied in Synthetic Hexaploid Wheat populations (SHW), obtained from irradiated seeds with 150 Gy gamma rays and compared with their corresponding controls. The selection was performed in progenies of 20 initial plants from three amphiploids (8 from SHW32, 4 - SHW106 and 8 - SHW107) generating 19 $M_{1\text{-}3}$ and 19 $C_{2\text{-}5}$ lines. Two families did not survive winter in the first year. All selected lines expressed high germination, intermediate type of growth in winter and good seed set in the field conditions. The irradiation of seeds did not influence the germination and winter survival of the SHW plants. The response to direct selection was based on the mean performance of progenies for grain number and kernel weight per main spike and the selected elite plants in M_3 and $C_{4\text{-}5}$ generations. The coefficient of heritability and genetic advance for these traits were highest in SHW106, followed by SHW32. SHW107 displayed the largest morphological variability and sterility during the investigated period. All synthetics formed long, but sparse ears with seed fertility being lower than their tetraploid parents, but elite plants of SHW32 and 106 were equaled to tetraploid parent No 45432 on grain weight per major spike in 2013. Seed irradiation with 150 Gy gamma rays did not cause any effects on the two investigated traits. The selected subset of 10 lines from the three amphiploids represents a source of spike productivity for use in wheat breeding programs to enhance yield potential.

Keywords: Field emergence, Genetic parameters, Irradiation, Synthetic hexaploid wheat, Winter survival.

INTRODUCTION

Crop improvements include a wide range of traits such as enhanced yield and resistance to biotic and abiotic stresses. Wheat breeding, like any other crop, has relied on genetic diversity for enhancing its productivity. Genetic resources as landraces, wild progenitors, amphiploids, substitution and translocation genotypes have been utilized to enlarge the variability in common wheat. Induction of mutations leads also to selection of mutant genotypes that produce morphological changes, high yield potential, resistance to fungi and some biochemical variations (Czyczylo-Mysza *et al*., 2013; Plamenov *et al*., 2013; Cheng *et al*. 2015).

Winter wheat needs sufficient winter hardiness to survive unfavourable winter conditions and is dependent on both genotypic and environmental factors (Prášil *et al*., 2004). As a consequence, the grain yield is a complex trait underlined by several growth factors, one of which is winter hardiness. Evaluation of frost tolerant cereal genotypes under field conditions appears also as a difficult breeding task. The genetic factors for yield components are of most importance in wheat breeding and can be effectively used to improve the selection in

---

[1] Department of Plant Production, Technical University-Varna, Bulgaria.
[2] Aksakovo Center, 9154 Aksakovo, Varna, Bulgaria.
[*] Corresponding author; email: pspetsov@abv.bg

hybrid populations. One of the main characters accompanying domestication of bread wheat is the increase in grain number and size (Gegas *et al*., 2010). Mainly because of their effect on yield, increasing the two mentioned traits above continues to be a major selection and breeding target in modern hexaploid wheat (*Triticum aestivum* ssp. *aestivum* L.).

Broadening the genetic variability in wheat is the fundamental base in breeding of productive and adaptive varieties with high grain quality. Genetic resources of wild relatives are considered to have many valuable traits to improve the cultivated *Triticum* species. Synthetic Hexaploid Wheats (SHWs) resulting as products of wide hybridization, are involved in breeding of novel genetic lines and SHW-derived wheat varieties (Plamenov and Spetsov, 2011; Li *et al*., 2014). Genes of interest are being introgressed into common wheat by the 'bridge' of re-synthesized hexaploid (tetraploid wheats x *Aegilops tauschii)* as it has been occurred in the evolution of hexaploid wheat (Cooper *et al*., 2012).

Synthetic *D*-genome derived wheat resembles the bread wheat by the chromosome constitution (2n= 42), but 14 chromosomes originate from the wild diploid progenitor *Aegilops tauschii* (DD genomes). The addition of one set to BA^u-complement change the morphology of triploid hybrid, especially after duplication of its chromosome number. Significant variations have been reported in SHW including grain weight and morphology (Calderini and Ortiz-Monasterio, 2003; Kazi *et al*. 2012; Rasheed *et al*., 2014), bread-making quality (Pena *et al*., 1995), nutritional quality (Ram *et al*., 2010), resistance to biotic (Plamenov and Spetsov, 2011; Mulki *et al*., 2013) and abiotic stresses (Sohail *et al*., 2011; Ogbonnaya *et al*., 2013). Beneficial SHW traits such as large grains and high tiller number, were transferred into Sichuan varieties. Today, the synthetic-derived varieties 'Chuanmai-42', '-43', '-38' and '-47' are leading varieties and are now grown on more than 3,500 ha in China (Li *et al*., 2014).

This study conducted the selection for a number of breeding traits (field emergence, winter survival, grain number and kernel weight per main spike) in irradiated (treated seeds with γ-rays from a ^{60}Co gamma source, M_{1-4} generations) plants of three synthetic wheat (*Triticum dicoccum*/*Aegilops tauschii*) and their corresponding controls under field conditions. The objectives of this research were to: (i) Apply pureline selection for grain yield on the base of improved germination ability and winter growth in synthetic wheat populations, and (ii) Determine the effect of irradiation dose of 150 Gy gamma rays on several breeding traits in survived synthetic plants.

MATERIALS AND METHODS

Plant Material

The three investigated SHWs were derived from *Triticum dicoccum*/*Aegilops tauschii* and produced from the following crosses: No32, (F_1(44961/Zagorka/45432)/*Ae. tauschii* acc. 19089; No106, (F_2(44961/Zagorka/45432)/*Ae. tauschii* acc. 22744; No107, (45398/*Ae. tauschii* acc. 22744), made in the Dobroudja Agricultural Institute – General Toshevo through embryo culture (Spetsov *et al.,* 2009). Populations of Synthetic Hexaploid Wheat (SHW) originating from irradiated seeds with γ-rays in a dose of 150 Gy from a ^{60}Co gamma source (M-plants in M_1-$_3$) and their respective controls (N-plants in C_{1-4} and C_{2-5} generations), were grown in the field. The irradiation experiment was conducted in the Plant Breeding and Genetics Laboratory of the International Atomic Energy Agency (IAEA), Seibersdorf, Austria. Before irradiation, 20 plants from the three synthetics in C_1 and C_2 generations were chosen by seed productivity (at least 30 seeds per plant, divided in two parts - treated with gamma rays, and its corresponding control). During the first year (2010/2011), a large part of the materials was grown in the greenhouse. After that, all plants were sown and grown in the field.

Field Experiment

SHW progenies were grown in a crop rotation field in Varna (43º 12' N, 27º 54' E, 50 m), Bulgaria, during 2010-2014. The soil of the experimental site is haplic chernozem. Forage peas preceded and no fertilizers were applied. Weeds were controlled by herbicide glyphosate in early autumn. No other pesticides were applied during the plant growing seasons. The sowing dates were typical for Varna conditions, during October 10-20th. The seeds were manually planted on single-row plots at 20 seeds per row 1 m long and at an inter-row spacing of 40 cm using randomized design with two replications. The evaluation of germination was done in autumn at 1-2 leaf stage and the winter survival was calculated using all available plants for each family in the beginning of vegetation (March 15-April 15). The wheat parents of crosses and three varieties from the standard frost resistance scale -'Mironovskaya-808', 'Bezostaya-1' and No301, (Petrova *et al*., 2000)- were sown at regular intervals after every 25 rows.

Breeding Method

Pureline selection was applied in that individual plants were selected, their progeny were evaluated and the best three plants in derived progeny for grain number and kernel weight per main spike were selected and used to obtain the next generation (Baenziger and DePauw, 2009). Among the first 3-4 spikes per plant, the heaviest one (assessed by measuring) was chosen as a main spike. Each family obtained from a selected plant consisted of 20 seeds, sown in two replications. Response to selection was calculated as the difference between the mean phenotypic value of the progeny of a selected individual and the mean of the entire population before selection.

Meteorological Conditions

Meteorological factors in 2010-2014 are shown in Figure 1. In 2010-2011, the winter conditions were characterized by low precipitation level and cold weather during December-March. Snow depth on the field amounted to an average of 5 cm for the same period. The autumn winter seasons' conditions were characterized by a wet October, December and May, with a small snow cover and average minimum temperatures in winter. The temperature dropped below -17.0ºC in February 2012 and -10.4ºC in 2014. The temperature in October was optimal for the seed germination in the whole period. The winter conditions in 2010-2014 were very different concerning the presence of snow cover and duration of minimal freezing temperatures.

Rainfall varied between 280.5 mm in 2010-2011 and 527.6 mm in 2013-2014 (Figure 1). Usual rains dropped before the snowing in all seasons, but very week precipitation level occurred in Novembers. Heavy rains fell in December 2012, January and June 2014 which accelerated plant development. Snow was of small covering and varied from 1 to 9 cm in the period. The biggest snow was in December 2010 and 2013, and the thinnest blanket of snow was surveyed in 2011-2012. Concerning the four factors (average min t, average max t, rainfall and snowfall), the meteorological conditions were satisfactorily good for plant germination and growth to harvesting during the whole period.

Statistical Analysis

The data were statistically evaluated by analysis of variance to determine significant differences ($P< 0.01$ and $P< 0.05$) between

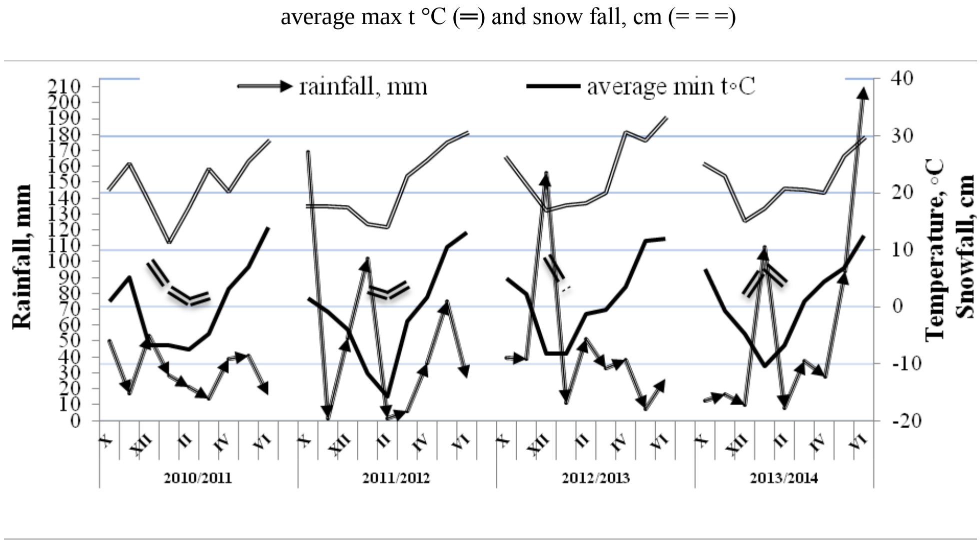

Figure 1. Climatic conditions for 2010-2014 years.

wheat genotypes with Tukey test using Assistat version 7.7 beta (www.assistat.com). Response (R) or advance in one generation of selection was calculated: $R= M_o–M_p= ih^2\sigma$ (Simmonds, 1979), where M_o is the mean phenotype of the offspring of selected plants, M_p the mean phenotype of the whole parental generation, h^2 the appropriate heritability, σ the phenotypic standard deviation of the parental population and i is the 'intensity of selection', a statistical factor that depends upon the selected portion of the population. Genetic advance in percent of the mean was estimated as: $GA\%= 100R/M_o$ (Singh and Chaudhary, 2004).

RESULTS

Germination and Winter Survival (2010-2014)

Data for field germination revealed differences among populations during the investigated period (Table 1). All progenies grown in the first year showed reduced germination ability, except those in 106- and 32-N plants. From 2011/2012 to 2013/2014, the tendency of germination was progressive in all synthetics. The largest differences were in populations' 107-N, 106-M, 106- and 32-N, ranging from 20 to 30% between germination values registered during the first and last year. Progenies obtained in each SHW from the irradiated seed (M-plants) did not show statistically proved differences from their respective controls. Thus, the irradiation of seeds with 150 Gy did not influence the germination of SHW in the field. In general, the small differences between investigated populations per year and the consecutive increasing values in the period indicated the positive role of pureline selection applied for improving the field emergence.

Table 2 represented the selection progress in amphiploid offsprings for plant survival during the four-year period and compared it to the performance of their wheat parents and frost resistant varieties. As in field emergence, large differences occurred in winter survival of SHW plants grown in 2011 and 2014. This fact clearly supported the heterogeneity of C_{2-3} seeds in wheat synthetics. Population 107-M was an exception from all other SHW in which plants did not differ in winter survival during the period of investigation. The difference between M- and N-plants was not statistically proved. A positive progress on this trait was observed in the last three years (2012–2014) since all populations were equal in 2014, displaying 95–98% plant survival. No effect of seed irradiation was found with 150 Gy on winter survival. The

Table 1. Field germination of six SHW populations in four years (2010/2011-2013/2014).[a]

SHW	2010	2011	2012	2013
107-M[b]	51.7 cd	70.3 abc	91.8 ab	95.9 a
107-N[c]	34.5 d	64.7 abcd	90.0 ab	97.3 a
106-M	60.3 bcd	69.2 abcd	92.1 ab	95.0 a
106-N	76.9 abc	72.1 abc	93.4 ab	93.8 a
32-M	75.7 abc	75.4 abc	90.7 ab	96.9 a
32-N	60.1 bcd	69.5 abcd	90.3 ab	98.2 a

[a] The letters note statistically significant (F= 7.9**, P< 0.0001) differences between the lines (smd= 35.0%) according to Tukey test.

[b] Plants obtained from irradiated seeds and propagated by selfing, [c] Controls.

Table 2. Winter survival of SHW populations in comparison with their wheat parents and standards. [a]

SHW/Parent/ Standard	2011	2012	2013	2014
107-M [b]	73.3 abcde	81.2 abcde	87.2 abcd	96.2 a
107-N [c]	54.4 bcde	86.7 abcd	84.5 abcd	95.3 a
106-M	51.1 cde	83.2 abcd	74.0 abcde	94.8 a
106-N	51.0 cde	82.6 abcde	68.0 abcde	95.0 a
32-M	43.6 e	81.7 abcde	79.7 abcde	95.1 a
32-N	49.4 de	83.4 abcd	77.4 abcde	94.3 a
No 45398	-	88.2 abcd	90.6 ab	94.7 a
No 45432	-	80.0 abcde	88.9 abcd	100.0 a
Mir 808	-	100.0 a	90.0 abc	100.0 a
Bez 1	-	100.0 a	90.0 abc	100.0 a
No 301	-	69.2 abcde	100.0 a	90.0 abc
Zagorka	-	-	100.0 a	93.0 ab

[a] The letters indicate statistically significant (P< 0.0001) differences between genotypes (smd= 39.2%) according to Tukey test.

Nos 45398, 45432, and winter wheat varieties ‘Mironovskaya-808’ (Mir 808), ‘Bezostaya-1’ (Bez1) and No 301 were grown in 3 years; Durum wheat ‘Zagorka’ was grown in 2 years; [b] Plants obtained from irradiated seeds and propagated by selfing, [c] Controls.

winter resistance of selected SHW progenies was compared to three wheat parents (durum variety ‘Zagorka’ was only grown in the last two years) and three cold resistant common wheat varieties (Table 2). Tetraploid parents No 45398 and 45432 showed the same tendency in plant survival (increase from 2012 to 2014), while the three cold standard varieties behaved differently. ‘Mironovskaya-808’ and ‘Bezostaya-1’ expressed a similar pattern in each year, but No 301 varied in winter resistance. The largest amount of plants from this variety survived in 2013 and the least in 2012. Pureline selection in the course of four years of investigation resulted in SHW-families with a high percentage of winter plant survival nearly equal to winter wheat used in the study.

Grain Number and Kernel Weight per Main Spike (2011–2013)

In total, 93 elite plants were selected for grain number and kernel weight from the six populations in 2011 (Table 3). A part of them (48 individuals) originated from the greenhouse. The elite plants yielded between 16 and 41 seeds per main spike as the highest values were in SHW32-N with mean of 31.8 and *VC*= 16.7%. The poorest seedset was

Table 3. Progress of pureline selection in SHW for grain number per main spike during three years (2011–2013).

SHW/ Group		2011					2012					2013				
		PG[c]	*SEP*[d]	Min-Max	Mean	*VC* (%)	PG	*SEP*	Min-Max	Mean	*VC* (%)	PG	*SEP*	Min-Max	Mean	VC (%)
107	M[a]	189 (138)[e]	18 (8)[e]	16 - 41	25.4	38.6	139	23	24 - 35	30.5	10.8	313	21	26 - 38	32.3	11.0
	N[b]	160 (150)	14 (11)	17 - 40	27.0	27.3	127	22	28 - 34	30.0	7.3	287	21	30 - 39	33.8	6.9
106	M	112 (78)	10 (5)	25 - 32	27.8	9.8	99	13	28 - 33	30.3	7.4	141	12	32 - 44	38.0	10.6
	N	122 (82)	11 (5)	25 - 29	26.9	8.4	100	13	27 - 32	29.5	6.9	129	12	35 - 47	37.8	9.1
32	M	159 (104)	20 (9)	23 - 36	28.6	15.4	179	24	27 - 34	31.3	8.3	301	24	34 - 42	37.1	5.2
	N	207 (125)	20 (10)	24 - 40	31.8	16.7	218	24	27 – 34	30.4	6.5	316	24	33 - 42	37.0	7.0
Total		949 (677)	93 (48)				862	119				1487	114			

[a] Plants obtained from irradiated seeds and propagated by selfing; [b] Controls; [c] Plants Grown in the field, [d] Selected Elite Plants. [e] In parentheses: Number of plants grown in greenhouse, and the selected individuals with highest grain number and kernel weight.

found in SHW107-M with mean of 25.4 and *VC*= 38.6%. In 2012, 119 SEPs (Selected Elite Plants) were settled, from which their performance was better for grain number than the previous year. Interestingly, all population means were almost equal, varying from 29.5 to 31.3 with lower coefficients of variation (6.5-10.8). SEP of 114 were chosen in the third year and the population means were larger (between 32.3 in 107-M and 38.0 seeds in 106-M) than those in 2012. Means of M- and N-families in each SHW were not statistically different. The largest seedset in the main spike with 47 grains was found in 106-N and this was the most distinctive value for this trait. Ten lines were determined in 2013 to have the highest seedset per main spike, ranging from 35 to 42 grains with high values of KW (Table 4). The most yielding families were selected in SHW106 (lines 11N, 11M and 12M).

Parallel progress during selection was also achieved for Kernel Weight (KW). In 2011, the SEP means varied from 0.95 to 1.22 g and increased to 1.2-1.5 and 1.69-1.92 in 2012 and 2013, respectively (Table 5). Coefficients of variation were largest in the first year (19.8-51.3) and the smallest in 2013 (8.6-13.4). As in grain number, differences between means for M- and N-populations were not statistically proved. Genetic parameters for grain number and kernel weight in selected lines are shown in Table 6. Five lines of SHW107 expressed

Table 4. SHW lines with highest values for Grain Number (GN) and Kernel Weight (KW) per main spike in 2013.

SHW	Line	GN	KW
107	13N[a]	35	1.08
	15N	35	1.18
	15M[b]	38	1.25
106	11N	39	1.12
	11M	42	1.44
	12M	40	1.41
32	17N	40	1.25
	17M	38	1.18
	18N	40	1.12
	21M	39	1.20

[a] Controls, [b] Plants obtained from irradiated seeds and propagated by selfing.

Table 5. Progress in selection for kernel weight during three years (2011-2013).

SHW Group	2011			2012			2013		
	Min-Max	Mean	*VC* (%)	Min-Max	Mean	*VC* (%)	Min-Max	Mean	*VC* (%)
107 M[a]	0.65-2.1	1.14	51.3	1.2-1.8	1.47	15.4	1.61-2.1	1.84	9.3
N[b]	0.68-2.1	1.22	35.0	1.4-1.7	1.5	7.3	1.66-2.1	1.92	8.6
106 M	0.93-1.4	1.07	19.8	1.2-1.4	1.27	9.1	1.48-2.0	1.82	13.4
N	0.75-1.3	0.95	23.6	1.1-1.4	1.2	9.8	1.45-1.9	1.7	11.0
32 M	0.81-1.6	1.17	26.7	1.01-1.6	1.24	15.7	1.48-1.9	1.69	9
N	0.64-1.7	1.18	37.7	1.01-1.5	1.2	14.4	1.48-2.1	1.7	11.5

[a] Plants obtained from irradiated seeds and propagated by selfing, [b] Controls.

Table 6. Genetic parameters for SHW lines (in M_3 and C_{4-5} generations) with positive response to selection in 2013.

SHW/Line	Grain number			Kernel weight		
	R[d]	*GA*[e] *%*	h^2[f]	*R*	*GA%*	h^2
SHW107 2M[a]	1.8	8.0	18.1	0.14	12.8	24.5
2N[b]	0.7	3.1	5.1	0.07	6.3	8.5
3M	3.6	15.8	39.6	0.22	19.8	44.1
14M	-	-	-	0.12	12.6	21.4
15M	2.6	10.0	19.8	0.14	10.4	17.0
Average	**2.2**	**9.2**	**20.7**	**0.13**	**12.4**	**23.1**
SHW106 5M	5.1	19.2	56.0	0.26	24.5	49.6
5N	6.2	22.1	70.3	0.28	25.7	66.9
6N	8.7	30.9	84.1	0.33	31.7	57.3
11M	3.5	10.3	46.1	0.19	13.2	35.5
11N	1.1	4.0	13.4	0.06	5.4	14.3
12M	6.1	19.4	71.4	0.28	20.6	53.9
12N	6.7	20.7	68.7	0.24	18.0	47.0
Average	**5.3**	**18.1**	**58.6**	**0.23**	**19.9**	**46.4**
SHW32 7M	6.2	22.4	60.6	0.36	31.0	58.4
7N	6.0	20.4	51.0	0.40	32.3	58.1
M8M[c]	4.8	15.8	28.4	0.31	24.2	34.5
8N	3.7	12.5	33.1	0.30	25.0	45.0
9M	3.7	13.1	34.1	0.27	22.7	44.7
9N	6.3	21.8	45.5	0.36	30.5	52.2
10M	4.6	16.6	47.5	0.24	22.0	41.1
10N	3.7	14.0	33.5	0.22	20.4	35.5
17M	0.8	2.8	8.0	0.01	0.8	1.6
17N	4.6	14.6	58.7	0.19	15.2	40.2
18M	7.4	26.7	91.1	0.14	15.6	36.6
18N	3.5	11.8	32.8	0.04	3.6	7.1
20M	3.2	11.2	26.4	0.18	15.7	27.2
20N	4.0	14.4	39.3	0.04	3.7	6.4
21M	5.8	19.6	64.8	0.25	20.8	48.3
21N	2.1	7.8	29.4	0.03	2.8	6.8
Average	**4.4**	**15.3**	**42.8**	**0.21**	**17.9**	**34.0**

[a] Plants obtained from irradiated seeds and propagated by selfing, [b] Controls; [c] Mutant line, selected in M_2 by its different plant habit and spike structure; [d] Response to selection; [e] Genetic advance as a percent of mean, [f] Heritability in percentage.

positive response to selection (R) except line 14M. The averaged *R* was 2.2 grains with 9.2 and 20.7% for *GA* and h^2, respectively. As expected, *KW* parameters were also of positive values. Seven lines of SHW106 had the highest R of 5.3 grains as compared to the other two SHW. Averaged *GA* (18.1%) and h^2 (58.6%) for the grain number, as well as the *KW* parameters, were also largest in the study. Sixteen lines of SHW32 from all 18 families studied, including one mutant line M8M, showed *R* between 0.8 and 7.4 grains. All genetic parameters of this synthetic line were in between SHW106 and 107. Line 18M displayed superior indications for grain number (7.4, 26.7 and 91.1) in contrast to its KW values with medium expression (Table 6).

Analysis of variance involving the three best yielding plants from each line per SHW harvested in 2013, executed different results (Table 7). The most productive were all eight lines of SHW106, producing 35 – 42 grains per main spike. Two lines from SHW32 (17N and 18N) also showed high seedset, 40 seeds per spike, which differed statistically from the rest by significant minimum difference (smd) of 5.2 grains. Line 15M in SHW107 was only prominent for grain number with 38 seeds per spike.

DISCUSSION

The primary synthetics reveal poor agronomical value since they are difficult to thresh, and they are generally tall and low-yielding (Mujeeb-Kazi *et al*., 2008). To date, SHW exposed significant new variation for morphological and agronomic traits (Villareal *et al*., 1994; Lage *et al*., 2006; Plamenov and Spetsov, 2011; Cooper *et al*., 2012). In our experiment, the selected lines showed a lower level of winter survival than the standard varieties 'Bezostaya-1' and 'Mironovskaya-808' (Table 2). From the three tetraploid parents, No45398, expressed better performance of plant survival rate during the period of investigation as compared to SHW and wheat No. 301, Emmer wheat acc.45398 was estimated to have adequate frost resistance (25% survived plants at -16°C (Plamenov *et al*., 2008). During the hard winter in 2011/2012 (average min t reached -17°C in February with a scanty snow layer), SHW and their parents survived better than No. 301 wheat. As a result of selection, in 2014, synthetic lines expressed better winter survival than No. 301. but lower than 'Mironovskaya-808'. SHW populations derived from irradiated seeds (designated as M) were almost equal to controls, and the differences between them were not significant on this trait. Mujeeb-Kazi *et al*. (1996) evaluated that SHW derived from *T. turgidum*/*Ae. tauschii* crosses as plants with spring habit, while in this experiment, SHWs were classified to have intermediate type of

Table 7. Analysis of variance in the SHW by using the best three plants for grain number in each family (line) harvested in 2013.

SHW/Line/Group		Mean	*Smd* [a]	*F* [b]	*P*	*VC* [c] (%)
SHW107	15M	37.7a [d]	7.1	3.1**	0.0057	7.19
	11 lines	32 – 35.3ab				
	4M, 19M	28.3 – 29b				
SHW106	8 lines	34.7 – 41.7a	9.8	1.4ns	0.2858	9.18
SHW32	17N, 18N	39.7 – 40a	5.2	3.2**	0.0027	4.66
	12 lines	35.3 – 39.3ab				
	7N, 10N	34.3b				

[a] Significant minimum difference according to Tukey test; [b] Statistics of the test; [c] Variation Coefficient in percentage, [d] Means followed by the same letter are not significantly different.** Significative at a level of 1% of probability (P< 0.01).

growth in winter. Bazhenov *et al*. (2015) used field emergence and winter survival as counting all available plants from each family to reveal the effect of 2D(2R) substitution on plant height and yield components in winter triticale. Cooper *et al*. (2012) recorded poorer performance of hybrid plants in environments with harsh winters due to a lack of winter-hardiness in the primary synthetics involved in crosses with bread wheat.

Genetic variability is essential in order to realize response to selection pressure as the estimation of genetic parameters of variation are specific for a particular population and the phenotypic expression of the quantitative character may be altered by environmental stress. The utility of ionizing radiation was best exemplified in wheat breeding. Czyczylo-Mysza *et al*. (2013) irradiated dry seeds of winter wheat cv. ‘Kobra’ with 300 Gy radiation from a cobalt 60 gamma irradiator and found no clear effect on germination and vernalization requirements of plants in M_1 and M_2 generations. Similar results were previously reported by Borzouei *et al*. (2010). Lai *et al*. (2014) demonstrated that ^{60}Co gamma irradiation caused HMW-GS variation in wheat ‘Vortex 9722’ and found some mutated glutenin loci. Information on applying irradiation in synthetic wheat is limited. Using radiation dosages of 350 and 450 Gy for seed irradiation of synthetic hexaploid wheat, Kumar *et al*. (2012) crossed the survived plants to durum wheat to produce radiation hybrid plants for mapping gene based markers. We involved dose of 150 Gy from a ^{60}Co gamma source as a lack of information for minimal doses of irradiation in SHW. Future experiments could be initiated with synthetic wheat plants with double dose (300 Gy) or more due to results obtained recently in common wheat (Kumar *et al*., 2012; Czyczylo-Mysza *et al*., 2013; Cheng *et al*., 2015).

The estimation of heritability and genetic advance as percentage mean considered together will no doubt help in drawing conclusion about the nature of gene action governing a particular character. Seven lines of SHW106 had the highest R of 5.3 grains in the study. Averaged GA (18.1%) and h^2 (58.6%) for the grain number, as well as the kernel weight’ parameters, were also largest in the investigation. All the genetic parameters were in between SHW106 and 107. Earlier, Mujeeb-Kazi *et al*. (2000) differentiated an Elite-1 subset from a wide array of CIMMYT’s synthetic hexaploids produced possessing an agronomically grown habit under three Mexican locations. Up to date, no data have been published for estimating the genetic factors of SHW in breeding. Studies on the variance and genetic parameters for different traits in wheat revealed low heritability values in narrow sense and expected genetic advance, but very high genetic values for grain yield/plant and straw yield/plant (Badran and Moustafa, 2015).

Erkul *et al*. (2010) pointed that selection in the advanced generations might be effective for a number of kernels per spike, number of kernels per spikelet, thousand kernel weight and grain yield. Ten elite lines have been selected in this study with high breeding traits, Grain Number (GN, between 35-42 seeds) and Kernel Weight (KW) per main spike (between 1.08 and 1.44 g, Table 4). Based on the best three plants for *GN* and *KW* selected from each family in 2013, the analysis of variance showed significant differences among elite families except for lines in SHW106 (Table 7). These results indicated the potential of a subsequent selection procedure (after C_5 and M_4 generations) for the *GN* in SHW32 and 107. Badran and Moustafa (2015) investigated 17 wheat parents and their 30 F_1 progenies to estimate several breeding traits, including the number of grains per spike. They found a medium level of expression for heritability and expected genetic advance, 0.36 and 22.97, respectively. In Table 6, mean values for h^2 and the genetic advance were different from the results published in common wheat.

The significance of SHW’s traits (field emergence, winter hardiness, grain per head, etc.) for wheat improvement was noticed by Cooper *et al*. (2012), investigating synthetic BCF_4 and BCF_5 populations. Authors stated that improved yield could result from selecting for an increased number of heads per unit area and grains per head in lines derived from synthetic populations. This study provides quantitative results for three SHW from the cross *Triticum dicoccum/ Aegilops tauschii* and information that will help optimize it in the future.

CONCLUSIONS

Comparison of SHW selected populations (M_{1-3}) derived from irradiated seeds with 150 Gy gamma rays with their corresponding controls, did not show any significant differences in field emergence and plant survival during winters of 2010–2014. Plant variation was maximum during the first year and two families which derived from SHW107 froze completely. Advancing of generations by pureline selection led to improvement of winter survival in SHW as the selected lines were equalized to winter wheat varieties 'Mironovskaya-808' and 'Bezostaya-1' in the fourth year. The realized gains during the selection for increased grain/spike were 15.3, 18.1 and 9.2% for SHW32, 106 and 107, respectively. Pureline selection was found efficient for grain number and kernel weight per main spike for 27 M_3 and C_{4-5} derived lines. A subset of 10 lines with 35–42 seeds and 1.08–1.44 g per main spike was finally extracted from all 38 families and considered the best synthetic lines for wheat breeding program.

REFERENCES

1. Badran, A. E. and Moustafa, E. S. A. 2015. Genetic Parameters of Some Wheat (*Triticum aestivum* L.) Genotypes Using Factorial Mating Design. *J. Agr. Sci.*, **7**: 101-105.
2. Baenziger, P. S. and DePauw, R. M. 2009. Wheat Breeding: Procedures and Strategies. In: "*Wheat Science and Trade*", (Ed.): Carver, B. F. Wiley–Blackwell, Oxford, UK.
3. Bazhenov, M. S., Divashuk, M. G., Kroupin, P. Y., Pylnev, V. V. and Karlov, G. I. 2015. The Effect of 2D(2R) Substitution on the Agronomical Traits of Winter Triticale in Early Generations of Two Connected Crosses. *Cereal Res. Commun.*, **43 (3)**: 504-514.
4. Borzouei, A., Kafi, M., Khazaei, H., Naseriyan, B. and Majdabadi, A. 2010. Effects of Gamma Radiation on Germination and Physiological Aspects of Wheat (*Triticum aestivum* L.) Seedlings. *Pak. J. Bot.*, **42 (4)**: 2281-2290.
5. Calderini, D. F. and Ortiz-Monasterio, I. 2003. Are Synthetic Hexaploids a Means of Increasing Grain Element Concentrations in Wheat? *Euphytica*, **134**: 169-178.
6. Cheng, X., Chai, L., Chen, Z., Xu, L., Zhai, H., Zhao, A., Peng, H., Yao, Y., You, M., Sun, Q. and Ni, Z., 2015. Identification and Characterization of a High Kernel Weight Mutant Induced by Gamma Radiation in Wheat (*Triticum aestivum* L.). *BMC Genet.*, **16**: 127.
7. Cooper, J. K., Ibrahim, A. M. H., Rudd, J., Malla, S., Hays, D. B. and Baker, J. 2012. Increasing Hard Winter Wheat Yield Potential *via* Synthetic Wheat: I. Path-coefficient Analysis of Yield and Its Components. *Crop Sci*., **52**: 2014-2022.
8. Czyczylo-Mysza, I. M., Marcinska, I., Jankowicz-Cieslak, J. and Dubert, F. 2013. The Effect of Ionizing Radiation on Vernalization, Growth and Development of Winter Wheat. *Acta Biol. Cracov. Bot.*, **55 (1)**, 23-28.
9. Erkul, A., Unay, A. and Konak, C. 2010. Inheritance of Yield and Yield Components in a Bread Wheat (*Triticum aestivum* L.) Cross. *Turk. J. Field Crop.*, **15 (2)**: 137-140.
10. Gegas, V.C., Nazari, A., Griffiths, S., Simmonds, J., Fish, L., Orford, S., Sayers, L., Doonan, J.H., Snape, J.W. 2010. A Genetic Framework for Grain Size and Shape Variation in Wheat. *The Plant Cell*, **22**: 1046-1056.
11. Kazi, A.G., Rasheed, A., Mahmood, T. and Mujeeb-Kazi, A. 2012. Molecular and Morphological Diversity with Biotic Stress Resistance of High 1000-grain Weight Synthetic Hexaploid Wheats. *Pak. J. Bot.*, **44**: 1021-1028.

12. Kumar, A., Simons, K., Iqbal, M.J., de Jimenez, M.M., Bassi, F.M., Ghavami, F., Al-Azzam, O., Drader, T., Wang, Y., Luo, M.C., Gu, Y.Q., Denton, A., Lazo, G.R., Xu, S.S., Dvorak, J., Kianian, P.M.A. and Kianian, S.F. 2012. Physical Mapping Resources for Large Plant Genomes: Radiation Hybrids for Wheat D-genome Progenitor *Aegilops tauschii*. *BMC Genom.*, **13**: 597.
13. Lage, J., Skovmand, B., Pena, J. and Andersen, S. B. 2006. Grain Quality of *Triticum dicoccum* x *Aegilops tauschii* Derived Synthetic Hexaploid Wheats. *Genet. Resour. Crop Evol.*, **53**: 955-962.
14. Lai, D. E., Wang, M. and Zhang, C. Y. 2014. Quality Trait Variations in ^{60}Co-irradiated Wheat and High-Molecular-Weight Glutenin Subunit Mutant Identification. *Genet. Mol. Res.*, **13(4)**: 9024-9031.
15. Li, J., Wan, H. and Yang, W. 2014. Synthetic Hexaploid Wheat Enhances Variation and Adaptive Evolution of Bread Wheat in Breeding Processes. *J. Syst. Evol.*, **52**: 735-742.
16. Mulki, M. A., Jighly, A., Ye, G., Emebiri, L. C., Moody, D., Ansari, O. and Ogbonnaya, F. C. 2013. Association Mapping for Soilborne Pathogen Resistance in Synthetic Hexaploid Wheat. *Mol. Breed.*, **31**: 299-311.
17. Mujeeb-Kazi, A., Rosas, V. and Roldan, S. 1996. Conservation of the Genetic Variation of *Triticum tauschii* (Coss.) Schmalh. (*Aegilops squarrosa* auct. Non L.) in Synthetic Hexaploid Wheats (*T. turgidum* L.×*T. tauschii*, 2n= 6x= 42, AABBDD) and Its Potential Utilization for Wheat Improvement. *Genet. Resour. Crop Ev.*, **43**: 129-134.
18. Mujeeb-Kazi, A., Fuentes-Davila, G., Delgado, R., Rosas, V., Cano, S., Cortés, A., Juarez, L. and Sanchez, J. 2000. Current Status of *D*-Genome Based Synthetic Hexaploid Wheats and the Characterization of an Elite Subset. *Ann. Wheat Newsl.*, **46**: 76-79.
19. Mujeeb-Kazi, A., Gul, A., Farooq, M., Rizwan, S. and Ahmad, I. 2008. Rebirth of Synthetic Hexaploids with Global Implications for Wheat Improvement. *Austr. J. Agr. Res.*, **59**: 391-398.
20. Ogbonnaya, F. C., Abdalla, O., Mujeeb-Kazi, A., Kazi, A.G., Xu, S. S., Gosman, N. and Tsujimoto, H. 2013. Synthetic Hexaploids: Harnessing Species of the Primary Gene Pool for Wheat Improvement. *Plant Breed. Rev.*, **37**: 35-122.
21. Pena, R.J., Zarco-Hernandez, .J and Mujeeb-Kazi, A. 1995. Glutenin Subunit Compositions and Bread Making Quality Characteristics of Synthetic Hexaploid Wheats Derived from *Triticum turgidum*×*Triticum tauschii* (coss.) Schmal Crosses. *J. Cereal Sci.*, **21**: 15-23.
22. Petrova, T., Kostov, K., Penchev, E. 2000. Frost Resistance of *T. aestivum* L. Varieties from Different Geographical Origin. *Bulg. J. Agric. Sci.*, **6**: 133-138.
23. Plamenov, D. and Spetsov, P. 2011. Synthetic Hexaploid Lines are Valuable Resources for Biotic Stress Resistance in Wheat Improvement. *J. Plant Pathol.*, **93 (2)**: 251-262.
24. Plamenov, D., Kiryakova, V., Petrova, T. and Spetsov, P. 2008. Characterization of *Triticum turgidum* ssp. *dicoccon* Accessions as Sources for use in Common Wheat Breeding. *Plant Sci.*, **45**: 99-106. (in Bg)
25. Plamenov, D., Belchev, I., Daskalova, N., Spetsov, P., and Moraliyski, T. 2013. Application of a Low Dose of Gamma Rays in Wheat Androgenesis. *Arch. Biol. Sci.*, **65 (1)**, 291-296.
26. Prášil, I. T., Prášilová, P. and Pánková, K. 2004. Relationships among Vernalization, Shoot Apex Development and Frost Tolerance in Wheat. *Annal. Bot.*, **94**: 413-418.
27. Ram, S., Verma, A., Sharma, S. 2010. Large Variability Exits in Phytase Levels Among Indian Wheat Varieties and Synthetic Hexaploids. *J. Cereal Sci.*, **52**: 486-490.
28. Rasheed, A., Xia, X., Ogbonnaya, F., Mahmood, T., Zhang, Z., Mujeeb-Kazi, A. and He, Z. 2014. Genome-Wide Association for Grain Morphology in Synthetic Hexaploid Wheats Using Digital Imaging Analysis. *BMC Plant Biol.*, **14**: 128.
29. Simmonds, N. W. 1979. Principles of Crop Improvement. Longman Inc. Publisher, New York, USA.
30. Singh, R. K. and Chaudhary, B. D. 2004. *Biometrical Methods in Quantitative Genetic Analysis*. Kalyani Publishers, New Delhi, India.
31. Sohail, Q., Inoue, T., Tanaka, H., Eltayeb, A.E., Matsuoka, Y. and Tsujimoto, H. 2011. Applicability of *Aegilops tauschii* Drought Tolerance Traits to Breeding of Hexaploid Wheat. *Breed. Sci.*, **61**: 347-357.

32. Spetsov, P., Plamenov, D. and Belchev, I. 2009. Breeding of Synthetic Wheats: Analysis of Amphidiploid Plants Obtained with *Aegilops tauschii* Coss. *Field Crop. Stud.*, v. v-**2:** 207-216. (in Bg)
33. Villareal, R. L., Mujeeb-Kazi, A., Del Toro, E., Crossa, J. and Rajaram, S. 1994. Agronomic Variability in Selected *Triticum turgidum*×*T. tauschii* Synthetic Hexaploid Wheats. *J. Agron. Crop Sci.*, **173:** 307-317.

واکنش ها به انتخاب برای بقای زمستانه و عملکرد در جمعیت های مختلف گندم های هگزاپلوئیدی مصنوعی (***Triticum dicoccum / Aegilops tauschii***)

ن. داسکالوا، و پ. اسپتسو

چکیده

انتخاب خالص در گیاهان مصنوعی هگزاپلوئید گندم (SHW) به دست آمده از دانه های اشعه دهی شده با اشعه های گاما ۱۵۰ G انجام شد و و با شاهد مربوطه مقایسه شد. انتخاب در نسل های ۲۰ گیاه اولیه از سه amphiploids (۸ از SHW32، SHW10 - 4 , و SHW107 - 8)، تولیدکننده لاین های ۱۹ M1-3 و ۱۹ C2-5 انجام شد. در سال اول، دو خانواده در زمستان زنده نماندند. تمام خطوط انتخاب شده جوانه زنی بالا، رشد متوسط در زمستان و مجموعه بذرهای خوب در شرایط مزرعه ای را نشان دادند. اشعه دهی به دانه ها بر جوانه زنی و بقای زمستانه گیاهان SHW تأثیر نگذاشت. واکنش به انتخاب مستقیم بر اساس میانگین عملکرد متوسط نتاج برای تعداد دانه و وزن دانه در سنبله اصلی و گیاهان برتر انتخاب شده در نسل های M3 و C4-5 بود. ضریب وراثت پذیری و پیشرفت ژنتیکی برای این صفات ابتدا در SHW106 و بعدSHW32 بیشتر بود. SHW107 بزرگترین تنوع مورفولوژیکی و عقیمی در طول دوره مورد بررسی نشان داد. تمام مصنوعی ها گوش های بلند اما تنکی تشکیل دادند و حاصلخیزی دانه ها در آن ها نسبت به والد تتراپنوئیدکمتر بود، اما گیاهان برتر SHW32 و ۱۰۶ با والد تتراپلوئید No45432 در سال ۲۰۱۳ در وزن دانه در سنبله اصلی برابر بودند. تابش دانه با اشعه های گاما ۱۵۰ یک ژن هیچ تأثیری بر دو صفت تحقیق شده نکرد. زیر مجموعه ای از ۱۰ خط از سه amphiploids منبعی از باروری spike برای استفاده در برنامه های اصلاح گندم به منظور افزایش پتانسیل عملکرد نشان داد.