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Effects of Gamma Rays on Bread Wheat (*Triticum Aestivum L.*), Cultivar "Zakia" for Grain Attributes and Rust Resistance

Modather Galal Abdaldiem Abdalla*; Abbas Mohamed Suliman; Izzat Seidahmed Ali Tahir; Hashim Abdelkareem Ibrahim Mohammed

Agricultural Research Corporation, P.O. Box 126,Wad Medani, Sudan

***Corresponding Author(s): Modather Galal Abdaldiem Abdalla**

Agricultural Research Corporation, P.O. Box 126,Wad Medani, Sudan

Email: modatherarc@yahoo.com

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Abstract

Wheat (*Triticum aestivum* L.) is basic stable among cereals in the world. It is a main source for essential calories and protein, supplying more than 75% of protein and 56% of calories in human diet [1]. In the Sudan wheat is the most important crop comes after sorghum. Improved varieties to wide range of agro-ecologies are more essential to enhance wheat productivity and increasing yield. Seven doses of gamma rays (0, 150, 300, 450, 600, 750 and 900 gray) have been used to irradiate one Kg seeds of cultivar Zakia in 2013 in Sibersdorve laboratory to induce mutation. In this study fifty lines of Zakia derivatives including three checks were evaluated over two consecutive seasons (2016/ 17 and 2017/18) at two locations, vis. Dongola and New Halfa Research Station Farms of the Agricultural Research Corporation (ARC)- Sudan. Parallel 174 of Zakia progenies were screened for stem and leaf rust over two seasons under disease pressure in New Halfa. The objectives were to evaluate these mutant lines under different conditions for grain yield and its related attributes. In addition to, study their resistance to leaf and stem rusts. Significant differences among mutant lines were found for most of the traits studied for each season and combined. The combined analysis indicated that high significant differences ($P \leq 0.01$) were found on days to heading, harvest index and biomass (at $P \leq 0.01$). Significant difference was found on grain yield ($P \leq 0.05$) but no significant effect was observed on days to maturity, plant height, spike / m^2, no. of grains / spike and thousand grain weight. Sixteen mutant lines were performed better than the check Zakia on their grain yields. Seven mutant lines (No. 324, 333, 336, 356, 357, 388 and 410) have a resistance to stem and leaf rusts. The lines numbers 11 (333) and 16 (356) were improved for grain yield and rust resistance.

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Introduction

Wheat is a major grain crop of the world and is the stable food of millions of people globally. This crop is widely adapted to wide range of climatic conditions. It has many uses such as bread making, chapattis, cakes, biscuits, cookies and many other confectionary items are prepared from wheat.

Wheat in Sudan is the most important crop comes after sorghum. Wheat demand is increasing yearly due to population densities, change in habits and increase per capita consumption. Improving wheat productivity is more essential to fill the gap between production and consumption. Many constrains are facing wheat breeder in Sudan such as heat stress, salinity, short duration and rust diseases. Successful breeding activities have been done to solve these problems through introduced wheat materials, crossing, and double haploid technique. One of wheat challenges in Sudan is narrow genetic diversity because wheat is a temperate crop introduced to Sudan early times. Looking for faster new method such as mutation breeding is important to increase genetic variability. Mutations are the primary source of all genetic variations existing in any organism, including plants. Mutation breeding involves the development of new varieties by generating and utilizing genetic variability through chemical and physical mutagenesis. It is now a pillar of modern plant breeding, along with recombinant breeding and transgenic breeding [2].

Average yield of wheat crop in Sudan is generally low due to many reasons including production and environmental factors. These limiting factors such as heat stress, cultivars, nutrients, cultural practices and biological factors. Rust disease is one of the major constrains of wheat production especially in eastern Sudan where wheat has been expanded to that new area in the second half of the last century. Thus developing wheat cultivars tolerance or resistance to diseases (stem and leaf rusts) are of paramount importance in determining the final wheat grain yield. The main objective of this study is evaluate some mutant lines derived from cultivar Zakia for its grain yields across the two contrasting areas in Sudan Dongola (Normal condition) and New Halfa (Rust disease infection). Secondly identification of tolerant or resistant lines to stem and leaf rusts under disease pressure only in Eastern Sudan (New Halfa scheame).

Methodology

The International Atomic Energy Agency (IAEA) supported the development of mutant lines derived from bread wheat cultivar (Zakia). This cultivar was classified as moderately resistant to moderately susceptible to stem rust disease and high grain yield. One Kg seeds were divided and treated with physical mutation (gamma ray) in Seibersdorf laboratory- Austria 2013. Seven doses have been used to induce mutations (150, 300, 450, 600, 700 and 750 and 900 gray). The M1 seeds were planted in season 2013 /14 at Shambat Research Station Farm. M2 seeds were sown at Dongola Research Station Farm in 2014 /15. Two sets of M3 lines were planted at New Halfa Research Station Farm (under rust disease pressure) and at Dongola Research Farm (Traditional wheat areas) in season 2015 / 2016. Two yield trials were assembled Zakia derivative lines depending on their agronomic performance to planted at the two locations (Dongola and New Halfa) for the two seasons (2016 / 17 and 2017 /18. The set was consisting of fifty lines including three checks Bohain, Imam and Zakia. Dongola Research Station Farm (high terrace) is located within Latitude 19◦ - 10◦ N and Longitude 29◦ - 30◦ E. Soil was described as sandy clay loam in texture, deficient in nitrogen and phosphorus as well as low in organic matter. The pH of soil is 7.6 [3]. The second experimental site New Halfa Research Station Farm lies in North East of New Halfa town (Latitude 15◦ N and Longitude 35◦ E). Generally, the mean maximum temperature of the hottest month (May) is 42.5 C° and the mean minimum temperature (January) is 14.1C°.The relative humidity of the air is high during the peak of the rainy season and low from November (New Halfa meteorological station, 1999). Soil is heavy clay textured soil with clay content less than 60%. The yield trials were laid in alpha lattice design with four replications. Five lines were planted in each sub-plot. The planted area of each plot was four rows, 2.5m length and 0.2 apart. Parallel 174 mutant lines derived from Zakia (including fifty lines selected to use in a trial) were screened for rust diseases only in New Halfa, seasons (2016/17 and 2017/18). The net area was one meter long (0.2 m^2). Each fifteen lines were surrounded by a mixture of susceptible variety (Baladi type) and were artificially inoculated at panicle initiation stage using a mixture of stem and leaf rusts urediospores. The disease intensity was recorded as disease severity (percentage of rust infection on the plant) and plant response (type of infection) following an international standardized method of evaluation.

The following type of infections was used:

0 = Immune

R = Resistant (minute uredia surrounded by distinct necrotic areas)

MR= moderately resistant (small to medium uredia surrounded by chlorotic or necrotic areas)

MS = moderately susceptible (medium uredia, no necrosis but chlorotic areas may present)

S = Susceptible (large uredia, no necrosis)

Tr = trace infection

The data was subjected to Analysis of Variance (ANOVA) by using the software Genestat 13th edition. The Least Significant Differences (LSD) test at 5% level of probability procedure was used to determine differences between treatments. The statistical analysis was conducted for each location in each year to test significant differences among lines. Each season and location was considered as an environment. The top twenty five yielding lines including three checks with their disease reactions were presented in **Table 1**.

Results and discussion

The combined analysis of Zakia mutant yield trials across the two seasons and the two locations showed highly significant differences due to environment effects for all the traits studied including yield **(Table 2)**. Highly significant differences were found on days to heading, plant height, Spikes / m^2, grains per spike, thousand grain weight, harvest index, biomass and grain yield. Days to maturity is only trait had no significant effects. The effect of genotypes was highly significant differences ($P \leq 0.01$) for days to heading, harvest index and biomass. Grain yield was affected significantly ($P \leq 0.05$). No significant differences between progenies and three checks on days to maturity, plant height, spikes / m^2, grain / spike and thousand grain weight. The interactions between genotypes and environments showed that no significant differences for all the traits studied except harvest index where high significant difference was found.

Genotype by environment interactions is of great interest when evaluating the plant materials under different environmental conditions. The reliability of genotype performance across different environmental conditions can be an important consideration in plant breeding, and breeders are primarily concerned with high yielding and stable cultivars as possible since cultivar development is a time consuming and endeavor. A successfully developed new cultivar should have stable performance and broad adaptation over a wide range of environments. The results showed that grain yield was affected significantly due to genotypes and environment but, in their interactions had no significant effects. Among Zakia derivatives significant differences were found on days to heading, harvest index, biomass and grain yield due to genotype effects. This results in same line with that found by [4,5] whom reported that variations in various traits have been done due to mutation.

Grain Yield (t/ha)

The analysis of variance presented in **Table 2** of Zakia mutant lines were showed that grain yield was affected significantly (P ≤ 0.01) at New Halfa season (2017/18). No significant differences were found on grain yield at Dongola in both seasons (2016/17 and 2017/18) season 2017/18 and New Halfa. In combined grain yield was affected significantly (P ≤ 0.05). The grand mean of grain yield of top twenty five yielding lines was (4.7 and 2.788 t/ha) at Dongola while, New Halfa was (3.132 and 1.985 t/ha) for the two seasons, respectively. Decreasing trend on grain yield was found at New Halfa for both seasons due to many reasons such as rust disease and high temperature compared with other location which has been classified as normal conditions and free of rust diseases.

In combined, the two checks Imam and Bohaine are superior on grain yield while, sixteen mutant lines were ranking over the third check Zakia. The highest progenies over the check Zakia were ranging from (3.465 t/ha) obtained by the line number 17 to (2.995 t/ha) obtained by the line number 11.

Table 1: Top yielding lines of Zakia derivatives with their treated doses and their reactions to stem and leaf rusts.

Ent	Source	Gamma Doses	Intensity %	
		(Gray)	Stem rust	Leaf rust
1	Zakia	0 (Check)	20 MS-S	20 MS-S
2	Bohaine	0 (Check)	30 MS-S	20 MS-S
3	Imam	0 (Check)	40 MS-S	30 MS-S
4	291	150	10 MR-MS	20 MR-MS
5	296	150	10 MS-S	tr MS-S
6	303	150	20 MS-S	10 MS-S
7	304	150	10 MS-S	20 MS-S
8	306	150	10 MS-S	tr MS-S
9	307	150	30 MS-S	tr MR-MS
10	313	150	10 MS-S	tr MR-MS
11	333	600	tr MR-MS	tr MR
12	340	600	10 MS-S	tr MR-MS
13	341	600	20 MS-S	20 R-MR
14	346	600	10 MS-S	10 R-MR
15	351	600	10 MS-S	tr MR-MS
16	356	600	10 MR-MS	tr MS-S
17	361	600	10 MS-S	tr R-MR
18	362	600	30 MS-S	10 MS-S
19	370	600	20 MS-S	10 MR-MS
20	382	750	20 MS-S	10 MR-MS
21	389	750	10 MR-MS	tr R-MR
22	404	750	20 MS-S	tr MR
23	413	900	30 MS-S	tr MR-MS
24	430	900	20 MS-S	10 MS-S
25	431	900	30 MS-S	tr MR-MS

R: Resistant; S: Susceptible; MR: Moderate Resistant; MS: Moderate Susceptible; TR: Trace Resistant.

Table 2: Mean squares for environment, genotype and their interaction of nine characters of 25 Zakia mutant lines over two locations (Dongola and New Halfa) and seasons (2016/17 and 2017/18).

Trait	Environment (E)	Genotype (G)	G x E
Days to heading	531.79**	23.45**	12.3297^{ns}
Days to maturity	36792.83^{ns}	17209.18^{ns}	17668.15^{ns}
plant high	29093.09**	34.68^{ns}	32.188ns
Spikes / m2	448215.22**	3139.07^{ns}	3805.14^{ns}
Grain / spike	23446.79**	47.092^{ns}	35.551^{ns}
Thousand grain weight	6119.663**	39.79^{ns}	45.768^{ns}
Harvest index	10146.95**	169.33**	104.709**
Biomass	1137.884**	8.809**	2.73579^{ns}
Yields	261782678**	1336352.1*	637352.1^{ns}

*, ** significant at ≤ 0.05and P 0.01 probability levels, respectively
ns: not significant

Table 3: Rank and means of grain yield (t/ha) for 22 selected Zakia mutant lines and three checks grown at Dongola and New Halfa, seasons 2016/17 and 2017/18.

	Mean					Rank				
Ent No	Dongola		New Halfa		Combined	Dongola		New Halfa		combined
	2017	2018	2017	2018		2017	2018	2017	2018	
1	4.89	2.37	2.86	1.80	2.980	11	22	20	20	19
2	4.96	3.91	3.16	1.87	3.475	9	1	10	17	2
3	5.03	2.69	3.92	2.46	3.525	7	12	1	1	1
4	4.52	2.14	3.11	1.73	2.875	15	24	12	23	23
5	4.50	3.02	3.30	1.99	3.203	17	8	8	10	10
6	5.08	2.71	3.41	2.17	3.343	5	11	4	5	6
7	4.92	3.14	2.76	2.05	3.218	10	7	23	9	9
8	4.78	2.64	3.31	1.77	3.125	12	15	7	21	14
9	4.23	3.59	2.97	1.91	3.175	20	2	18	16	12
10	4.59	2.59	3.11	2.15	3.110	14	17	13	6	15
11	5.01	1.91	3.07	1.99	2.995	8	25	14	12	18
12	4.65	3.38	3.28	2.15	3.365	13	4	9	8	4
13	5.39	2.81	2.99	1.99	3.295	3	10	17	13	8
14	5.21	3.20	2.65	2.34	3.350	4	5	25	2	5
15	5.07	2.87	3.02	1.83	3.198	6	9	15	19	11
16	4.12	3.15	3.54	1.61	3.105	23	6	3	25	16
17	5.66	3.39	3.14	1.67	3.465	2	3	11	24	3
18	4.25	2.68	3.40	1.99	3.080	19	13	5	11	17
19	4.21	2.67	3.64	2.15	3.168	21	14	2	7	13
20	4.41	2.62	2.73	1.98	2.935	18	16	24	14	20
21	4.51	2.45	2.84	1.77	2.893	16	19	21	22	22
22	3.93	2.35	3.02	1.92	2.805	24	23	16	15	25
23	3.68	2.42	3.33	2.27	2.925	25	21	6	3	21
24	4.20	2.43	2.90	1.84	2.843	22	20	19	18	24
25	5.69	2.57	2.83	2.22	3.328	1	18	22	4	7
Mean	4.700	2.788	3.132	1.985	3.151					
CV %	18.25	28.58	10.36	23.11	32.4					
SE±	0.842	0.762	0.31	0.446	0.9					
Effect	NS	NS	**	NS	*					

*, ** significant at ≤ 0.05and P 0.01 probability levels, respectively
ns: not significant

Rust disease test

Parallel to the yield Trials another experiment of screening 174 of Zakia mutant lines including check has been tested for rust diseases at New Halfa for the two seasons (2016/17 and 2017/18). The check Zakia showed a disease reaction of moderate resistance to moderate susceptibility with the disease incidence of 20 % in similar with that found by [6]. Our findings indicated that some of Zakia derivatives appeared resistant to leaf and stem rust disease **(Table 4)**. The severity of leaf rust was not consistent and no leaf rust was reported in the second season. Stem rust has been reported in the two seasons (2016/17 and 2017/18). Second season (2016/2018) classified as severe case along with many years in New Halfa. Seven progenies of Zakia derivative no. 324, 333, 336, 356, 357, 388 and 410 showed reaction to stem rust of moderately resistant to moderately susceptible across the two seasons while, other five progenies no. 291, 301, 315, 316 and 319 have good reaction only for the first season. These lines were susceptible in the second season where high infections have been found. The two mutant wheat genotypes no. 4 and 16, source no 291 and 356 had better effect in reducing stem rust epidemics, increasing yield and showed higher economic benefits over the check Zakia. Similar results were found by [7,8] who reported that host resistance is the most economical and safest method for controlling the disease and they reported that the high grain yield were obtained by some mutant lines. Also our findings in same-line with that found by [9], who reported that, induced mutation helped to develop many agronomical traits and increasing tolerance or resistance to abiotic and biotic stresses use in major crops such as wheat.

Table 4: Reaction of Zakia mutant lines to wheat stem and leaf rust diseases seasons 2016/2017 and 2017/2018) at New Halfa Research Farm.

	Season 2016 / 2017 Season 2017 / 2018		
Entry No.	%Intensity of Stem rust	%Intensity of leaf rust	%Intensity of Stem rust
291	10 MR-MS	20 MR-MS	20 MS-S
301	10 MR-MS	TR R-MR	10 MS-S
315	10 MR-MS	TR R-MR	TR MS-S
316	10 MR-MS	TR R-MR	10 MS-S
319	TR R-MR	TR R-MR	20 MS-S
324	20 MR-MS	TR MR-S	10 MR-MS
333	TR MR-MS	TR MR	TR MR-MS
336	10 MR-MS	TR R-MR	TR MR-MS
356	10 MR-MS	TR MR	10 MR-MS
357	TR MR-MS	TR R-MR	20 MR-MS
388	TR MR-MS	TR R-MR	TR MR-MS
410	TR MR-MS	TR R-MR	TR MR-MS
Zakia	20 MS-S	TR MS-S	20 MS-S
El Neelain	60 S	50 S	70 S
Bohaine	30 MS-S	20 MS-S	30 MS-S

R: Resistant; S: Susceptible; MR: Moderate resistant MS: Moderate Susceptible; TR: Trace Resistant.

Conclusion

Induce mutation may create and obtained the possible elite or advanced wheat mutant lines having an adequate levels of plant resistance to stem and leaf rusts, combined with the desirable yield attributes. From this study, two mutant lines no 11 and 16 were improved for grain yield and rust resistance. In addition to, seven mutant lines (No, 324, 333, 336, 356, 357, 388 and 410) were improved for stem and leaf rusts. These advanced mutant lines could be successfully used as the new good source of resistance to rust pathogens.

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