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Mutagenic Effectiveness of Gamma Rays in Inducing Polygenic Variability in Maize (*Zea mays* L.)

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Abstract
The present investigation was carried out to assess the mutagenic effectiveness in inducing favorable genetic variability for maize population improvement. Gamma rays were used to induce mutation in maize variety Sultan with four irradiation doses (20 Gray, 40 Gray, 60 Gray and 80 Gray). Data were collected for various agronomic traits including plant height (cm), number of days to silking, number of days to tasseling, number of grain rows per cob, cob length (cm), number of cobs per plant, diameter of the cob (cm), number of grains per row, number of grains per cob, grain weight per cob (g), 100 grain weight (g) and grain yield per plant (g). The results showed a positive response to mutagenic changes at the specific dose; plant height increased to 192 cm, cob length increased to 23 cm, grain weight per cob improved to 160 g and 100 grains weight showed 1 g increase at the dose of 20 gray as compared to respective traits at normal conditions. Number of grain rows per cob increased up to 22 rows per cob and number of cobs per plant increased up to 8 at the dose of 40 gray compared to the normal treatment. Days taken to silking reduced to 57 days from 62 days and days taken to tasseling showed early development in 53 days at the dose of 60 gray which showed positive mutation. On the other hand, some traits showed negative response owing to mutagenic treatments. Most of the cobs were unfertile, diameter of the cob, number of grains per row and number of grains per cob were reduced as compared to control (untreated). Principal component analysis conducted in the present study, showed a high level of positive associations among cob diameter, cob length, grains per row, grains per cob, grain weight per cob and grain yield under untreated control conditions. While plant height, days to tasseling and number of cobs per plant showed high mean performance and positive associations under 60 gray treatments. It has been concluded that gamma radiation induced effective mutations in some of the agronomic traits at specific dose especially 60 gray which could be further utilized to induce effective mutations in future maize breeding programs.
Keywords: Maize, gamma rays, mutagenic effectiveness, genetic variability, principal component analysis.

Introduction

Maize is one of the most important cereals in the world. It provides staple food to the millions of inhabitants around the globe (Tagne *et al*., 2008). It is a staple food for around 200 million people in developing countries from morning till noon. In developed countries, maize is used as a second-cycle product, in the form of meat, eggs and dairy products (Rensburg, 2012). The grains of maize contain vitamins A, C, E carbohydrates, essential minerals, and almost 9 % protein in addition to fuel and starch in processed form. During enzymatic process, starch converts into sorbitol, dextrin, ascorbic and lactic acid. These starch products are used in beer, ice cream, syrup, shoe polish, glue, fireworks, ink, batteries, mustard, cosmetics, aspirin, and paint. Around 60% of world maize is used for animal feed due to which its importance is increasing day by day indirectly due to the increasing demand of meat; it is necessary to raise a greater number of animal heads to meet human requirement of meat. This means that the global importance of maize is expanding where growth in meat consumption is increasing (Jatta, 2013). It is also necessary to develop high yielding climate resilient maize hybrids, inbred lines and open pollinated varieties (OPVs) to feed the overwhelmingly increasing global population with every tick of the clock.

As illustrated above, there is a dire need to grow, cultivate and to develop maize varieties, inbred lines and hybrids to meet the demand of overwhelmingly increasing population of the world which use the maize crop directly and indirectly to live in this world successfully. Availability of a diverse genetic pool is one of the most important factors required to run a successful breeding program. Therefore, genetic variability is a key to ensure effective selection of superior breeding lines from a diverse genetic pool to develop genetically divergent maize inbred lines which ultimately lead to the development of high yielding maize hybrids. To create variation in the existing varieties of the concerned crop; natural and induced mutations play a key role to bring diversity in plant species.

Mutagenic agents are the basic sources to induce mutation in various fields of crop plant research i.e., plant physiology, genetics and plant breeding. Physical mutagens are alpha rays, beta rays, fast neutrons, electromagnetic radiations, X-rays, gamma rays and chemical mutagens are (ethyl methane sulphonate, methyl methane sulphonate, acridine dye etc.). Biological mutagens are also used to generate mutation such as T-DNA insertion and transposons tagging. In China, spacecraft, recovery satellites, and high-altitude balloons are used to bring seeds in space to create mutation induction (Shu, 2009). Mutation can also be created by using restriction endonucleases which are helpful for inducing double strand breaks in the plant genome. This technology is further integrated with the zinc finger DNA binding proteins (zinc finger nucleases) and it is also used for site-specific mutagenesis (Belhaj, 2013).

Successful attempts to reproduce and scaling up the occurrence of natural phenomenon through induced mutation are fruitfully exploited. Through induced mutation, one can exploit both polygenic and monogenic traits of any crop for the improvement of existing germplasm. Developing embryo is suitable to study and to evaluate the comparative analysis of genetic effects which are caused by the gamma rays and chemical mutants. Furthermore, comparison of these effects might be helpful in determining linkage between endosperm and other seedling markers to point out exact genetic changes. Physical mutagens are high energy alpha (α) and beta (β) particles and neutrons. These physical agents are used to create chromosomal aberrations by breaking the chemical bonds, deletion, duplication, inversion, translocation, or addition of nucleotides. These agents can also be used to substitute one nucleotide by another nucleotide. Mutants can also be engaged to break and in rearrangement of chromosomes (Ahloowalia *et al*., 2001).

Gamma rays emitted by physical mutagens from the radioisotopes like cobalt-60 (60Co), cesium-137 (137Cs) and to a lesser extent plutonium-239 (239Pu); these mutants are helpful as a raw material for crop improvement (Mba, 2013). These mutants create mutation on the reproductive and somatic cells of the plant or any other exposed surface of the living object. The mutation is the only subject which contributes to dissect the evolutionary basis of crop specie as it can be passed from one generation to another generation, when genetically induced. Small percentage of mutation actually improves the function of gene and gene product which provides a way to improve the performance and adaptability of particular crop specie. Therefore, present investigation was carried out to assess the mutagenic effectiveness of different gamma ray treatments in inducing favorable genetic diversity in maize.

Materials and Methods

Present study was carried out in research area of the department of Plant Breeding and Genetics, University of Agriculture, Faisalabad during summer season 2013-14. Dried seeds of variety named “Sultan” were irradiated with 20 Gray, 40 Gray, 60 Gray and 80 Gray doses of gamma rays by using Cobalt-60 as a mutagenic agent at Nuclear Institute of Agriculture and Biology (NIAB), Faisalabad. Treated seeds along with normal ones (untreated) were then dibbled in the field by following randomized complete block design (RCBD) with three replications. Row to row and plant to plant distances were 75 cm and 25 cm respectively. Recommended cultural and agronomic practices were followed throughout the growing period of the crop. Three plants from each treatment were then selected and subjected to further evaluation based on various agronomic attributes including plant height (cm), days to silking, days to tasseling, no. of grain rows per cob, cob length (cm), no. of cobs per plant, cob diameter (cm), no. of grains per row, no. of grains per cob, grain weight per cob (g), 100 grain weight (g) and grain yield per plant (g).

Data of all the agronomic attributes were recorded, means were computed and statistically analyzed for summary statistics (table 1a, b, c and d). Summary statistics was used to summarize the set of recorded observations, in order to elaborate the largest amount of information into a simpler form. Furthermore, principal component analysis (table 2 and figure 1) was carried out by using XLSTAT 2014.5 statistical software according to Sneath and Sokal (1973).

Results and discussion

The mutagenic effectiveness of gamma radiation has been widely acknowledged in modern day agricultural research to induce favorable genetic variability for crop improvement. Several studies identify the gamma rays as an effective mutagenic agent in order to generate favorable and genetically stable mutants in major food crops i.e., in chickpea by Shah *et al*. (2008), in rice by Siddiqui and Singh (2010), in canola by Emrani *et al*. (2012), in lentil by Laskar and Khan (2017) and in bread wheat by Abaza *et al*. (2020). Likewise, gamma radiation significantly contributed in developing desirable maize mutant genotypes with superior agronomic performance (Sajid *et al*.,

2016) and disease resistance (Rose *et al*., 2018). In the present study, mean values for the plant height were 137.33 cm in normal conditions, 133.36 cm at 20 gray, 116.18 cm at 40 gray, 111.57 cm at 60 gray and 107.39 cm at 80 gray gamma radiations while maximum individual plant height (192 cm) was observed at 20 gray (Table 1a). It showed that irradiation with lower doses of gamma rays significantly improved the vegetative growth (20 gray) while higher doses proved depressing behavior in 60 Gray and 80 Gray (142 cm and 151cm plant height respectively).

The stimulatory effects of low gamma radiation doses to increase overall vegetative growth of maize might be due to increased hormonal signaling as observed by Wi *et al*. (2007). Moreover, similar results were observed in various crops like in triticale by Trivedi and Dubey (1988), in faba beans by Laskar and Khan (2014) and in lentils by Amin *et al*. (2015). On the other hand, according to Preuss *et al*. (2003) the inhibitory effects in vegetative growth due to lower doses of gamma radiations are most probably due to some genetic aberrations and abnormalities occur in the cellular genome. Moreover, deviation in the vegetative growth in all treatments as compared to the normal plants might be due to the effect of radiation on the photosynthetic activity which ultimately led to variable plant growth especially plant height (Jansen *et al*., 1998). The range of plant height showed that different doses of irradiation brought random changes in genetic material.

Coefficients of variation were 16.04 % for the plant height in normal conditions, 22.42 % at 20 gray, 24.78 % at 40 gray, 15.14 % at 60 gray and 20.80 at 80 gray. Overall, the gamma rays affected the genome of the maize as was observed in case of finger millet; after the treatment of seed of finger millet with the gamma rays doses, it was found that shoot length of the finger millet was reduced as compared to the normal plants (Ambavane *et al.,* 2014). But in plant height of the maize, the mutagenic effectiveness and its efficiency behaved in both ways i.e., positively and negatively. Plant height of the evaluated maize genotype was reduced in acute doses of gamma radiations just like in the study conducted by Singh and Balyan (2009) in which the plant height of bread wheat reduced due to mutagenesis with gamma radiations. Irradiation with lower doses of gamma rays significantly improved the vegetative traits. The overall long-term changes in plant development and its growth which ultimately affect the plant height may be attributed to changes in plant genome as reported earlier (Jan *et al.,* 2011).

Days taken to silking and tasseling were also observed to be significantly deviated in different treatments as compared to untreated normal maize population. A slight decrease in days to tasselling and silking was observed in the normal plants (53.44 and 49.07 days respectively) as compared to the gamma radiation treatment having dose 60 Gy (58.00 and 54.00 days respectively). On the other hand, treatments with doses 20, 40 and 80 Gy showed an intermediate duration taken to silking and taselling in the evaluated maize genotype. Ravilla *et al*. (1999) and Torun *et al*. (1999) found significant GCA and SCA effects for days to silking, grains per cob, cobs per plant, cob length, and 100-seed weight which had significant direct effects on grain yield. That is why days taken to silking ultimately play a major role in determining the final yield of the plant. Because of failure in fertilization due to the large difference in emergence of tasseling and silking surely lead towards increased anthesis silky interval (ASI) and the loss in yield of the plant. Maximum 62 days to silking were observed in normal conditions and minimum value 51 days was observed at 40 gray (Table 1a). This variation showed that different doses of irradiation brought changes in genetic material which changes the genetic material randomly. Coefficient of variation for days to silking and tasseling was 7.72 % and 8.85 % respectively in normal untreated conditions whereas, 2.46 % and 2.85 % respectively at 20 gray, 2.33 % and 3.32 % respectively at 40 gray, 3.73 % and 2.83 % respectively at 60 gray and 2.63 % and 3.66 % respectively at 80 gray. Days to silking showed 51 to 58 values due to gamma irradiation which brought genetic changes due to the effect of mutagen at the dose of 20 gray. Wenzel *et al.* (2000) and Zelleke (2000) revealed that 44 % grain yield was reduced and SCA effects were observed just because of silking and other yield related component. Umakanth *et al*. (2000); Desai and Singh (2001) and Iqbal *et al*. (2001) observed significant differences in GCA and SCA effects for different traits including days taken to silking. Results of the present study are quite in accordance with the study conducted by Irish (1997) in which the tassel elongation slowed down in mutant (Tassel Seed 6) as compared to the wild maize plant. Prakash *et al*. (2004) and Zho *et al*. (2004) estimated GCA and SCA effects for days taken to 50% tasseling and other yield related components and found that additive type of gene action persist for day to tasseling.

Number of grain rows per cob exhibited variation between the treatments of different gamma irradiations. Mean value for the number of grain rows per cobs per plant was 13.78 in normal conditions, 12.10 at 20 gray, 14.97 at 40 gray, 10.14 at 60 gray and 11.94 at 80 gray gamma radiations. Mather *et al*. (1998); San-vicente *et al*. (1998); Almeida *et al*. (1999) and Nass *et al*. (2000) concluded that number of grain rows per cob had significant correlation with the yield per plant. As above mentioned, that mean value of mutant seed at 40 gray showed higher number of grain rows per cob as compared to the normal plants, surely those mutant plants with higher number of grain rows per cobs will lead towards the higher yield per plant. Maximum number of grain rows per cob was observed at 40 gray and minimum values for number of rows per cob were observed at 60 gray as shown in table 1b. This showed that different doses of radiation brought changes in genetic material which results in changes in number of rows per cobs randomly. Number of grain rows per cob is an important agronomic trait which helps us to estimate the total production/yield of the maize crop.

Cob length is an important morphological trait which helps us to estimate the total production of the maize crop. If the length of the cob is increased, and with fertile ovaries on extended area; there will be a chance of increase in number of grains on the cob. Summary statistics for cob length showed variation between the treatments of different gamma irradiations. Mean value for cob length was 13.16 cm in normal conditions, 10.73 cm at 20 gray, 9.41 cm at 40 gray, 10.28 cm at 60 gray and 12.27 cm at 80 gray gamma radiations. Chapman *et al*. (1997) and Tusuz and Balabanli (1997) reported that cob length showed low broad sense heritability while grain yield was positively and significantly correlated with cob length. Mather *et al*. (1998); San-vicente *et al*. (1998) concluded that grain yield had a positive and significant genotypic correlation with number of grains per cob, number of grain rows per cob, cob length, 100-seed weight and grain oil contents. Ravilla *et al*. (1999) and Torun *et al*. (1999) found significant GCA and SCA effects were found for grains per cob, cobs per plant, cob length, and 100-seed weight had significant direct effects on grain yield. All above discussion has reached on one point; cob length directly influenced the yield of the maize crop. Maximum value of cobs length 23 cm was observed at 20 gray which will surely lead towards the higher yield of the crop and minimum value for cobs length 19cm was observed at 40 gray (Table 1b). This showed that different doses of irradiation brought changes in genetic material due to mutagenic effect of different doses. Number of cobs per plant is an important morphological trait which helps us to estimate the total production of the maize crop. Number of cobs per plant showed variation between the treatments of different gamma irradiations. Mean value for number of cobs per plant was 1.023 in normal conditions, 1.52 at 20 gray, 1.90 at 40 gray, 2.29 at 60 gray and 1.98 at 80 gray gamma radiations. Maximum 8 cobs per plant were observed at 60 gray and minimum value for number of cobs per plant was observed 2 in normal condition (Table 1b). This shows that different doses of radiation bring changes in genetic material which results in changes in number of cobs per plant randomly.

Diameter of the cobs is an important morphological trait which helps us to estimate the ultimate productivity of the maize crop. Ali *et al.* (2014) concluded that with all other yield and yield components, diameter of the cob is an effective tool to improve the grain yield and fodder yield per plant at maturity stage. Summary statistics for diameter of the cobs showed variation between the treatments of different gamma irradiations. Mean value for diameter of the cobs was 35.09 cm in normal conditions, 24.15 cm at the mutagenic dose of 20 gray, 23.68 cm at 40 gray, 20.86 cm at 60 gray cm and 28.61 cm at 80 gray gamma radiations. Maximum diameter of cobs was observed in normal conditions and minimum value of cob diameter was observed 20.86 cm at 60 gray (Table 1c). It showed that different doses of radiation brought changes in genetic material which effect randomly. Although mutagenic treatments did not induce effective mutations to increase the diameter of the cob but it played a key role to increase the cob length as explained earlier.

Summary statistics for number of grains per row showed variation between treatments of different gamma irradiations. Mean value for number of grains per row was 19.86 in normal conditions, 6.57 at 20 gray, 6.60 at 40 gray, 7.57 at 60 gray and 6.84 at 80 gray gamma radiations. Maximum number of grains per row was observed in normal conditions and minimum value for number of grains per row "0" was observed at in all doses (Table 1c) because in most of the cases, unfertile cob was developed. It was found that unfertile ovaries were present and there was blatant separation between rows of ovaries without grain. This showed that different doses of radiation brought changes in genetic material which brought changes randomly. Wali *et al*. (2010) observed significant interaction between grains per row and grain yield per plant. But in present scenario, it can be concluded that mutation did not induce mutation positively especially in case of number of grains per row because number of grains per row was reduced due to increased infertility in different mutagenized populations. Recently, similar results were observed by Kumari *et al*. (2016) and Prashanth *et al.* (2020) where negative effects of gamma radiations were observed in tomato plant which ultimately leads to the development of sterile flowers thus inhibited fruit setting.

Number of grains per cob is an important agronomic trait to estimate the total production of the maize crop. El-Hosary *et al*. (1994); Lee *et al*. (1995); Bolanos and Edmeades (1996); Flower *et al*. (1996); Singh and Mishra (1996); Balderrama *et al*. (1997) and Chapman *et al*. (1997) found additive type of gene action for number of grains per cob with some other yield related parameters.

Summary statistics for number of grains per cob showed variation between the treatments of different gamma irradiations. Mean value for number of grains per cob was 288.53 in normal conditions, 89.89 at 20 gray, 88.52 at 40 gray, 94.00 at 60 gray and 88.22 at 80 gray gamma radiations. Maximum number of grains per cob was observed 673 in normal conditions and minimum value for number of grains per cob was observed 308 at 80 gray (Table 1c). This showed that different doses of radiation brought changes in genetic material which results in changes in randomly. Grain weight per cob is an important morphological trait which helps us to estimate the total production of the maize crop. The grain weight per cob showed variation between the treatments of different gamma irradiations. Mean value for the grain weight per cob was 68.23g in normal conditions, 23.19g at 20 gray, 24.76g at 40 gray, 26.43g at 60 gray and 26.45g at 80 gray gamma radiations. Maximum grain weight per cob was observed 160g at 20 gray and minimum value for grain weight per cob was observed 86g at 60 gray (Table 1d). This showed that different doses of radiation brought changes in genetic material which changes randomly but 20 gray dose induced mutation through which grain weight was increased as compare to the normal treatment.

Summary statistics for 100 grain weight showed variation between the treatments of different gamma irradiations. Mean value for 100 grain weight was 22.65g in normal conditions, 17.67g at 20 gray, 17.40g at 40 gray, 15.86g at 60 gray and 22.14g at 80 gray gamma irradiations. Maximum 100 grain weight was observed 40g at 20 gray and minimum value for 100 grain weight was observed 28g at 60 gray as in Table 1d. This showed that different doses of radiation brought changes in genetic material which changes randomly. Summary statistics for yield per plant showed variation between the treatments of different gamma irradiations. Mean value for yield per plant was 70.50g in normal conditions, 27.37g at 20 gray, 26.13g at 40 gray, 34.43g at 60 gray and 29.78g at 80 gray gamma radiations. Maximum yield per plant was observed 194g in normal conditions and minimum value for yield per plant was observed 86g at 60 gray (Table 1d). This showed that different doses of irradiation brought changes in genetic material which changes randomly. Yield per plant is an important morphological trait which helps us to estimate the total production of the maize crop.

Principle component analysis

Principal component analysis (PCA) is an algebraic way to facilitate the selection of desirable genotypes based on highly correlated superior agronomic traits from genetically diverse pool of Germplasm. PCA help to determine the major contributors based on proportion of relative variance exhibited by each principal component from the total computed variability (Sharma, 1998). Thus, PCA generally determines the significance of each of the generated components to the total calculated variance. In present study, the data collected from all treatments along with the control (untreated) were subjected to principal component analysis (PCA) in order to assess the effectiveness of gamma radiation as well as radio-sensitivity of the evaluated maize cultivar. The cumulative variance (84.88 %) generated by the first two principal components (PC_1 and PC_2) along with Eigen values more than 1.0 (Figure 1) elucidated that the agronomic characters with in these first two principal components showed comparatively greater impact on overall performance and phenotype in all the treatments along with the control (untreated) (Table 2).

PCA can also determine the individual effect of a specific character on the total variance. On the other hand, the coefficients of vectors showed the relative contribution of all the characters under study to which it is primarily associated (Table 2). High values of the computed coefficients either with positive or negative signs showed their higher degree of variability among various treatments being applied. The present investigation followed the classification criteria based on proportion of variance proposed by Rourke and Hatcher (2013) and extracted four principal components (PCs) out of which the first two components (PC_1 and PC_2) exhibit 84.89% cumulative variance (Figure 1). All of the agronomic characters under study contributed to the overall variability for all of the principal components. In principal component 1 (PC_1), the traits contributed to total computed variance are; days to silking (loadings 0.246), cob length (0.428), number of cobs per plant (-0.334), cob diameter (0.337), number of grains per row (0.332), grain weight per cob (0.325) and grain yield (0.309) has been observed to be contributed 67.551 % in total computed variance. In principal component 2 (PC_2), plant height (0.525) and days to tasseling (0.424) contributed 17.335 % in total variance computed (See figure 1). Likewise, in PC_3 and PC_4 100 grain weight (0.531) and number of grain rows per cob (0.560) contributed 10.426 % and 4.688% variability respectively. The results of the present investigation revealed that first two principal components were majorly associated with the different agronomic growth attributes recorded in maize with high associations.

The biplot analysis (Figure 1) elucidated that almost all of the reproductive growth attributes which determine the ultimate yield fall in the first and best quadrant and showed promising results in control. The reason behind the poor performance regarding the gamma radiation treatments might be due to increased tendency of infertility in maize plants which might be occur due to genetic aberrations occur in the reproductive pathway. On the other hand, vegetative growth has been observed to be increased in case of 60 Gray gamma radiation treatment as compared to the control and other treatment levels. In second quadrant plant height showed positive associations with days taken to tasseling and number of cobs per plant showing adaptive response in the prevailing environment specifically in case of 60 Gray treatments as. As shown by the biplot analysis, characters including days taken to silking, 100 grain weight and number of grain rows per cob showed poor performance with respect to all of the treatments along with control (untreated). The findings of the biplot analysis exposed that 60 Gy dose could be use further experiments to generate genetically diverse and superior maize populations. However, comprehensive research is needed to be accomplished by manipulating the gamma radiation doses to make more improvements in maize.

Conclusion

The positive and negative effects of mutation were observed at all mutagenic levels including 20 gray, 40 gray, 60 gray and 80 grays. But it has been concluded that polygenic mutation always occurs at random and do not follow any particular pattern as stated by Brock (1965) and Astveit (1967). The positive shift in the mean values of characters indicates that there was a scope for selection and further improvement in maize.

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Table 1a: Summary statistics for Plant height, days to silking and days to tasseling in M_1 generation of maize (*Zea mays* L.) var. Sultan

	Plant Height (cm)						Days to Silking						Days to Tasseling					
	Mean ± SE	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**
Control	137.33 ± 2.57	78-185	136	23.41	540.37	16.04	53.44 ± 0.63	46-62	54	4.13	16.01	7.72	49.07 ± 0.46	42-46	49	4.35	18.87	8.85
20 GY	133.36 ± 3.65	45-192	135	29.9	894.11	22.42	54.21 ± 0.16	51-58	54	1.34	1.78	2.46	50.4 ± 0.17	47-53	51	1.42	2.06	2.85
40 GY	116.18 ± 4.67	60-160	124	28.79	829.24	24.78	53.58 ± 0.2	51-57	54	1.24	1.55	2.33	50.24 ± 0.27	47-53	50	1.67	2.78	3.32
60 GY	111.57 ± 6.38	98-142	104	16.89	285.29	15.14	58 ± 0.82	55-61	58	2.16	4.67	3.73	54 ± 0.58	52-56	54	1.53	2.33	2.83
80 GY	107.39 ± 3.13	57-151	103	22.35	499.32	20.8	53.45 ± 0.2	52-58	54	1.4	1.97	2.63	50.96 0.26	47-55	51	1.86	3.48	3.66

Table 1b: Summary statistics for no. of grain rows per cob, cob length and no. of cobs per plant in M_1 generation of maize (*Zea mays* L.) var. Sultan

	No. of Grain Rows per Cob						Cob Length (cm)						No. of Cobs per Plant					
	Mean ± SE	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**
Control	13.78 ± 0.25	8.0-20.0	14	2.31	5.33	16.75	13.16 ± 0.63	4.0-20	13	4.13	16.997	31.32	1.023 ± 0.01	1.0-2.0	1	0.16	0.03	14.9
20 GY	12.1 ± 0.36	5-18.5	12	2.91	8.46	24.05	10.73 ± 0.54	3.0-20	10	4.42	19.56	41.22	1.52 ± 0.11	1.0-6.0	1	0.9	0.8	58.71
40 GY	14.97 ± 0.49	6.5-22	14	3.04	9.16	27.58	9.4 ± 0.74	2.0-19	9	4.57	20.89	48.66	1.9 ± 0.27	1.0-8.0	1	1.65	2.72	85.9
60 GY	10.14 ± 0.71	8.0-12.0	10	1.87	3.48	18.38	10.28 ± 1.78	6.0-18	8	4.72	22.24	45.85	2.29 ± 0.52	1.0-4.0	2	1.38	1.91	60.38
80 GY	11.94 ± 0.46	0-18	12	3.29	10.82	27.54	12.27 ± 0.64	0-22	13	4.57	20.88	37.23	1.98 ± 0.19	0-7.0	1	1.38	1.91	69.59

Table 1c: Summary statistics for cob diameter, no. of grains per row and no. of grains per cob in M1 generation of maize (*Zea mays* L.) var. Sultan

	Cob Diameter (cm)						No. of Grains per Row						No. of Grains per Cob					
	Mean ± SE	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**
Control	35.09 ± 0.99	22-48	36	6.43	41.42	18.33	19.86 ± 1.61	4.0-42.0	21	10.53	110.84	53.09	288.53 ± 18.93	30-673	277	175.64	30833	60.22
20 GY	24.15 ± 1.41	0-44	27	11.5	132.22	47.62	6.57 ± 1.07	0-39	3	8.72	76.37	133.07	89.89 ± 15.3	0-553	45	125.27	15693	139.35
40 GY	23.68 ± 1.82	Jun-40	24.5	11.21	125.57	47.31	6.6 ± 1.3	0-27	2.5	8.02	64.19	121.3	88.52 ± 18.77	0-433	21	115.68	13382	130.68
60 GY	20.86 ± 4.57	Jul-34	17	12.09	146.14	57.96	7.57 ± 3.84	0-28	4	10.15	102.95	134.01	94 ± 46.28	0-341	54	122.45	14995	130.27
80 GY	28.61 ± 1.32	0-43	30	9.42	88.76	32.93	6.84 ± 0.85	0-22	5	6.01	36.05	87.75	88.22 ± 11.47	0-308	58	81.88	6704.9	92.8

Table 1d: Summary statistics for grain weight per cob, 100 grain weight and grain yield per plant in M_1 generation of maize (*Zea mays* L.) var. Sultan

	Grain Weight per Cob (g)						100 Grain Weight (g)						Grain Yield per Plant (g)					
	Mean ± SE	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**	**Mean ± SE**	**Range**	**Median**	**SD**	**Variance**	**CV %**
Control	68.23 ± 5.17	6-154	65	46	2183.1	68.9	22.65 ± 0.71	12.0 - 39	22	6.64	43.994	29.11	70.5 ± 5.42	6-194	65	50.6	2530.8	71.79
20 GY	23.19 ± 4.14	0-160	12	33.85	1146	145.95	17.67 ± 1.42	0 - 40	20	11.62	135.01	65.75	27.37 ± 4.48	0-160	12	36.66	1344.1	133.93
40 GY	24.76 ± 5.1	0-110	11	31.3	979.48	126.38	17.4 ± 1.89	0 - 35	19.5	11.68	136.52	67.17	26.13 ± 5.10	0-110	11.5	31.43	987.79	120.27
60 GY	26.43 ± 11.7	0-86	13	30.97	958.95	117.17	15.86 ± 4.51	0 - 28	19	11.92	142.48	75.27	34.43 ± 12.16	0-86	43	32.17	1035	93.44
80 GY	26.45 ± 3.63	0-88	17	25.9	670.89	97.92	22.14 ± 1.56	0 - 42	25	11.11	123.44	50.19	29.78 ± 3.96	0-97	24	28.27	798.93	94.9

Table 2: Eigen values and total percent variation along with principal components

	PC_1	**PC_2**	**PC_3**	**PC_4**
Eigenvalue	8.106	2.080	1.251	0.563
Variability (%)	67.551	17.335	10.426	4.688
Cumulative %	67.551	84.886	95.312	100.000
DTS	**0.246**	-0.028	-0.524	-0.538
PH	-0.212	**0.525**	-0.217	0.078
DTT	-0.276	**0.424**	0.045	0.104
GRPC	0.175	-0.502	-0.201	**0.560**
CL	**0.428**	0.205	0.280	-0.289
CPP	**-0.334**	0.100	0.236	0.324
CD	**0.337**	0.008	0.250	0.025
GPR	**0.322**	0.236	-0.126	0.213
GPC	**0.327**	0.208	-0.139	0.191
GWPC	**0.325**	0.219	-0.090	0.239
100 GW	0.281	-0.048	**0.531**	-0.043
GYPP	**0.309**	0.301	-0.100	0.206

PH = Plant Height; DTT = Days to Tasseling; DTS = Days to Silking; GRPC = No. of Grain Rows per Cob; CL = Cob Length; CPP = No. of Cobs per Plant; CD = Cob Diameter; GPR = No. of Grains per Row; GPC = No. of Grains per Cob; GWPC = Grain Weight per Cob; 100 GW = 100 Grain Weight; GYPP = Grain Yield per Plant

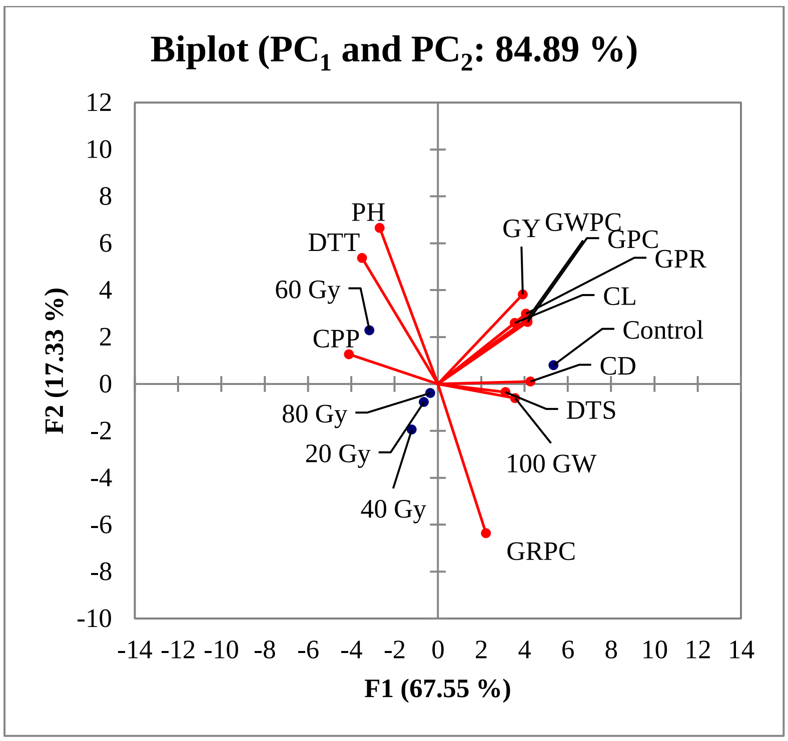

Figure 1: Biplot analysis of first two principal components