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# Yield and Fiber Quality Characteristics of Mutation-Based IMI Tolerant Cotton (*Gossypium hirsutum* L.) Lines

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**Abstract:** The economical and effective weed control in cotton can succeed by breeding IMI-tolerant genotypes. For this purpose, we treated seeds with gamma rays at different doses and sprayed the plants with imazamox in $M_1$-$M_5$ generations. Thirty-three $M_4$ lines in 2020 and seventeen $M_5$ lines in 2021 with two comparative varieties were arranged in a Randomized Complete Block Design with three replications. $M_4$ lines generally had superior fiber properties than standard varieties. We transferred 17 $M_4$ lines, superior in terms of yield, ginning out-turn and fiber quality, to the $M_5$ generation. All $M_5$ lines exhibited finer fibers than comparative varieties. Seed cotton yield and ginning out-turn of eight $M_5$ lines were superior to the comparative varieties. Five IMI-tolerant genotypes with high yield and favourable fiber quality were transferred to further generations.

**Keywords:** Fiber quality, gamma rays, IMI-tolerant, mutation, variation

**Mutasyon Yoluyla Elde Edilmiş IMI Toleranslı Pamuk (*Gossypium hirsutum* L.) Hatlarının Verim ve Lif Kalite Özellikleri**

***Öz:*** *IMI-toleranslı pamuk ıslahı ile pamukta etkin ve ekonomik bir şekilde yabancı ot mücadelesi gerçekleştirilebilir. Bu amaçla pamuk tohumları farklı dozlarda gama ışınları ile muamele edildi ve* $M_1$-$M_5$ *generasyonlarında bitkilere imazamox uygulandı. 2020 yılında 33* $M_4$ *ve 2021 yılında 17* $M_5$ *hattı 2 kontrol çeşit ile birlikte 3 tekerrürlü olarak Tesadüf Blokları Deneme Desenine göre ekildi.* $M_4$ *hatlarının kalite özellikleri çoğunlukla kontrol çeşitlerden daha üstün bulundu. Verim, çırçır randımanı ve lif kalite özellikleri yönünden 17* $M_4$ *hattı* $M_5$ *generasyonuna aktarıldı. Tüm* $M_5$ *hatlarının lif incelikleri kontrol çeşitlerden daha düşük bulundu. Benzer şekilde 8* $M_5$ *hattının kütlü pamuk verimi ve çırçır randımanı performansı kontrol çeşitlerden daha yüksek olarak belirlendi. IMI-toleranslı ve verim ve lif kalite özellikleri üstün 5 hattın sonraki generasyonlara aktarılması gerektiği sonucuna varıldı.*

***Anahtar kelimeler:*** *Gama ışınları, IMI-toleranslı, lif kalite özellikleri, mutasyon, varyasyon*

## INTRODUCTION

Although imidazolinone (IMI) herbicides have controlled weeds in many IMI-tolerant crops, they have not been found to be used in cotton farming (Tcach et al., 2022). Imidazolinone (IMI) is a group of herbicides that inhibit acetolactate synthesis (ALS). This enzyme (also called acetohydroxyacid synthase; AHAS) is involved in the first step of valine, leucine and isoleucine synthesis. Low doses of IMI group herbicides are effective on grass and broadleaf weeds and are defined as environmentally friendly herbicides. IMI group herbicides such as imazapyr, imazapic and imazamox controlled the important broadleaf and summer weeds such as common lambsquarters (*Chenopodium album*), rough cocklebur (*Xanthium strumarium*), jimsonweed (*Datura stramonium*) and black nightshade (*Solanum nigrum*). Therefore, improving IMI-tolerant crops has been recognized as an important strategy for effective weed control (Tan et al., 2005).

The use of IMI-tolerant cotton varieties in cotton farming will positively affect the success of weed control (Bechere et al., 2009). At the same time, cotton can be included in the crop rotation with IMI-tolerant crops (York et al., 2000). Maize (*Zea mays* L.), canola (*Brassica napus* L.), sunflower (*Helianthus annuus* L.), soybean (*Glycine max* L.), and wheat (*Triticum aestivum* L.) are important crops that have recently developed resistance to AHAS inhibitory herbicides using various methods (Ustun and Uzun, 2023). Previous studies show that it is possible to confer herbicide resistance to cultivated plants by mutation of ALS genes as a result of amino acid substitution (Sala et al., 2012; Li et al., 2015; Hu et al., 2017; Zhang et al., 2019; Li et al., 2020; Chen et al., 2021). Although IMI-tolerant cotton cultivars are not yet registered, some mutant lines that can be used in obtaining IMI-tolerant commercial cotton cultivars were obtained (Bechere et al., 2009; Cutts, 2013; Tcach et al., 2022). However, it was emphasized that plant growth and vigour were adversely affected by mutations due to negative pleiotropic effects (Vila-Aiub et al., 2009).

We conducted this study to test IMI tolerant lines of $M_4$ and $M_5$ generations for yield and quality traits. In addition, we also planned to test the selection success in terms of the examined traits.

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**MATERIAL AND METHODS**

Seeds of standard cotton cultivar Gloria (*Gossypium hirsutum* L.) were irradiated with 100, 200 and 300 Gy gamma rays. Results of $M_1$ and $M_2$ generation have been reported by Altintas and Unay (2021). At the $M_3$, $M_4$ and $M_5$ generations, mutant plants were grown in Nazilli Cotton Research Institute, and at a dose of 1250 ml/ha, imazamox was sprayed to plants at the stage of 5-6 true leaves emerged. During the $M_4$ generation, 33 mutant lines were selected, and 17 of their mutant lines, superior in yield, ginning out-turn and fiber quality were transferred to the $M_5$ generation. In this study, 33 $M_4$ and 17 $M_5$ mutant lines and two comparative cultivars, ST-468 and Gloria, were used as genetic material according to the method applied by Key et al. (1998) and Jankowicz-Cieslak et al. (2017). Mutant lines were planted in a Randomized Complete Block Design with three replications. Each plot consisted of 4 rows of 12 m in length. The distances between rows and plant to plant were 0.7 m and 0.20 m, respectively. Standard cultural management for regional cotton growing was fulfilled. Twenty plants were randomly sampled in the harvest period. Seed cotton yield per plant (SCY; g), ginning out-turn (GOT; %), fiber fineness (FF; mic.), fiber length (FL; mm) and fiber strength (FS; g $tex^{-1}$) were measured. The fiber quality traits were determined by Uster® High Volume Instrument (HVI) 1000 (USTER Technologies, Inc., Knoxville, TN, USA). Data for each trait were analysed using two-way ANOVA according to Randomized Complete Block Design using the 'agricolae' package (de Mendiburu and de Mendiburu, 2019) in R studio. Tukey's HSD (Honestly Significant Differences) test with a probability level of $P = 0.05$ was used to compare genotypes (Tukey, 1949).

**RESULTS AND DISCUSSION**

Stunted shoots and reddening of leaf veins are the most common symptoms after imazamox treatment (Bechere et al., 2009), and original images of these symptoms are presented in Figure 1. These symptoms were not observed in $M_4$ and $M_5$ plants in our study. We compared mutant lines with standard check varieties, Gloria and St-468. In the $M_4$ generation, genotypic differences were significant for all observed traits. The seed cotton yield per plant of all mutant lines except GR-200 V and GR-200 VIII was significantly lower than that of standard varieties. Mutant lines GR-100 VI, GR-100 III, GR-200 X and GR-200 XI had higher GOT than standard varieties. Regarding fiber length, 15 of the 33 mutant lines performed better than the standard varieties. Although all mutant lines had fine fiber compared with standard varieties, fiber fineness values of four lines were below 3.0 micronaire. Fourteen lines exhibited superior fiber strength than standard varieties. Unlike the results in our study, Cutts (2013) reported that the differences among $M_6$ and $M_7$ lines (treated with imazamox) and comparative varieties were non-significant for yield, ginning out-turn, fiber strength, fiber length and micronaire.


**Figure 1.** Original images (A) plant adversely affected by imazamox; (B) rows adversely affected by imazamox; (C) non-affected plant and (D) non-affected rows

**Table 1.** Average seed cotton yield (SCY), ginning out-turn (GOT), fiber length (FL), fiber fineness (FF) and fiber strength (FS) in $M_4$ generation

| Genotypes | SCY (g plant$^{-1}$) | GOT (%) | FL (mm) | FF (mic) | FS (g tex$^{-1}$) |
|---|---|---|---|---|---|
| GR-100 I | 29.60 r | 41.89 f | 28.84 g-i | 4.30 c | 28.53 j |
| GR-100 II | 45.00 j | 40.44 ij | 27.44 lm | 3.86 g-j | 31.78 b-d |
| GR-100 III | 31.30 q | 43.12 b | 28.75 g-l | 4.13 c-e | 28.82 ij |
| GR-100 IV | 50.80 gh | 40.35 i-k | 26.27 o | 4.06 d-f | 23.62 lm |
| GR-100 V | 19.60 v | 40.62 i | 31.20 b | 3.23 rs | 30.92 d-f |
| GR-100 VI | 47.40 i | 43.66 a | 29.02 fg | 3.82 h-k | 30.79 e-g |
| GR-100 A I | 40.00 m | 40.49 i | 28.17 i-k | 3.50 m-o | 29.61 hi |
| GR-100 A II | 33.60 o | 36.30 o | 30.93 bc | 3.46 n-p | 34.98 a |
| GR-100 A III | 50.40 h | 42.06 ef | 26.47 no | 3.45 n-p | 28.53 j |
| GR-200 I | 99.20 a | 39.01 m | 30.23 c-d | 3.71 j-l | 34.98 a |
| GR-200 II | 37.00 n | 39.99 j-l | 32.03 a | 3.78 i-k | 34.18 a |
| GR-200 III | 57.30 e | 41.88 d | 28.42 g-i | 3.80 h-k | 29.55 hi |
| GR-200 IV | 45.80 j | 42.35 de | 30.40 cd | 3.59 l-n | 31.64 b-e |
| GR-200 V | 76.70 b | 40.64 i | 28.23 h-k | 3.49 m-o | 32.53 b |
| GR-200 VI | 55.80 f | 41.39 gh | 29.68 ef | 3.51 mn | 34.94 a |
| GR-200 VII | 32.20 pq | 40.68 i | 29.95 de | 2.87 t | 29.64 hi |
| GR-200 VIII | 77.10 b | 41.82 fg | 28.67 g-i | 4.16 cd | 31.10 c-f |
| GR-200 IX | 51.43 g | 39.99 j-l | 29.81 de | 3.56 l-n | 31.28 c-f |
| GR-200 X | 17.05 w | 42.89 bc | 28.41 g-j | 3.90 f-i | 30.66 fg |
| GR-200 XI | 63.20 c | 42.87 bc | 28.49 g-i | 3.29 p-s | 30.89 d-g |
| GR-200 XII | 30.30 r | 39.60 l | 27.73 j-l | 3.43 n-q | 29.97 gh |
| GR-200 XIII | 32.30 p | 37.76 n | 27.56 k-m | 2.58 u | 26.45 k |
| GR-200 XIV | 41.50 l | 36.62 o | 29.08 fg | 3.19 rs | 30.69 fg |
| GR-200 XV | 41.60 l | 41.34 h | 26.87 m-o | 3.97 e-h | 23.67 l |
| GR-200 XVI | 28.30 s | 42.40 h | 27.12 l-n | 3.33 o-r | 25.86 k |
| GR-200 XVII | 45.00 j | 39.55 l | 27.34 lm | 3.66 k-m | 22.66 n |
| GR-300 I | 43.50 k | 40.73 i | 28.56 g-l | 3.12 s | 32.00 bc |
| GR-300 II | 22.50 tu | 40.67 i | 29.10 fg | 3.99 d-g | 31.20 c-f |
| GR-300 III | 22.87 t | 42.01 ef | 28.87 gh | 2.90 t | 23.50 l-n |
| GR-300 IV | 16.87 w | 42.65 cd | 28.20 h-k | 3.13 s | 22.70 mn |
| GR-300 V | 14.10 x | 40.70 i | 27.25 lm | 3.26 q-s | 25.60 k |
| GR-300 VI | 14.27 x | 41.99 ef | 28.18 h-k | 2.83 t | 23.30 l-n |
| GR-300 VII | 21.88 u | 39.90 kl | 29.03 fg | 3.12 s | 25.90 k |
| Gloria | 61.30 d | 41.37 gh | 30.15 de | 4.88 b | 30.70 e-g |
| ST-468 | 61.53 d | 42.71 b-d | 28.63 g-i | 5.10 a | 30.37 f-h |
| Genotype | ** | ** | ** | ** | ** |
| Mutant's Mean | 40.46 | 40.72 | 28.67 | 3.51 | 29.17 |
| HSD | 0.97 | 0.47 | 0.69 | 0.17 | 0.95 |

**: $p \leq 0.01$. Means within a column for each trait followed by the same letter are not significantly different at the 0.05 probability level by Tukey's HSD test.

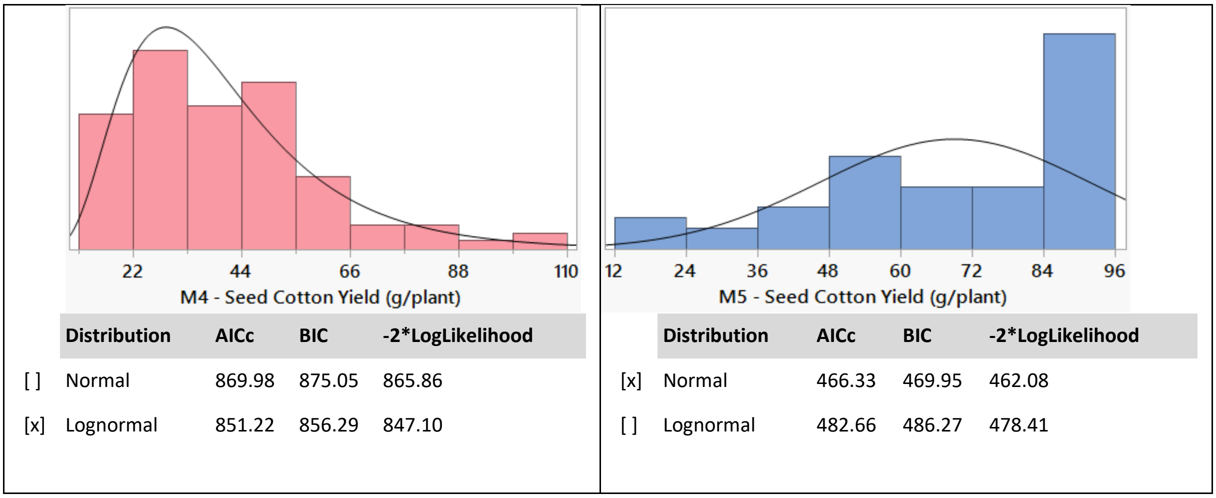
We evaluated all the traits of the mutant lines collectively. We choose the seed cotton yield per plant of 30 g ≤, the ginning out-turn of 36% ≤, fiber length of 28 mm ≤, fiber fineness between 3.0 and 4.6 mic. and fiber strength of 28 g tex$^{-1}$≤ as criteria. As a result, 17 mutant lines were selected and transferred to the $M_5$ generation. In the $M_5$ generation, significant differences were observed among mutant lines and standard varieties for all studied traits (Table 2). Earlier studies reported the genetic variations caused by gamma radiation (Raffat, 1995; Muthusamy et al., 2005; Muthusamy and Jayabalan, 2011; Yilmaz et al., 2018). In contrast to the $M_3$ and $M_4$ generations, non-significant variations were obtained for yield in the M5 generation (Herring et al., 2004). Eight mutant lines for seed cotton yield and ginning out-turn, 13 mutant lines for fiber length and 7 mutant lines for fiber strength were highly performed compared to standard varieties, while all mutant lines had fine fiber. GR-200 III, GR-200 V, GR-200 I and GR-200 XII, especially GR-100 A II, drew attention as mutant lines with high ginning efficiency and superior fiber properties, as productive as or more than the standard varieties. Our study's most successful mutant lines were obtained from a moderate level of gamma radiation (200 GR), which was in agreement with Muthusamy and Jayabalan (2011). In addition, the doses of effective gamma radiations were different in the studied traits and cotton varieties (Khan et al., 2017). The distribution of $M_4$ and $M_5$ populations based on studied traits was presented in Figures 2 and 3. Curve analysis indicated that the frequency distribution of both populations was a normal curve for all traits except the seed cotton yield of $M_4$ populations. The formed curve was lognormal and skewed to the left side with the highest frequency at a class of 22.0 - 44.0 seed cotton yield per plant for $M_4$ populations.

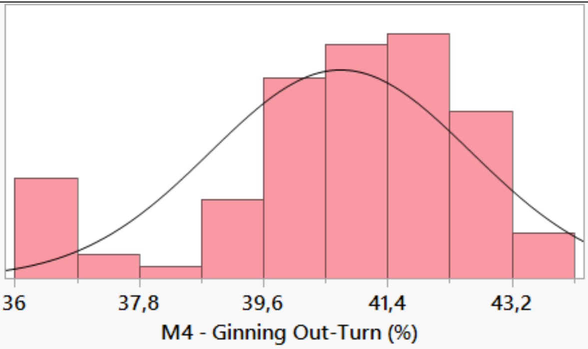
**Table 2.** Average seed cotton yield (SCY), ginning out-turn (GOT), fiber length (FL), fiber fineness (FF) and fiber strength (FS) in $M_5$ generation

| Genotypes | SCY (g plant$^{-1}$) | GOT (%) | FL (mm) | FF (mic) | FS (g tex$^{-1}$) |
|---|---|---|---|---|---|
| GR-100 VI | 21.10 m | 39.34 | 29.75 ef | 5.12 ab | 34.38 ab |
| GR-100 A I | 55.20 i | 46.28 cd | 26.74 i | 2.97 j | 31.70 ef |
| GR-100 A II | 89.90 cd | 43.36 g | 30.91 ab | 4.16 fg | 34.43 ab |
| GR-100 A III | 90.20 cd | 44.46 ef | 29.08 fg | 5.24 ab | 32.25 de |
| GR-200 I | 85.70 e | 46.32 cd | 30.88 ab | 4.61 c-e | 32.51 cd |
| GR-200 II | 40.00 k | 46.25 cd | 27.48 h | 4.48 d-f | 29.48 i |
| GR-200 III | 73.00 g | 46.85 bc | 31.18 a | 4.83 d-b | 33.94 b |
| GR-200 IV | 35.70 l | 47.90 a | 29.84 de | 4.12 fg | 30.36 h |
| GR-200 V | 91.50 bc | 42.51 gh | 30.85 a-c | 3.99 gh | 31.13 fg |
| GR-200 VI | 88.70 d | 42.16 hi | 29.90 de | 4.42 d-f | 30.31 h |
| GR-200 VIII | 94.90 a | 42.15 hi | 28.87 g | 4.70 vd | 31.09 fg |
| GR-200 IX | 71.10 g | 45.43 de | 30.48 b-d | 4.10 fg | 31.65 ef |
| GR-200 X | 51.30 j | 46.00 cd | 30.87 a-c | 3.64 hi | 34.81 a |
| GR-200 XII | 78.90 f | 42.21 hi | 30.20 c-e | 4.26 e-g | 33.13 c |
| GR-200 IVX | 50.10 j | 47.70 ab | 30.25 b-e | 3.91 gh | 30.69 gh |
| GR-300 I | 64.50 h | 41.40 i | 30.19 c-e | 3.33 ij | 33.07 c |
| GR-300 II | 92.90 ab | 44.38 f | 27.60 h | 5.02 a-c | 34.96 a |
| Gloria | 73.06 ef | 42.49 gh | 28.91 g | 5.34 a | 32.79 cd |
| ST-468 | 76.68 de | 44.61 ef | 27.43 h | 5.40 a | 30.21 h |
| Genotype | ** | ** | ** | ** | ** |
| Mutants Mean | 68.97 | 44.39 | 29.71 | 4.29 | 32.35 |
| HSD | 2.51 | 1.01 | 0.69 | 0.42 | 0.70 |

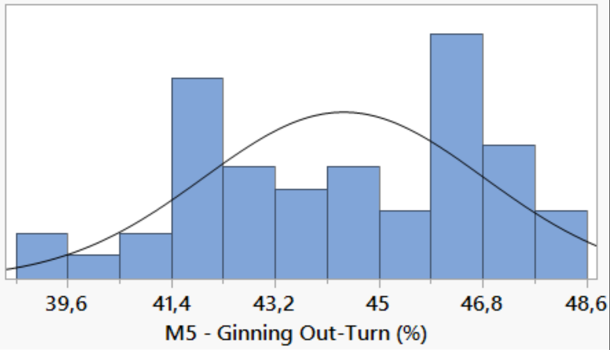
**: $p \leq 0.01$. Means within a column for each trait followed by the same letter are not significantly different at the 0.05 probability level by Tukey's HSD test.

The average seed cotton yield in the $M_4$ generation increased by 28.64 g in the $M_5$ generation after selection, and a class of 84.0 – 96.0 g seed cotton yield constituted the highest frequency. The fact that the range in the $M_5$ generation is higher than the $M_4$ generation shows that the segregation continues in the $M_5$ generation for all traits except fiber length, and the induced variability in the mutant population could not be fixed by selection. (Figure 3). On the contrary, it was reported that the later mutant generations remained uniform compared with earlier mutant generations in soybean (Inis, 1972), wheat (Sarkar (1986; Borojevic, 1991) and mungbean (Khan and Goyal, 2009). $M_5$ generation mean performance to $M_4$ was 3.67% for ginning out-turn, 1.04 mm for fiber length and 3.18 g tex$^{-1}$ for fiber strength, whereas fiber fineness of $M_5$ populations coarsened to 0.78 micronaire. We commented that the fibers, which were at quite fine class in the $M_4$ generation, coarsed in the $M_5$ generation as an indicator of maturity.



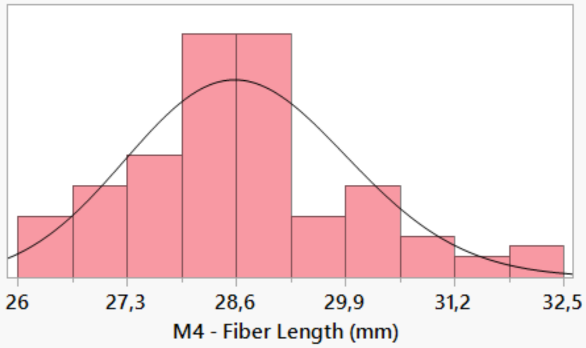



| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 409.81 | 414.87 | 405.68 |
| [ ] | Lognormal | 414.26 | 419.32 | 410.13 |

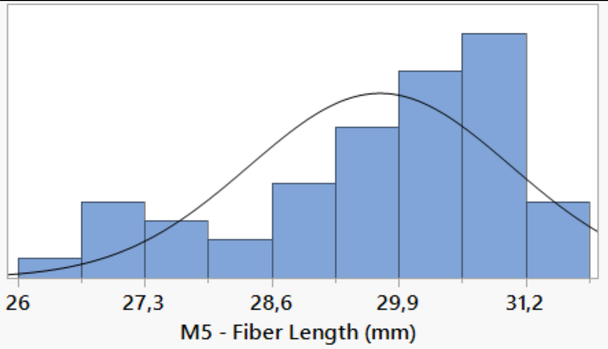



| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 238.71 | 242.32 | 234.46 |
| [ ] | Lognormal | 239.69 | 243.31 | 235.44 |

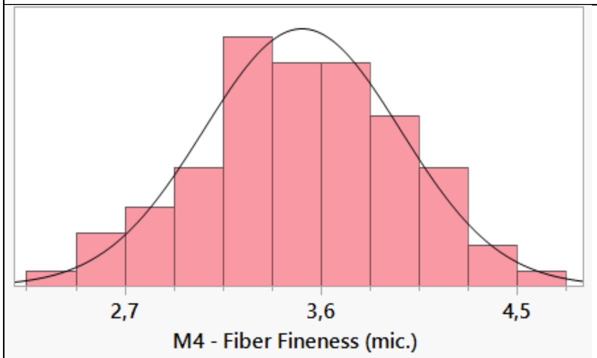
**Figure 2.** Density graphs of seed cotton yield and ginning out-turn in $M_4$ and $M_5$ generations



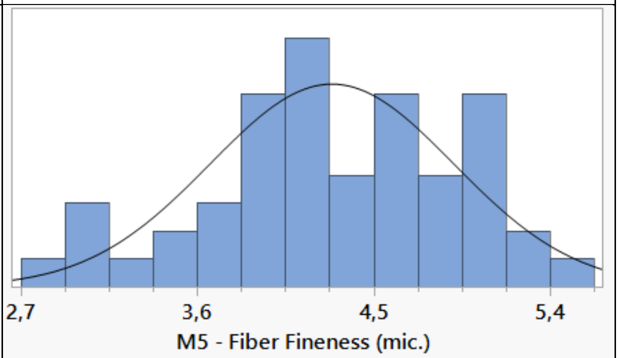

| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Lognormal | 339.06 | 344.13 | 334.94 |
| [ ] | Normal | 340.86 | 345.93 | 336.74 |



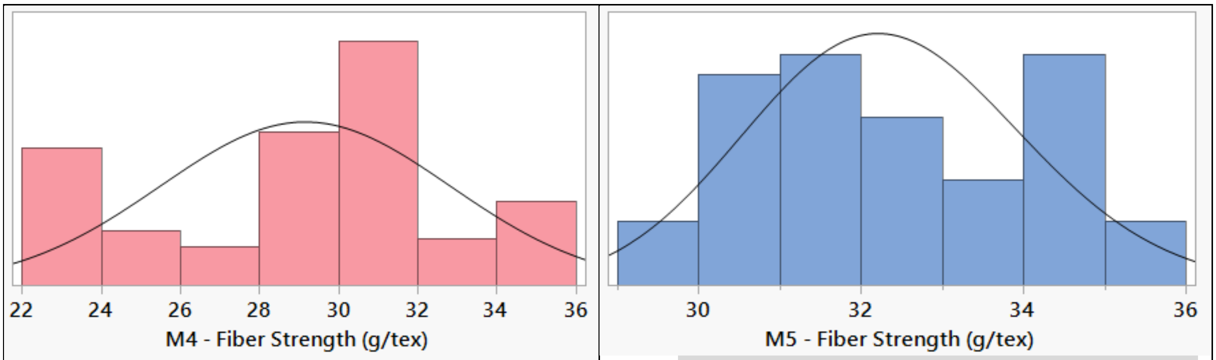

| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 177.79 | 181.40 | 173.54 |
| [ ] | Lognormal | 180.12 | 183.74 | 175.87 |




| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 126.28 | 131.34 | 122.15 |
| [ ] | Lognormal | 129.92 | 134.98 | 125.79 |




| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 99.37 | 102.98 | 95.12 |
| [ ] | Lognormal | 103.33 | 106.94 | 99.08 |




| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Normal | 541.62 | 546.68 | 537.49 |
| [ ] | Lognormal | 546.88 | 551.94 | 542.75 |

| | Distribution | AICc | BIC | -2*LogLikelihood |
|---|---|---|---|---|
| [x] | Lognormal | 202.72 | 206.33 | 198.47 |
| [ ] | Normal | 202.91 | 206.52 | 198.66 |

**Figure 3.** Density graphs of fiber quality traits in $M_4$ and $M_5$ generations

## CONCLUSION

We have shown that IMI-tolerant genotypes with superior agronomic characteristics can be developed in cotton by mutation and have identified five promising genotypes that we can transfer to the next generations. This result clearly proved that there is no negative linkage between IMI tolerant and agronomic traits.

## REFERENCES

Altintas D, Unay A (2021) Evaluation of Possibilities to Improve Herbicide Tolerant Genotype in Cotton (Gossypium hirsutum L.) through Mutation Breeding. The Journal of Scientific and Engineering Research 8(10): 11-17

Bechere E, Auld DL, Dotray PA, Gilbert LV, Kebede H (2009) Imazamox Tolerance in Mutation-derived Lines of Upland Cotton. Crop Science 49(5): 1586-1592. https://doi.org/10.2135/cropsci2008.09.0528

Borojevic K (1991) Induced Mutations and Their Genetic Aspects in Wheat (Triticum aestivum vulgare). In International Symposium on the Contribution of Plant Mutation Breeding for Crop Improvement; Vienna (Austria); 18-22 Jun 1990. International Atomic Energy Agency, Vienna (Austria); Food and Agriculture Organization of the United Nations, Rome (Italy); Proceeding series; p. 317-326, ISBN 92-0-010191-7.

Chen L, Gu G, Wang, CX, Chen ZF, Yan W, Jin M, Xie G, Zhou JL, Deng XW, Tang XY (2021) Trp548Met Mutation of Acetolactate Synthase in Rice Confers Resistance to A Broad Spectrum of Als-Inhibiting Herbicides. The Crop Journal 9(4): 750–758. https://doi.org/10.1016/j.cj.2020.11.003

Cutts GS (2013) Genetic Analysis, Inheritance and Stability of Mutation-based Herbicide Tolerance in Cotton (Gossypium hirsutum L.). Doctoral Dissertation, Texas A&M University, Texas, USA.

De Mendiburu F, De Mendiburu MF (2019) Package 'agricolae'. R Package, Version, 1, 3. Available from: https://cran.rproject.org/web/packages/agricolae/agricolae.pdf

Herring AD, Auld DL, Ethridge MD, Hequet EF, Bechere E, Green CJ, Cantrell RG (2004) Inheritance of Fiber Quality and Lint Yield in A Chemically Mutated Population of Cotton. Euphytica 136: 333-339. https://doi.org/10.1023/B:EUPH.0000032747.97343.54

Hu ML, Pu HM, Gao JQ, Long WH, Chen F, Zhou XY, Zhang W, Peng Q, Chen S, Zhang JF (2017) Inheritance and Molecular Characterization of Resistance to Ahas-Inhibiting Herbicides in Rapeseed. Journal of Integrative Agriculture 16(11): 2421–2433. https://doi.org/10.1016/S2095-3119(17)61659-9

Inis-XA X (1972) Joint FAO/IAEA Division of Atomic Energy in Food and Agriculture. International Atomic Energy Agency (IAEA) Mutation Breeding Newsletter No. 3. ISSN 1011-260X.

Jankowicz-Cieslak J, Mba C, Till BJ (2017) Mutagenesis for Crop Breeding and Functional Genomics. In: Jankowicz-Cieslak J, Thomas HT, Jochen K, Bradley JT (eds.), Biotechnologies for Plant Mutation Breeding: Protocols, Springer, Switzerland, 3-18. ISBN 978-3-319-45019-3, https://doi.org/10.1007/978-3-319-45021-6

Key CA, Dever JK, Auld DL, Baker RJ (1998) Selection of Stovepipe Lines from Chemically Mutated Cotton. In Beltwide Cotton Conferences (USA).

Khan S, Goyal S (2009) Improvement of Mungbean Varieties Through Induced Mutations. African Journal of Plant Science 3(8): 174-180.

Khan S, Hamza A, Khan F, Subhan M, Khan A, Shah IA, Khan SS (2017) Effects of Gamma Irradiation on some Growth Attributes in Cotton (Gossypium hirsutum L.). Pakistan Journal of Agricultural Research 30(3): 233-241. http://dx.doi.org/10.17582/journal.pjar/2017.30.3.233.241

Li YM, Zhu JJ, Wu H, Liu CL, Huang CL, Lan JH, Zhao YM, Xie CX (2020) Precise Base Editing of Non-Allelic Acetolactate Synthase Genes Confers Sulfonylurea Herbicide Resistance in Maize. The Crop Journal 8(3): 449–456. https://doi.org/10.1016/j.cj.2019.10.001

Li Z, Liu ZB, Xing A, Moon BP, Koellhoffer JP (2015). Cas9-Guide RNA Directed Genome Editing in Soybean. Plant Physiology 169(2): 960-970. https://doi.org/10.1104/pp.15.00783

Liu C, Zhang T, Yang X, Wang L, Long Y, Hasi A, Pei X (2023) A LuALS Mutation with High Sulfonylurea Herbicide Resistance in Linum usitatissimum L. International Journal of Molecular Sciences 24(3): 2820. https://doi.org/10.3390/ijms24032820

Muthusamy A, Vasanth K, Jayabalan N (2005) Induced High Yielding Mutant in Cotton (Gossypium hirsutum L.). Mutation Breeding Newsletter 1: 6–8.

Muthusamy A, Jayabalan N (2011) In Vitro Induction of Mutation in Cotton (Gossypium hirsutum L.) and Isolation of Mutants with Improved Yield and Fiber Characters. Acta Physiologiae Plantarum 33: 1793-1801. https://doi.org/10.1007/s11738-011-0718-8

Raffat M (1995) Effect of Seed Irradiation on Genetic Variability and Recombination of Some Economic Yield Components in Egyptian Cotton. In: Proc Beltwide Cotton Prod Res Conf Memphis, TN, pp 492–498.

R Core Team (2021) R: A language and environment for statistical computing. R foundation for statistical computing, Vienna, Austria. https://www.R-project.org/

Sala CA, Bulos M (2012) Inheritance and Molecular Characterization of Broad Range Tolerance to Herbicides Targeting Acetohydroxyacid Synthase in Sunflower. Theoretical and Applied Genetics 124: 355–364. https://doi.org/10.1007/s00122-011-1710-9

Sarkar HK (1986) Induced Variability of Quantitative Characters of Wheat in M2 and M3 Generations. Environment and Ecology 4: 725-729.

Tan S, Evans RR, Dahmer ML, Singh BK, Shaner DL (2005) Imidazolinone-tolerant Crops: History, Current Status and Future. Pest Management Science: Formerly Pesticide Science 61(3): 246-257. https://doi.org/10.1002/ps.993

Tcach MA, Landau AM, Montenegro A, Díaz D, Acuña C, Prina AR (2022) Isolation and Characterization of a New Imidazolinone-tolerant Mutant in Cotton. Crop Science 62(6): 2222-2232. https://doi.org/10.1002/csc2.20814

Tukey, J. W. (1949). Comparing individual means in the analysis of variance. Biometrics, 5(2): 99-114. https://doi.org/10.2307/3001913.

Ustun R, Uzun B (2023) Development of a High Yielded Chlorsulfuron-Resistant Soybean (Glycine max L.) Variety through Mutation Breeding. Agriculture 13(3): 559. https://doi.org/10.3390/agriculture13030559

Vila-Aiub MM, Neve P, Powles SB (2009) Fitness Costs Associated with Evolved Herbicide Resistance Alleles in Plants. New Phytologist 184(4): 751-767. https://doi.org/10.1111/j.1469-8137.2009.03055.x

Yilmaz A, Haliloglu H, Beyyavas V, Cevheri CI, Copur O (2018) The Effect of Gamma Irradiation at Different Doses Applied to Sayar-314 and Acalpi-1952 Cotton Varieties Seeds on Yield, Yield Components and Fiber Technological Properties in M5 Generation. Feb-Fresenius Environmental Bulletin 27(12B): 9887-9893.

York AC, Jordan DL, Batts RB, Culpepper AS (2000) Cotton Response to Imazapic and Imazethapyr Applied to a Preceding Peanut Crop. Journal of Cotton Science 4: 210–216.

Zhang R, Liu JX, Chai ZZ, Chen S, Bai Y, Zong Y, Chen KL, Li JY, Jiang LJ, Gao CX (2019) Generation of Herbicide Tolerance Traits and a New Selectable Marker in Wheat Using Base Editing. Nature Plants 5(5): 480–485. https://doi.org/10.1038/s41477-019-0405-0.