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COBALT-60-Γ-RADIATION EFFECT ON MORPHO-YIELD AND EARLINESS TRAITS IN COLORED COTTON (*GOSSYPIUM HIRSUTUM* L.)

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SUMMARY

Cotton plant is a valuable technical crop grown in various regions of the world. For assessing the five colored cotton (*Gossypium hirsutum* L.) genotypes, the yield contributing traits received 60Co γ-ray irradiation at 0 (control), 100, 150, and 200 Gy. By treating colored cotton cultivars with 100 and 200 Gy rays, variations were visible in early maturity properties. An enhancement in bolls per plant were evident when treating the cream-colored cotton genotypes; however, a decrease occurred in the green-colored cotton genotype. Notably, the colored fiber genotypes treated with 200 Gy ray showed an increased number of bolls per plant. Colored fiber genotypes treated with 200 Gy ray caused a slight fiber elongation than with lower doses of 100 and 150 Gy and the control. The result further revealed cotton genotypes treated with 100 and 200 Gy rays positively affected the yield-contributing traits. The above properties can be beneficial in the selection and improvement of colored fiber cotton genotypes.

Keywords: Upland cotton (*G. hirsutum* L.), colored cotton, genotypes, flowering, maturity, bolls per plant, seed cotton yield per plant, fiber length

Key findings: Colored fiber cotton (*G. hirsutum* L.) genotypes treated with 200 Gy had a positive effect on early maturity, bolls per plant, seed cotton yield, and fiber length compared with the 100 and 150 Gy and control.

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INTRODUCTION

Cotton (*Gossypium hirsutum* L.) is one of the valuable fibers and cash crops worldwide. Uzbekistan ranks fifth in cotton production and fourth in the export of cotton raw materials. It is one of the largest cotton-growing countries in the world. About 93% of the country's cotton plantations contain upland cotton varieties (Sanaev *et al.,* 2021; Amanov *et al.,* 2022; Makamov *et al.,* 2023). Cotton ginning and processing plants and the textile industry are the main sources of employment for millions of people. They constitute a significant share of the gross domestic product in various countries, including Uzbekistan, Australia, Greece, India, China, and Pakistan (Matniyazova *et al.,* 2022; Muminov *et al.,* 2023; Samanov *et al.,* 2024).

Improving fiber quality while increasing yield is the main goal of cotton breeding programs (Naoumkina *et al.,* 2019; Narimonov *et al.,* 2023). Fiber quality is a comprehensive index that includes fiber length, strength, and fineness. Seed cotton yield has several traits determining it, i.e., the number of bolls per plant, the number of plants per unit area, the lint percentage, and the single boll weight (Khamdullaev *et al.,* 2021; Shavkiev *et al.,* 2020, 2021; Azimov *et al.,* 2024a). However, a negative association mostly exists between fiber quality and seed cotton yield, and achieving a synchronous improvement of these traits through conventional breeding is difficult.

Worldwide, the most commonly cultivated cotton species is *Gossypium hirsutum* L., a tetraploid, also called upland cotton. It provides 90% fiber production, while *Gossypium barbadense* called the Egyptian cotton produces only 3% fiber. These species have also become the New World cotton (Amanov *et al.,* 2020; Shavkiev *et al.,* 2022, 2023; Chorshanbiev *et al.,* 2023; Azimov *et al.,* 2024c). Cotton varieties belonging to *G. hirsutum* L. are the main type cultivated as field crop in 77 countries worldwide, occupying an area of about 32.0 million ha and grown under various soil and climate conditions (Nabiev *et al.,* 2020; Shavkiev *et al.,* 2023; Azimov *et al.,* 2024c).

In plant genetics, a mutant material is the basis for understanding the function and relationship between genes controlling various traits. Early genetic research generally adopts positive methods to determine the genes controlling specific traits through the analysis of gene mutations (Masuka *et al.,* 2012). Radiation mutagenesis has been a widely used method in cotton breeding. Using cottonseeds irradiated by γ-rays have obtained the heat-tolerant and early maturing genotypes (Miroslaw *et al.,* 1995). The cotton variety 'Lumian 1', with a high and stable seed cotton yield, was also a cultivar developed through X-ray radiation from the hybrid population of cotton lines 'Zhongmian 2' and '1195' (Zhao *et al.,* 2022). Recently, a series of mutants have also resulted from space-based mutagenesis (Jia-He *et al.,* 2002).

For instance, Song *et al.* (2012) obtained and characterized the leaf-yellowing mutant by space-based mutation. Wang *et al.* (2012) isolated and characterized dwarf mutants through atomic energy mutation. Tong (2011) screened cotton mutants for glyphosate resistance through 60 Co-γ-ray mutations. Additionally, Yue *et al.* (2002) identified cotton mutants with gossypol-free glands through 60 Co-γ-ray radiations. The ion-beam implantation technology has also helped develop new germplasm for improving the cotton fiber quality (Yu *et al*., 2008). Chen and Liu (1993) found laser treatment of cotton could promote the general growth, seed cotton yield, and fiber quality variables of cotton. The establishment of the mutant form provides a powerful germplasm resource for accelerating research of cotton gene function and the development of new high-quality cotton cultivars. Therefore, the presented study sought to develop the positive mutant forms using ^{60}Co-γ-ray radiation in colored fiber cotton genotypes.

MATERIALS AND METHODS

Experimental site and genetic material

This study proceeded during 2022–2023 in the Tashkent Region of Uzbekistan (41.389° N and 69.465° E). This region experiences cold winters and long, hot, and dry summers. The

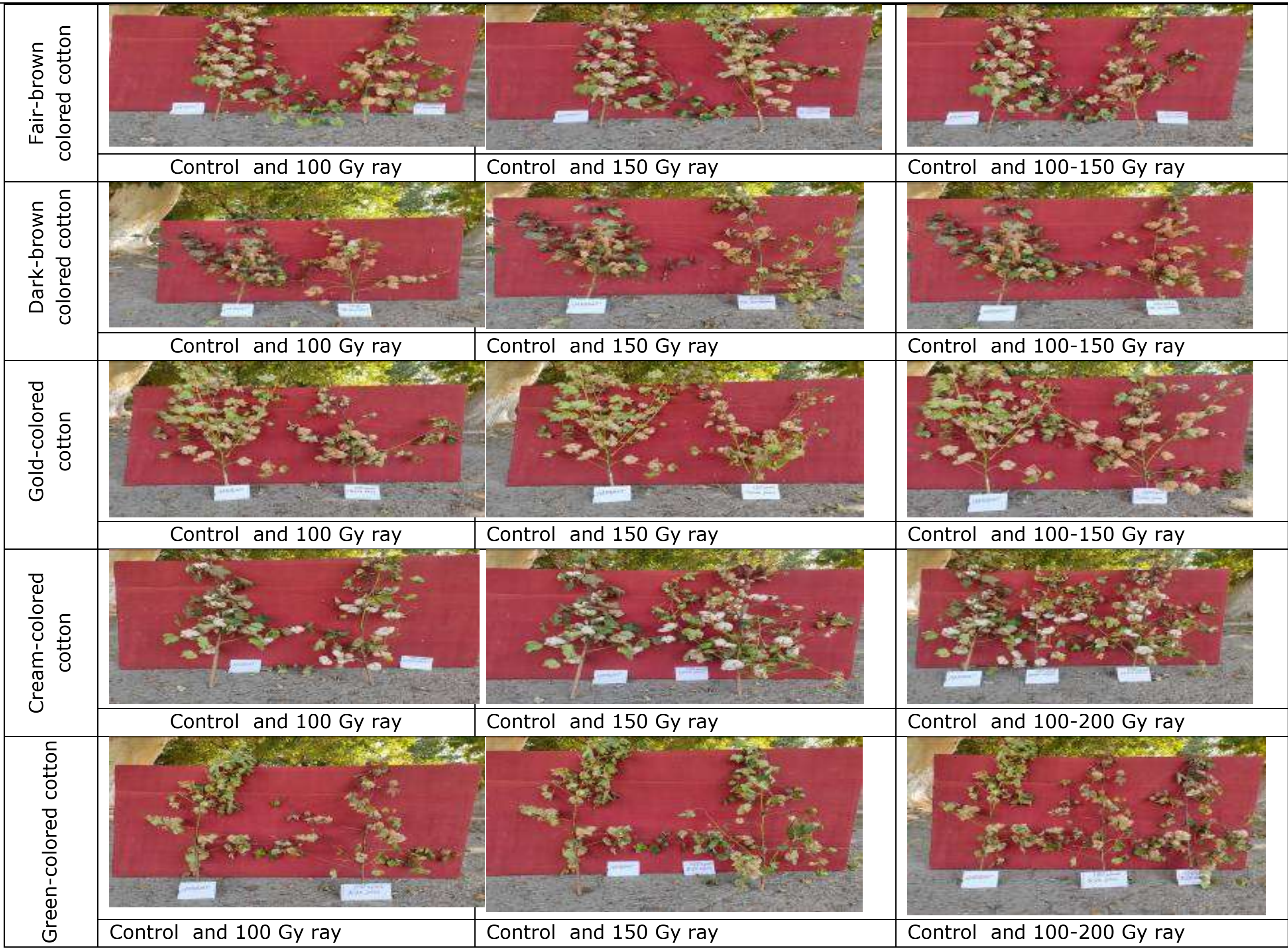

Figure 1. Phenotypic representation of the colored cotton genotypes treated with different doses of ^{60}Co-γ-radiation.

annual photoperiod (light/dark) is 16/8 h. These investigations involved studying the genetic potential and genetic aspects of five colored cotton (*G. hirsutum* L.) cultivars after ^{60}Co-γ-ray radiation. The cotton genotypes, divided into five different categories, comprised fair brown, dark-brown, gold-colored, cream-colored, and green-colored genotypes (Figure 1). Growing the five cultivars had a randomized complete block design with factorial arrangement and four replications. The cotton genotypes planted with plants and rows had spacings of 20 and 90 cm in 25-m long furrows. The temperature increased in April during the cotton-sowing season and decreased in late October before crop harvesting. The seasonal application of fertilizers proceeded during tillage and before irrigation annually, with 250:180:115 NPK kg ha^{-1}.

Linear electron accelerator radiation mutagenesis

The five-colored cotton genotypes used were under the care of the Institute of Nuclear Physics, Academy of Sciences of Uzbekistan, Tashkent, Uzbekistan. Plump seeds, uniform size, and clean epidermis seeds were samples in this experiment. Seeds reached exposure to a 60Co-γ-ray radiation dose of 0, 100, 150, and 200 Gy rays for an hour in a 10 MeV/20 kW reverse wave electron accelerator. This instrument functions automatically and can switch on automatically. The study followed the best radiation procedure for the experiment, with the results shown in Table 1.

Data recorded and statistical analysis

In the colored cotton genotypes, the data recorded comprised the morpho-yield and fiber quality traits. These are seed germination, flowering plant, early maturity, plant height, sympodial branches per plant, boll weight, bolls per plant, seed cotton yield per plant, and fiber length. These cotton parameters served to assess the effect of 100, 150, and 200 Gy ray conditions in comparison with optimal (control) conditions. The data also underwent the analysis of variance (Steel *et al.,* 1997).

RESULTS

Discussion on the fair brown, dark brown, gold-colored, cream-colored, and green-colored genotypes follows (Figure 1).

Fair-brown cotton genotypes

In this experiment, the seeds of fair brown-colored cotton (*Gossypium hirsutum* L.) genotypes sustained irradiation with Cobalt-60-Γ at 0 (control), 100, 150, and 200 Gy rays. The seed germination index of fair brown cotton genotypes under field conditions was 28 days in the control, while in the cotton genotypes treated with 100 to 200 Gy rays, the seed germination index was 24 and 25 days, respectively (Table 2).

By treating the seeds of fair brown cotton genotypes with control (0 Gy), 100, 150, and 200 Gy rays, the flowering period ranged from 74 to 76 days. However, no reliable difference appeared among the cotton genotypes with different radiation treatments for the following period. Although, significant differences were evident among the genotypes for early cotton maturity. It was noticeable that maturity was 106 days in the control version of the fair brown genotype, while 119 and 120 days in the 100 and 150 Gy rays treated genotypes, respectively. By treating the seeds of the fair brown cotton genotype with 200 Gy ray, recorded maturity increased up to 128 days.

Table 1. Mutation of cottonseeds treated with different mutagenic parameters.

Mutagenic dose	Mutagenic time	Fatality rate/Yellowing rate
100 Gy	1 hour	＜1%
150 Gy	1 hour	1%–10%
200 Gy	1 hour	＞10%

Table 2. Fair-brown colored cotton genotypes treated with different doses of ^{60}Co-γ-ray radiation for various morpho-yield traits.

Traits	0 Mean±SE	100 Mean±SE	150 Mean±SE	200 Mean±SE
Seed germination (days)	28.2±0.58	24.33±0.67	25±1.15	24.67±0.88
Flowering period (days)	76±1.73	74.33±0.88	76±1.15	75.5±1.22
Early maturity (days)	105.67±1.45	119±0.58	120±0.58	127.67±1.2
Plant height (cm)	125±4.66	120±3.66	120±2.89	112.5±1.44
Sympodial branches plant^{-1}	14.5±0.87	13.5±1.44	13±0.58	12±0.58
Bolls plant^{-1}	19.5±0.58	26±1.15	27.5±3.18	22.5±1.44
Boll weight (g)	5.5±0.83	4.4±0.18	4.08±0.20	5.9±0.36
Seed cotton yield plant^{-1} (g)	107.3±1.33	102.3±4.73	91.35±1.47	98.6±3.81
Fiber length (mm)	27.6±0.35	27.2±0.46	27.5±0.06	30.4±0.35

Plant height evaluation in cotton genotypes also occurred. The plant height was 125 cm in the control and 100-150 Gy rays, while it lowered to 112 cm in the treatment of 200 Gy rays. In fair brown cotton genotypes, the sympodial branches per plant decreased to 14 in the control and reached 12 to 13 in the experimental seeds treated with different Gy rays. The bolls per plant appeared to be 19 in the control, 26 to 27 bolls per plant in genotypes treated with 100 and 150 Gy rays, and up to 22 bolls per plant in the treatment of 200 Gy rays (Table 2). In cotton genotypes, the average boll weight was 5.5 g in the control, 4.4 g in the genotype treated with 100 Gy rays, 4.08 and 5.9 g, respectively, in the cotton genotypes treated with 150 and 200 Gy rays.

In fair brown cotton genotypes, the seed cotton yield per plant was 107.3 g in the control, 102.3 g in the genotype treated with 100 Gy ray, 91.3 g (150 Gy ray), and up to 98.6 g with 200 Gy ray treatment. For fiber length, no significant differences emerged in the fair brown cotton genotypes after treating with 0, 100, and 150 Gy, with a fiber length of 27 mm. However, by treating with 200 Gy ray, an increase of 30 mm was prominent in the fiber length of the fair brown colored cotton genotypes (Table 2).

Dark-brown cotton genotypes

In dark-brown cotton genotypes, the seed germination index under field conditions was 25 days in the control, while with 100 to 200 Gy treatments, it was 27 days (Table 3). The results further revealed the seed germination of dark brown cotton genotypes increased in the ray-treated compared with the control. No significant difference happened among the genotypes for flowering period. The flowering period of dark-brown genotypes had a range from 75 to 79 days in genotypes exposed to Gy ray at 0, 100, and 200 Gy seeds. However, by treating with only 150 Gy ray, the genotypes notably had an increased level at 85 days. In the dark-brown cotton genotypes, the early maturity ranged from 118 to 124 days in the genotypes treated with 0, 100, and 200 Gy rays. Differences were nonsignificant among the genotypes according to early ripening period. However, the cotton genotype increased up to 129 days by treating their seeds with 150 Gy ray.

In the dark-brown cotton genotypes, the control variant showed a plant height of 112 cm, 125 cm in the genotype treated with 100 Gy ray, 102 cm with 150 Gy, and 120 cm when treated with 200 Gy ray. The sympodial branches per plant increased to 12 in the control and reached 13 to 14 in the genotypes treated and irradiated with Gy rays. The bolls per plant in dark-brown cotton genotypes elevated from 24 to 28 when exposed to Gy rays with 0, 100, and 200 Gy seeds. However, the cotton seeds treated with 150 Gy ray showed a decrease of up to 20 (Table 3). The control variant in this genotype showed a boll weight of 6.4 g, 4.8 g in the genotype treated with 100 Gy ray, 5.8 g with 150 Gy, and 5.1 g with 200 Gy treatment.

Table 3. Dark-brown colored cotton genotypes treated with different doses of ^{60}Co-γ-ray radiation for various morpho-yield traits.

Traits	0 Mean±SE	100 Mean±SE	150 Mean±SE	200 Mean±SE
Seed germination (days)	24.7±1.5	26.7±0.9	26.7±1.8	27±1.2
Flowering period (days)	76.7±0.9	75±0.6	85.3±2.9	79.3±1.8
Early maturity (days)	123.7±1.9	118.3±2	129.3±1.8	121.7±2.0
Plant height (cm)	112.5±1.4	125±2.9	102.5±1.4	120±5.8
Sympodial branches plant^{-1}	12.5±0.3	14±0.6	13±0.6	14.3±1.2
Bolls plant^{-1}	24.5±0.9	26.3±1.2	20.5±2.0	28.7±0.7
Boll weight (g)	6.4±0.2	4.8±0.45	5.8±0.1	5.1±0.2
Seed cotton yield plant^{-1} (g)	115.4±2.8	100.6±10.8	58.3±5.5	133±10.2
Fiber length (mm)	28.8±0.6	28.1±0.5	28.1±0.4	28.3±0.4

Table 4. Cream-colored cotton genotypes treated with different doses of ^{60}Co-γ-ray radiation for various morpho-yield traits.

Traits	0 Mean±SE	100 Mean±SE	150 Mean±SE	200 Mean±SE
Seed germination (days)	27±0.6	25±1.2	27±1.2	26±0.6
Flowering period (days)	92±1.2	79±0.6	82±1.2	88.3±1.5
Early maturity (days)	125±0.6	116.7±1.5	125±0.6	124±1.5
Plant height (cm)	101.7±1.7	111.7±4.4	117.5±4.3	112.5±1.4
Sympodial branches plant^{-1}	12.7±0.3	13±0.6	15±0.1	14.5±0.9
Bolls plant^{-1}	25±1.2	28.3±2.3	26±0.6	26.5±2.0
Boll weight (g)	5.4±0.1	5.2±0.3	4.8±0.2	4.9±0.4
Seed cotton yield plant^{-1} (g)	67.9±1.4	79±3.6	73.5±8.7	84.5±3.4
Fiber length (mm)	31.4±0.4	28.3±0.7	30.7±0.2	31.8±0.1

Notably, the seed cotton yield per plant was 115.4 g in the control, 100.6 g in the dark-brown cotton genotype treated with 100 Gy ray, 58.3 g (150 Gy), and 133 g in the cotton seeds treated with 200 Gy ray. For fiber length, non-significant differences were typical in dark-brown cotton genotypes treated with 0, 100, 150, and 200 Gy rays with a fiber length of 28 mm (Table 3).

Cream-colored cotton genotypes

Seeds of cream-colored cotton genotypes irradiated with 0 (control), 100, 150, and 200 Gy rays had a seed germination index of 25 to 27 days under field conditions. Nonsignificant differences appeared among the cotton genotypes even by exposing Gy ray for the said character (Table 4).

The results further detailed the flowering period was 92 days in the control, 79 days by treatment with 100 Gy rays, 82 days (150 Gy), and 88 days in the cotton seeds treated with 200 Gy rays. However, cream-colored cotton genotypes showed significant differences by treatment with 0 (control), 150, and 200 Gy rays, except for the genotype treated with 100 Gy rays. Cream-colored cotton genotypes treated with 100 Gy ray exhibited early maturity and decreased up to 117 days. By comparing the plant height in cream-colored genotypes in control and treated with various doses of Gy, the cotton genotypes treated with 100, 150, and 200 Gy rays showed a range from 112 to 118 cm, while the control variant's plant height was 102 cm.

Sympodial branches per plant in cream-colored cotton genotypes ranged from 13 to 15 in control and cotton genotypes with 100, 150, and 200 Gy rays irradiation. However, no significant differences showed in the cotton genotypes for all treatments (0 [control], 100, 150, and 200 Gy rays). The bolls per plant amounted to be 25 to 28 in cotton genotypes irradiated with all treatments, and the genotypes revealed non-significant differences for the said trait (Table 4). In cream-colored cotton genotypes, the boll weight was 5.4 g in the control variant, 5.2 g in the genotype treated with 100 Gy rays, 4.8 g (150 Gy), and 4.9 g treated with 200 Gy rays. However, the results revealed the boll weight declined in the genotypes treated with Gy rays compared with the control.

Cream-colored cotton genotypes' seed cotton yield per plant provided 67.9 g in the control, 79.0 g in 100 Gy, 73.5 g in 150 Gy, and 84.5 g by treating cotton seeds with 200 Gy rays. It was evident that seed cotton yield per plant increased in the cream-colored cotton genotypes by treating with different doses of Gy versus the control treatment. The fiber length emerged to be 28 mm in the cream-colored cotton genotypes treated with 100 Gy rays. However, the fiber values of the genotypes treated with 0, 150, and 200 Gy rays were notably higher than 30 mm, with nonsignificant differences observed among these cotton genotypes for fiber length (Table 4).

Gold-colored cotton genotypes

In the seeds of gold-colored cotton genotypes with control and treatments with 100, 150, and 200 Gy rays, the seed germination ranged from 24 to 27 days under field conditions (Table 5). The flowering period was 80 days in the control, 75 days (100 Gy), 83 days (150 Gy), and 82 days with 200 Gy rays treatment. For early maturity, 127 days resulted in the control, 117 days (100 Gy), 125 days (150 Gy), and 115 days by treating cottonseeds with 200 Gy rays. In gold-colored genotypes of cotton, the plant height recorded was 119 cm in the control, 112 cm (100 Gy), 107 cm (150 Gy), and 117 cm by treating the cotton genotypes with 200 Gy rays.

The sympodial branches per plant for this cotton genotype decreased from 15 (control) and 11 to 13 in the experimental variants treated with different doses of Gy. The bolls per plant were 24 in the control, 17 (100 Gy), 21 (150 Gy), and 29 in the cotton genotypes with 200 Gy rays treatment (Table 5). In these gold-colored cotton genotypes, the boll weight was 5.7 g in the control, 4.5 g (100 Gy), 4.7 g (150 Gy), and 4.9 g in the cotton genotypes treated with 200 Gy rays.

The seed cotton yield per plant was 49.5 g in the control, 82.4 g (100 Gy), 66.6 g (150 Gy), and 99.7 g by treating cottonseeds with 200 Gy rays (Table 5). In the gold-colored cotton genotypes with control and treated with 150 and 200 Gy rays, the fiber length ranged from 27 to 28 mm. The treatment with 100 Gy rays gave an increase in fiber length (29 mm) in these cotton genotypes.

Green-colored cotton genotypes

The seed germination indexes were 27 days in the control, 25 days in variants treated with 100 to 150 Gy rays, and 26 days by treating the green-colored cotton genotypes with 200 Gy under field conditions (Table 6). For the seed germination index, these cotton genotypes showed nonsignificant differences when treated with different doses of Gy.

In green-colored cotton genotypes with control and treatment with 100 and 200 Gy, the flowering period ranged from 84 to 86 days. However, no reliable difference among the genotypes appeared for the flowering period by treating with different doses of Gy rays. However, the cotton genotypes treated with 150 Gy gave the flowering period of 76 days, while with the control and irradiated 150 Gy, a significant difference in the reduction emerged compared with genotypes treated with 100 and 200 Gy rays.

In green-colored cotton genotypes, the early maturity was 114 days in control, and the cotton genotypes treated with 100, 150, and 200 Gy recorded 120, 121, and 107 days, respectively. The plant height was 120 cm in the control, while with 100 and 150 Gy rays, the plant height was 113 and 110 cm, respectively. However, the variant with 200 Gy showed a significant difference, with the plant height reduced to 102 cm. The green-colored cotton genotypes had reduced sympodial branches per plant to 13 in the variants treated with 100 to 150 Gy and further reduced to nine in the cotton genotypes treated with 200 Gy rays.

Table 5. Gold-colored cotton genotypes treated with different doses of ^{60}Co-γ-ray radiation for various morpho-yield traits.

Traits	0 Mean±SE	100 Mean±SE	150 Mean±SE	200 Mean±SE
Seed germination (days)	27.3±0.9	25.3±0.9	26±0.6	24.3±1.2
Flowering period (days)	79.7±0.9	74.7±0.9	83±1.5	82.3±1.5
Early maturity (days)	127±0.6	116.7±0.9	125±0.6	114.7±0.9
Plant height (cm)	119±0.6	112.5±1.4	107.5±1.4	117.5±1.4
Sympodial branches plant^{-1}	15±0.6	12±0.6	11.5±0.3	13.5±0.3
Bolls plant^{-1}	24.5±0.3	17±1.2	21.5±0.3	29.5±0.3
Boll weight (g)	5.7±0.2	4.5±0.1	4.7±0.2	4.9±0.1
Seed cotton yield plant^{-1} (g)	49.5±0.7	82.4±4.5	66.6±10.9	99.7±3.2
Fiber length (mm)	27.5±0.1	29±0.1	27.8±0.5	28.7±0.2

Table 6. Green-colored cotton genotypes treated with different doses of ^{60}Co-γ-ray radiation for various morpho-yield traits.

Traits	0 Mean±SE	100 Mean±SE	150 Mean±SE	200 Mean±SE
Seed germination (days)	27.3±0.9	24.7±0.9	25.3±0.9	26±0.6
Flowering period (days)	86±0.6	76.7±1.8	83.7±1.9	86.3±1.5
Early maturity (days)	113.7±0.9	121.3±1.9	120±2.9	107±1.5
Plant height (cm)	120±2.9	113.3±4.4	110±2.9	102.5±1.4
Sympodial branches plant^{-1}	13.3±0.9	13.7±0.9	12.3±0.7	9.5±0.3
Bolls plant^{-1}	31±2.1	20.7±2.2	33.3±1.7	33.5±0.9
Boll weight (g)	4.8±0.1	4.5±0.1	5±0.8	4.1±0.2
Seed cotton yield plant^{-1} (g)	80.5±2.7	76.1±5.2	64.9±8.2	130.1±7.2
Fiber length (mm)	30.1±0.5	27.2±0.6	30.6±0.8	31.7±0.2

The bolls per plant showed to be 31 in the control variant, 33 in the irradiation treatments with 150 and 200 Gy rays, and up to 20 in the cotton genotypes treated with 100 Gy rays. In green-colored cotton genotypes, the number of flower buds opened with the control variant was eight, while 10 in the genotypes treated with 100 and 200 Gy rays, and nine buds in the cotton genotype treated with 150 Gy rays (Table 5). However, the cotton genotypes with control and different doses of Gy revealed nonsignificant differences for flower buds. In green-colored cotton genotypes, the boll weight was 4.8 g in the control variant, 4.5 g (100 Gy), 5.0 g (150 Gy), and 4.1 g in the genotypes treated with 200 Gy rays.

For these green-colored cotton genotypes, the seed cotton yield per plant was 80.5 g in the control variant, 76.1 g (100 Gy), 64.9 g (150 Gy), and 130.1 g with 200 Gy rays treatment. The fiber length of green-fiber cotton genotypes arose from 30 to 31 mm in the control and in the genotypes treated with 150 and 200 Gy rays. Overall, the cotton genotypes showed nonsignificant differences in the fiber length. However, the green-colored cotton genotypes treated with 100 Gy rays displayed a decrease in fiber length (27 mm) (Table 6).

In colored fiber cotton genotypes under field conditions, the seed germination index was 25 days with dark-brown fiber, while in the rest of the genotypes, the seed germination ranged from 27 to 28 days. It was notable that the longest flowering period was 92 days in the cream-colored cotton genotypes, while the shortest (76 days) in the brown-colored cotton genotypes. The plant height was highest (125 cm) in light-brown cotton genotypes, and the lowest value (101 cm) was in cream-colored cotton genotypes. The sympodial branches were close to each other in different colored cotton genotypes, and no considerable differences were evident among the genotypes for the said trait. Overall, in green-colored cotton genotypes, the bolls per plant were the highest (31). According to boll weight, the maximum boll weight (6.4 g) was prominent in dark-brown cotton genotypes, while the minimum boll weight (4.8 g) emerged in green-colored cotton genotypes. Seed cotton yield per plant proved to be higher (100 g) in brown-colored cotton than other fiber-colored cotton genotypes. In cream-colored cotton genotypes, it was visible that the fiber length was the maximum (31 mm).

The seed germination index appeared to be similar among the colored cotton genotypes treated with 100, 150, and 200 Gy rays. A prolonged flowering period was common in cotton genotypes treated with 100 to 200 Gy rays. The shortest days to maturity were distinct in green-colored cotton genotypes treated with 200 Gy rays (107 days), while other colored cotton genotypes manifested with 120 and 130 days, on average. In the presented experiment, the colored cotton genotypes treated with 150 Gy rays showed an increased plant height, while the genotypes treated with 200 Gy rays decreased in plant stature. Sympodial branches ranged from 11 to 14 in different colored cotton genotypes. However, the green-colored genotypes treated with 200 Gy showed a reduced number of sympodial branches (9). Overall, the bolls per plant were higher in green and gold-colored cotton genotypes treated with 100 to 200 Gy. Among the colored cotton genotypes treated with 100, 150, and 200 Gy rays, the boll weight increased and decreased with different degrees.

Seed cotton yield per plant occurred to be higher in colored fiber genotypes treated with 100 Gy rays than the genotypes treated with 150 Gy rays. The increase in cotton yield per plant was notable with a significant difference in the colored cotton genotypes treated with 200 Gy rays, primarily in dark brown-colored, gold-colored, and green-colored cotton genotypes. The colored cotton genotypes irradiated from 100 to 200 Gy, the fair brown-colored, cream-colored, and green-colored cotton genotypes showed a significant difference and displayed an increased fiber length, ranging from 30 to 31 mm.

DISCUSSION

Several studies indicated that gamma rays (γ-ray) were effective in shifting the means and increasing the genetic variance of quantitative characters in various genotypes of upland cotton (Yue and Zou, 2012; Muhammad *et al.,* 2015; Khan *et al.,* 2017). Colored cottons can reduce the bleaching and dyeing components of the textile process and potentially reduce environmental pollution. Therefore, since discovering the colored cotton mutants, it has become the research focus (Zhang *et al*., 2017).

At present, natural colors only have brown, green, and red (Zhu *et al.*, 2006). Although the genetic basis is unknown, natural-colored cotton has poor fiber quality and uneven color distribution, and therefore, it is not feasible for use by the textile industry. In analyzing the relationship between cotton color and quality, developing a series of brown and green-colored cotton cultivars progressed, each consisting of approximately five individuals. These new fair-brown, dark-brown, cream, gold, and green cotton mutants were similar to the control material about yield and fiber quality traits (Figure 1).

Notably, plant height decreased when increasing radiation dose in several cotton genotypes with colored fibers. Similar results have also come from Yue and Zou (2012). They observed, on exposure to radiation doses, the average plant height was shorter than the control in some varieties of cotton. These observations are reasonably in full conformity with a report by Muthusamy and Jayabalan (2012), who stated that some lower doses of both chemical and physical mutagens induced positive mutation for increasing seed yield in cotton. This experiment detailed the seed yield increased when increasing radiation in various cotton genotypes.

The development of cotton mutants is of great significance for cotton genetic improvement and in creating new cultivars. Conventional breeding has made countless contributions to the cultivation of cotton varieties. However, the increasingly biased manipulation of available genetic variability in cotton germplasm resources has led to much loss of genetic potential and eventually increased the susceptibility to pests (Aslam *et al.*, 2016). The cotton mutant types developed in the presented study provide valuable germplasm resources for cotton genetic improvement and functional genomics.

CONCLUSIONS

Early maturity recording resulted in some colored cotton (*G. hirsutum* L.) genotypes by treating them with 100 to 200 Gy rays. Color fiber genotypes treated with 200 Gy rays showed an increased number of bolls per plant. Seed cotton yield per plant was higher in the gold-colored and green-colored cotton genotypes treated with 200 Gy rays. Treating the colored cotton genotypes with 200 Gy caused a slight enhancement in fiber elongation compared with the control and irradiation with lower doses.

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