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Research Article

Morphological and agronomic characterization of colored cotton cultivars of *G. hirsutum* L.

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Abstract

Nowadays, the demand for organic products is increasing. Breeding of naturally colored cotton allows for saving the high costs of dyeing the fiber and obtaining a natural product that is harmless to the human body. Natural colored fiber has air permeable, antiseptic and hydrophobic properties. However, the use of natural colored cotton in the textile industry is limited due to its low fiber quality. Solving this problem requires interdisciplinary research on colored cotton. In the article, morphological traits of natural brown and green cotton cultivars of *G.hirsutum* L. cotton - duration of vegetation period, plant height, leaf shape, color and hairiness of the main stem, boll shape, type of sympodial branching and fiber color also, agronomic traits – a boll weight, fiber yield and index, fiber length, weight of 1000 seeds were determined and analysis results were presented. The obtained results showed that the brown cotton samples are medium-ripening, the green cotton cultivars are late-ripening, and the plant height of the green cotton cultivars is higher compared to the brown cotton cultivars. Fiber length was longer in the cultivars cone-oval shape of boll than in cultivars with round shape. Fiber length was higher in green fiber cultivars A-800 and 010764 than dark brown fiber cultivars 011250 and 010108. In contrast, brown fiber cultivars had higher indicators than green fiber cultivars in terms of fiber yield, index and boll weight. Green cotton cultivar 011460 with low fiber yield had the highest index of 1000 seeds weight. In terms of cotton yield, dark brown fiber cultivar 011250 (97.4±2.0g) showed a higher index compared to other cultivars. This shows that cultivar 011250 can be used as a raw material to increase the yield of colored cotton.

Keywords: *G.hirsutum* L., colored cotton, morphology, trait, fiber length, seed weight, fiber yield.

Introduction

Currently, the textile industry is tasked with fully processing the fiber obtained from the cotton fields in our country, and making clothes and other products that satisfy the domestic demand and are aimed at export. Global fiber production has almost doubled in the last 20 years, increasing from 58 million tonnes in 2000 to 109 million tonnes in 2020, and is expected to increase another 34 percent in the next 10 years (https://textileexchange.org; Amanov *et al.*,2020; Chorshanbiev *et al.*,2023). An estimated 97% of global organic cotton was produced by just eight countries in 2020/21: - India (38%), Turkey (24%), China (10%), Kyrgyzstan (9%), Tanzania (6%), Kazakhstan (4%), Tajikistan (4%), and the US (2%). The remaining 13 organic cotton-producing countries accounted for 3% (https://textileexchange.org; Muminov *et al.*,2023;). The present top-producing countries of colored cotton in the world are China, USA, India, Pakistan, and Uzbekistan (Amanov *et al.*,2022). Among all, the United States of America possesses a considerable share in world exports. From the overall statistics, the average per capita annual consumption of textile fibers in the world is about 8 kg of which 3 kg is cotton (Dodamani et al.,2010). A research report by textile exchange.com revealed the total amount of organic cotton used by the top ten brands has grown by 25% since 2014, an increase of 39,950 metric tons of fiber (70.4 million lbs). All these factors are indications that the naturally colored cotton material also will get its market position as soon as possible. In 2014, around 46% of C&A's cotton collection was made out of more sustainable cotton, close to 40% of organic cotton (https://store.textileexchange.org).

It is known that the main cost of making clothes and other products from the white fiber is spent on dyeing chemicals and the dyeing process. Such products hurt the human body and lead to large costs. Therefore, in modern cotton farming, much attention is paid to organic production. In this case, fertilizers, along with abandoning toxic chemicals, did not use artificial chemical dyes, which are widely used in the process of dyeing gauze in the textile industry and cause various allergic diseases of the human body and high costs, obtaining ecologically pure, naturally colored fiber and textile products made from it is of practical importance.

Naturally colored cotton, resist pests, salt, and drought better, so it reduces toxic pesticide application, thereby causing less environmental pollution and is very adaptable to dry land and organic farming (Günaydin et al.,2009) and Khan et al., 2010, Shavkiev et al., 2021, Shavkiev et al., 2022; Matniyazova et al., 2022; Shavkiev et al., 2023; Makamov et al., 2023). These cotton varieties also eliminate the bleaching and dyeing costs and excessive energy usage (Crews and Hustvedt, 2005; Atav et al., 2022). The unique property of the colored cotton is non-necessity of dyeing. According to the statistics, the colored cotton would eliminate the cost of dyeing by 50% and also it is an environment-friendly fiber which could result in disposal cost of toxic dye waste (Rathinamoorthly and Parthiban, 2017). The antibacterial activity of naturally colored cotton is also evaluated by researchers. In their findings, they report that, compared to the conventional white cotton, brown naturally colored cottons were found to exhibit excellent antibacterial activity with a reduction rate of 89.1% and 96.7%, when in contact with two species of bacteria, *staphylococcus aureus* and *Klebsiella pneumoniae*, respectively (Ma *et al.,* 2013). There is a high necessity for natural colored fibers in the textile, military, and medical fields. The fiber of samples with colored fiber is short, fiber strength is low, and it is urgent to carry out genetic-selection research to eliminate such defects. Naturally coloured cotton grown using organic farming methods is the most suitable alternative for a cleaner eco-friendly environment. National Cotton GeneBank is maintained by The Central Institute for Cotton Research (Cicr, Nagpur, which preserves nearly 6000 varieties of cotton germplasm grown in India and abroad of which nearly' 40 are of coloured cotton (Chhabra *et al.,* 2010). After more than 30 years of research and breeding, Chinese researchers have developed 38 color cotton varieties, which account for 90% of all color cotton varieties registered in the world (Gong *et al., 2018*). In the international market colored linted cottons ranging from beige to light, chocolate brown and green is now available. However, cotton with colored lint is low-yielding and produces inferior fiber, which does not usually meet the minimum spinning requirements (Feng *et al.*, 2015; Nivedha *et al.*, 2020).

According to UNITEXTIL (Unidade Têxtil Nordeste Ltda, João Pessoa-PB, Brazil), the consumption of water required to manufacture 300 kg of mesh with colored fiber, in a machine with a ratio of 1:4, is 1,200 liters, while with white fiber, the consumption is of 9,600 litres, equivalent to a ratio of 1:8 (Barros *et al*., 2020). Conventional breeding provides the means for improving yield, fiber quality and lint colors in cotton. The pioneer breeding work done by Fox revealed that seed cotton yield, fiber characters and different lint colors might be improved (Günaydin *et al.*,2009; Matusiak *et al.*, 2007; Nivedha *et al.*, 2020). Research work on colored cotton in Turkmenistan, Fursov I.N. carried out by and natural colored Genetic-34, Genetic-37, Genetic-38, Genetic-40 varieties were created and information was given that the fibers of these varieties have antibacterial properties, that is elimination of dangerous human pathogens (Fursov, 1995). When *G.hirsutum* L. lines, having brown lint and possessing low fiber quality, were crossed with lines having white lint, high yield and superior fiber strength and length, the hybrids exhibited better fiber properties than those of brown lint parents (Campbell *et al*., 2009). Carvalho *et al*. (2014) in researches *G.barbadense* type fiber cross-bred brown and white samples to study the inheritance of the color of fiber. White fibrous plants with colored fiber gave separation in F_2 in a ratio of 3:1. The pigment stability of brown cottons differs greatly between genotypes. The brown cotton color is usually more stable in *G.arboretum* L than in *G. hirsutum* L. In *G.hirsutum* L, a great difference exists in terms of pigment stability. Green cottons are very unstable and fade rapidly. It is a common phenomenon to see a contrasting color difference between green cottons stored under dark and those stored under nature light (Gong *et al*., 2018).

Research has been carried out by scientists from Uzbekistan on the study of the inheritance of the color of fiber. Including Simongulyan N.G. *et al*. (1984) *G.hirsutum* L. varieties F-108 and 149-F with white fibers of interbreed with the brown fiber *mexicanum nervosium*. The resulting F_1 hybrids received an intermediate color according to the color of the fiber. In F_2, separation by fiber color was observed, with 9 parts colored and 7 parts white fibrous plants obtained. This ratio is characteristic of the Complementary type of gene interaction. Based on the genetic analysis of the obtained evidence, the authors express an opinion that fiber color is controlled by 3 genes - Lc- lc, Lc2 lc2, Lc3 lc3 (Simongulyan, 1984).

The lint colour is determined by, a group of genes situated at the 3 loci, LC1, LC2 and LC3. They are dominant over the white alleles and operate in association with modifier genes that are either intensifiers or suppressors. When strong suppressors are present, white fibre is produced. Genes for lint colour not only control the colour of the fibre but also other traits e.g. gene for the brown color in *G.arboreum* and *G.barbadense* L. suppresses lint length and fineness. Similarly in green and brown of *G.hirsutum* L. fibre development is inhibited (% mature fibres is low). But not all associations are unfavourable, in certain varieties boll weight is higher due to colour genes. Color development is also dependent on external factors like sunlight, soil type and soil nutrition (Chhabra *et al*., 2010). It should be noted that before carrying out genetic-selection studies on inheritance, variability and correlation of morphological and economic traits in colored fiber cotton, it is important to determine the indicators of these traits in the primary materials. The purpose of the study is to determine and analyze the indicators of morphological and major agronomic characteristics of *G.hirsutum* L. colored cotton cultivars.

Material and methods

The field experiments of our research were conducted at the experimental field of the regional experimental base of the Institute of Genetics and Plant Experimental Biology, located in Zangi-ota district, Tashkent region. This experimental base is located 398 meters above sea level. The land of the experimental field is low humus, typical meadow-saz soil according to its mechanical composition, the soil is moderately sandy. The terrain is slightly sloping, unsalted, weakly damaged by verticillium wilt. Groundwater is deep (7-8 m). The climate is sharply variable, summer (June, July, August) is very hot, and winter (especially December and January) is characterized by a sharp drop in air temperature. Sunny days are 175-185 days, the total cold-free period is 200-210 days. In autumn, winter and spring there is precipitation, and in summer the air is dry. This requires artificial irrigation of cotton.

Table 1. Maximum and minimum temperatures, air humidity, and total rainfall during the study period.

Months	Maximum temperature (°C)		Minimum temperature (°C)		Average relative humidity (%)		Total rainfall (mm)	
	2022	2023	2022	2023	2022	2023	2022	2023
April	+27	+29	+4	+4	32%	34%	3.98	4.38
May	+33	+35	+8	+10	30%	33%	2.95	3.36
June	+37	+38	+15	+16	25%	30%	1.15	1.90
July	+43	+40	+20	+19	15%	19%	0.00	0.12
August	+39	+36	+17	+15	14%	18%	0.00	0.05
September	+32	+30	+11	+10	22%	21%	0.36	0.31
October	+29	+26	+3	+4	29%	26%	2.74	2.55

Agrotechnical activities in the experimental area: in the autumn, the ground was plowed to a depth of 35 cm. Planting was carried out in the spring when the air and soil temperature were moderate. Planting was carried out in the 90x20x1 scheme on a marked field. The seeds were planted in the ground at a depth of 4-5 cm. The studied samples were planted in 3 replicates, 1 row per replicate, in 12 slots in each row by the randomization method. Work between the rows and weeding were carried out together with irrigation. In the experiment, watering was carried out according to the 1-2-1 scheme. *G. hirsutum* L. cultivars of brown fiber: catalog numbers, 010765, 010108, 011250 and green fiber catalog numbers: 010764, 011460 and A-800 were taken.

Laboratory and field experiments were performed according to generally accepted methods. Genetic-selection methods-phenological observations, statistical processing and scientific analysis methods were used. Among the major agronomic traits - cotton yield, a boll weight , fiber yield, fiber length, weight of 1000 seeds were determined by generally accepted methods (Jumanov *et al*., 2022; White *et al*., 2012). The obtained indicators were statistically analyzed, the reliability of the differences was determined by Fisher's criterion (F) of the Statgraphics 18 (ANOVA), the standard deviation (SD) of the experiment for each trait, the standard error (SE) of the average indicators.

010765 brown | 010108 dark brown | 011250 dark brown

011460 green | A-800 Green | 010764 light green

Figure 1. Objects of research and fiber color.

Results

Morphobiological traits in cotton directly affect the normal course of physiological and biochemical processes in plants, as well as their productivity and quality indicators. In our research, morphobiological traits of colored cotton cultivars (duration of vegetation period, plant height, plant stem color and hairiness, sympodial branching type, leaf and boll shape, fiber color) were studied.

The highest indicator of the length of the main stem was observed in the cultivar of green fiber, catalog number 011460, and the mark was 126.5±1.7 cm. The lowest indicator (103.0±0.8 cm.) was found in the cultivar of brown fiber, catalog number 010765. Studying the genetics of leaf shape is important not only for selection, but also for cotton phylogeny. It was observed that normal shape of the leaf is from 2-lobed to 5-lobed in all cultivars. It was found that the bolls have an cone-oval shape in green fiber cultivars 011460 and 010764, and all other cultivars have a round shape (see Table.1). The color of the main stem was found to be light green with anthocyanin spots (cultivar 010108) and green anthocyanin color (cultivars 010765 and 011250) in brown fiber samples. The color of the main stem of the green fiber samples was noted to be green with anthocyanin spots in cultivar A-800, green in the sample with catalogue number 011460, and weak green anthocyanin spots in a cultivar of catalogue number 010764. The main stem, green fiber catalog number 011460 was found to have short and thick hairiness and other cultivars had medium hairiness (Table 2).

The category and subcategories of the yield - sympodial branches of cotton belong to valuable - agronomic traits, therefore, it is of great importance to study the laws of the development of the category of sympodial branches of cotton. In the scientific literature, the cotton plant is grouped into limited and unlimited branches and, at the same time divided into cylindrical, cone-shaped and branched forms according to the types of branching (I, II, III) (Sanaev N.N. *et al*.) The type of branching was brown-fibered, catalog number of 010108 and green-fibered, catalog number of 011460, unlimited, type III branching. All other samples had unlimited type II branching (Table 2).

Table 2. Morphobiological traits (plant height, leaf shape, plant stem colour and hairiness, boll shape, sympodial branching types, fiber color) in colored cotton cultivars.

Catalog number of colored cotton cultivars	Plant height (sm)	Leaf shape	Plant stem colour and hairiness	Boll shape	Sympodial branching types	fiber color
010765	103.0±0.8	Normal	Green with anthocyanin spots, medium short hairy	Round	Unlimited, type II	brown
010108	104.5±1.4	Normal	Light green with anthocyanin spots, medium hairy	Round	Unlimited, type III	dark brown
011250	107.6±0.8	Normal	Green with anthocyanin spots, medium hairy	Round	Unlimited, type II	dark brown
A-800	115.5±1.5	Normal	Green with anthocyanin spots, medium hairy	Round	Unlimited, type II	green
011460	126.5±1.7	Normal	Green, thick short hair	Cone-oval	Unlimited, type III	green
010764	117.0±1.1	Normal	Green with weak anthocyanin spots, medium hairy	Cone-oval	Unlimited, type II	green

The duration of the vegetation period is a sign of early, medium or late ripening of the plant. Fast-ripening is determined by the duration of the periods from germination to budding, from budding to flowering and from flowering to ripening. In our research, the shortest duration of the vegetation period was observed in the cultivar of brown fiber 010108, which was 117.2±0.7 days. The longest duration of the vegetation period was recorded in the green fiber cultivar with catalog number 011460 (126.2±0.6 days). The remaining samples had intermediate indicators (Fig. 2).

September and October crops were harvested. agronomic characteristics (a boll weight, cotton yield, fiber yield, index and length, weight of 1000 seeds) were studied, indicators were determined, statistically processed and analyzed.

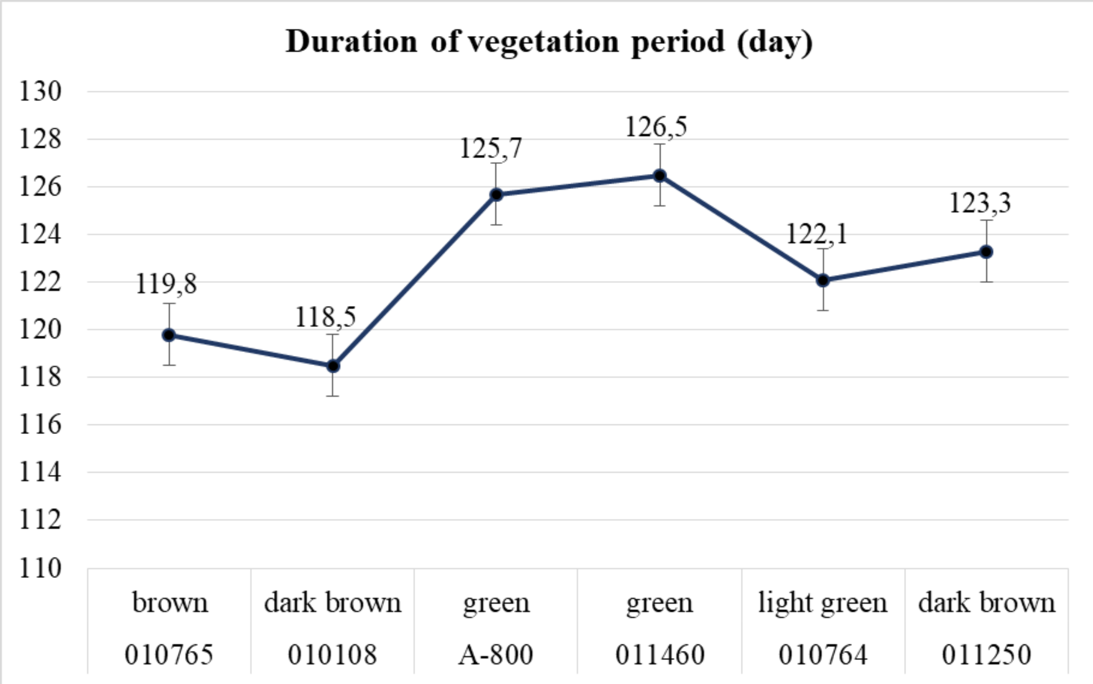

Figure 2. Indicators of the duration of vegetation period in colored cotton cultivars.

It is known that one of the components of productivity is the indicator of the boll weight The manifestation of this trait is substantially influenced by agrotechnical measures and external environmental conditions. The highest index of a boll weight is in the cultivar of with brown fiber, catalogue number 011250 (5.7±0.2 g), and the lowest index is in the cultivar of A-800 with green fiber (4.0±0.1 g) was determined (Figure 3).

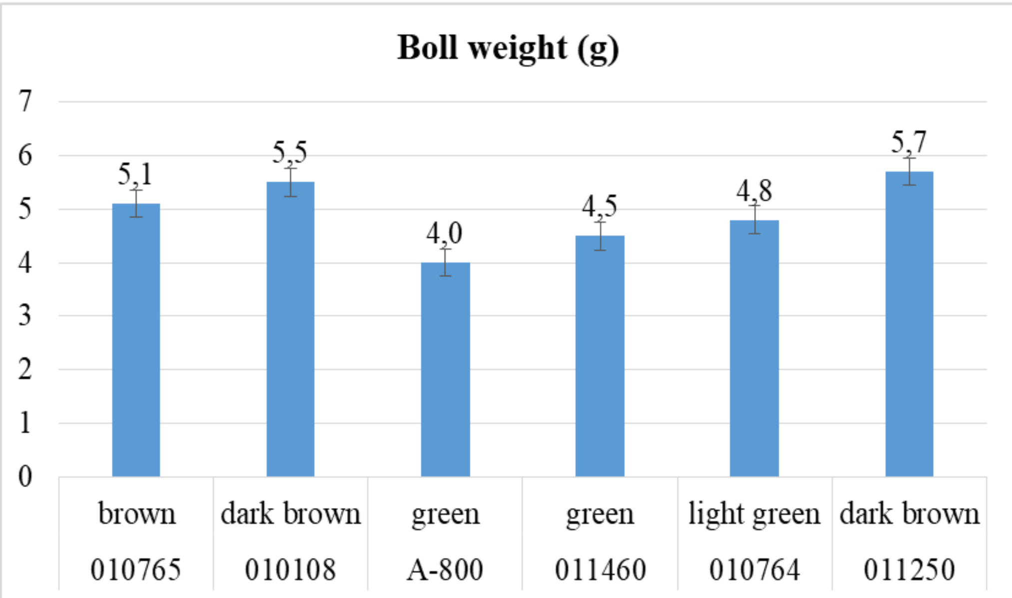

Figure 3. Indicators of a boll weight in colored cotton cultivars.

Cotton yield is an indicator of the total yield of one plant. In our experiment, the highest indicator of cotton yield was in the cultivar 011250 with brown fiber (97.4±2.0 g), and the lowest indicator in the cultivar A-800 with green fiber (62.8±2.4 g) was determined (see Table.2). Fiber yield is the ratio of fiber weight to total cotton weight. The yield of fiber depends on the weight of the seed, the absolute weight of the fiber in the seed and the quality of the fiber. In our study, when the indicators of fiber yield were analyzed, the highest fiber yield was found in the brown fiber cultivar 010765 (36.1±0.5%), and the lowest in the green fiber cultivar 011460 (18.3±0.1 %) recorded (Table.3). Fiber index - refers to the amount of fiber per 100 seeds. In our study, when the fiber index symbol was analyzed, the highest fiber index was found in the brown fiber sample of 010765 (6.2 ± 0.5 g), and the lowest index in the green fiber cultivar of 011460 (2.8 ± 0.1 g) determined (Table 3).

One of the important indicators of cotton fiber is fiber length. In our study, the highest values of fiber length were observed in green fiber A-800 (29.7±0.3 mm) and 010764 (29.0±0.1 mm) cultivars. The lowest indicator is 25.7±0.2 mm in cultivar 010108 observed (Table 3).

Table 3. Indicators of agronomic traits in the cultivars of colored cotton of *G.hirsutum* L.

Catalog number of colored cotton samples	Fiber color	Cotton yield (g)	Fiber yield (%)	Fiber index (g)	Fiber length (mm)	Weight of 1 000 seeds (g)
010765	brown	90.1±2.1	36.1±0.5	6.2±0.5	28.4±0.2	120.7±0.5
010108	dark brown	91.3±1.8	28.6±0.2	4.1±0.1	25.7±0.2	104.5±0.7
011250	dark brown	97.4±2.0	29.1±0.2	5.2±0.2	26.6±0.2	132.1±0.1
A-800	green	62.8±2.4	23.1±0.2	3.7±0.1	29.7±0.3	127.3±0.5
011460	green	90.0±1.5	18.3±0.1	2.8±0.1	28.5±0.4	139.2±0.1
010764	green	73.5±2.1	25.2±0.6	3.8±0.1	29.0±0.1	121.8±0.4

The weight of 1000 seeds is one of the main agronomic indicators determining the productivity of cotton. High-quality and large-sized seeds can be grown under suitable agrotechnical conditions. Because the larger the seed, the higher its germination capacity and viability. Therefore, it is appropriate to research the study of this important trait. In our study, when the indicators of the weight of 1000 seeds were analyzed, the highest indicator was determined in the cultivar of green fiber 011460 (139.2±0.1 g). The lowest indicator was in the brown fiber cultivar 010108, which was 104.5±0.7 g (Table 3).

Discussion

In cotton, morphobiological traits have a direct effect on the normal course of physiological and biochemical processes in plants, as well as productivity and quality indicators. Therefore, we paid special attention to morphological characters in our research. The duration of the vegetation period is a morphobiological sign indicating early or late ripening of the plant. Accordingly, it was observed that the duration of the vegetation period in colored cotton is long, that is, it is mid-ripening and late-ripening. On this trait studies carried out by Fursov N.I in colored fiber varieties have also been shown to be late-ripening (Fursov, 1995). The duration of the growing season is determined to depend on the period of growth and its passage, which is necessary for the bud to turn into a one-day flower and an opened boll from it. The faster each process is completed during cotton ontogenesis, the early ripening the variety or ridge created is considered. Early ripening is a complex polygenic trait that depends on the genotype of the variety and is also influenced to a certain extent by the environment, agrotechnical conditions and high temperature (Bekmuxamedov *et al*., 2014; Narkizilova *et al*., 2022).

The categories and subcategories of sympodial branches of cotton belong to the valuable and economic signs. Based on evidence from the literature and his own experience, Musaev et al.(2011) concludes: Inheritance of the main types of sympodial branching (unlimited-limited) is controlled by one main gene (S-s). Subcategories I, II and III of branching are controlled by additional polymer genes. There are about three of them: S1, S2 and S3. These genes function in the homo- and heterozygous state of the dominant allele (S) of the main gene. Therefore, four independently combinable genes (S-c, S1-c1, S2-c2, S3-c3) are involved in the inheritance of sympodial branching in *G.hirsitum* L. cotton. These genes affect the trait in the form of recessive epistasis and polygenic. The recessive homozygous genotype of the main gene stops the activity of the polymeric genes of branching (Bekmuxamedov *et al*., 2014; Musaev *et al*., 2011; Sanaev *et al*., 2021). In our research, it was found that our natural brown and green fiber samples have unlimited type II and III branching (Table 1). In plants of *G.hirsutum* L. species, R_1 gene controlling anthocyanin color has been shown to control the anthocyanin pigment in the body part of the plant and is located in group III. (Tursunov & Abzalov, 2020; Li *et al*., 2018; Zhang *et al*., 2015). In our research, the presence of strong to weak anthocyanin spots was found in natural colored brown and green fiber cotton s cultivars (only the green fiber cultivar 011460 did not have anthocyanin spots) (Table 2).

In order to further increase the fiber quality and productivity of natural colored cotton, many questions need to be addressed. Among them, the relationship between pigmentation and biosynthesis, cellulose deposition and fiber development, the specificity of green pigments, (epi-)genetic mechanisms regulating pigmentation, and the nature of the potential genetic burden should be thoroughly studied and researched. Answering these questions demands interdisciplinary research on colored cotton. (Li *et al*., 2019; Sun *et al*., 2021 and Tang *et al*., 2021). Chinese scientists in the research, the indicators of major agronomic traits of brown and green fiber varieties released in China since 2017 were cited. According to this, the fiber length of the brown fiber varieties is 30.83±0.51 mm, the fiber yield is 41.67±1.52%, and the boll weight is 5.82±0.52 g, while the green fiber varieties have fiber length is 27.62±1.91 mm, fiber yield is 28.59±3.44% and the weight of the boll is 4.64±0.39 g. (Sun *et al*., 2021).

In our research, the indicators of the major agronomic traits were as follows. In our brown fiber cultivar 010765, fiber length is 28.4±0.2 mm, fiber yield is 36.1±0.5%, a boll weight is 5.1±0.1g, light green fiber In cultivar 010764, it was determined that the fiber length was 29.0±0.1 mm, the fiber yield was 25.2±0.6%, and a boll weight was 4.8±0.1g (see Table 2). It has been studied by scientists that the weight of 1000 seeds, which is one of the traits that determine the yield of cotton, that is, the size of the seed, serves to increase the amount of oil and the number of fibers in one seed. Accordingly, it was mentioned that the weight of 1000 seeds has an inverse correlation with the fiber yield. Because cotton is mainly planted for its fiber, it is possible to observe a decrease in the weight of 1000 seeds in varieties with high fiber yield (Li *et al*., 2018; Musaev *et al.*, 2011). This situation was also confirmed in our research, that is, the green fiber cultivar with the highest indicator of 1000 seed weight was found to have a low fiber yield (Table 3).

Conclusion

To conclude from the experiment, it was found that some morphological and major agronomic traits of *G.hirsutum* L. colored fiber cultivars differed significantly from each other depending on the type of fiber. The analysis of cultivars during the vegetation period showed that brown fiber cotton cultivars were medium-ripening, and green fiber cotton cultivars were late-ripening. It was observed that height of plant green fiber cultivars is higher than brown fiber cultivars. Fiber length was longer in the cultivars' cone-oval shape of boll compared to cultivars with round shape. According to the fiber length sign, which is one of the important indicators of the cotton plant, in green fiber cultivars (A-800 sample 29.7±0.3mm and 010764 sample 29.0±0.1mm) to brown fiber cultivars (011250 cultivars 26.6±0.2mm and 010108 cultivar 25.7±0.2mm) was found to be relatively high. On the other hand, according to the trait of fiber yield, cultivar 010765 with brown fiber (36.1±0.5%), green fiber A-800 (23.1±0.2%) and

011460 (18.3± 0.1%) was higher than the cultivars. Brown fiber cultivars also had higher indicators in terms of fiber index and boll weight signs compared to green fiber cultivars. The cultivar of green fiber 011460 with a low fiber yield (18.3±0.1%) was found to have the highest index (139.2±0.1g) of 1000 seeds. Based on the results of our research, we can recommend the use of our brown fiber cultivars 011250 and 010765 as raw material to increase the productivity of colored cotton and fiber.

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