RESEARCH ARTICLE

SABRAO Journal of Breeding and Genetics
55 (2) 279-290, 2023
http://doi.org/10.54910/sabrao2023.55.2.1
http://sabraojournal.org/
pISSN 1029-7073; eISSN 2224-8978

COTTON ADVANCED LINES ASSESSMENT IN THE SOUTHERN REGION OF KAZAKHSTAN

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SUMMARY

The Turkestan region is a cotton-growing zone in South Kazakhstan, but also the northernmost cotton-growing area in the world. Annually, medium-staple cotton (*Gossypium hirsutum* L.) cultivation occurs on 115,000–125,000 ha, with 80,000–85,000 ha grown in the Districts of Maktaaral and Zhetysay, Kazakhstan. This region is highly susceptible to salinity, drought, invasion of dangerous pests (cotton budworm, beet borer, spider mites, and aphids), and diseases (fusarium blight [wilt] and gummosis). An extremely high salt content and aridity in the arable soil are the main limiting factors of that region, hence, genotype selection through genetic principles is the most effective and economical way to reduce their negative impacts on vegetation. Therefore, the research on developing resistant cotton cultivars suitable for such soil and climatic conditions is most relevant. Considering the above situation, assessment of newly developed high-yielding cotton cultivars with fiber quality of types III–IV for tolerance to heat and drought, salinization, and pests and diseases ensued during 2019, 2020, and 2021 at the Agricultural Experimental Station of Cotton and Melon Growing, Atakent, Kazakhstan. Their promising cotton genotypes resulted from strains developed through intraspecific and interspecific diallel hybridization. The newly developed eight cotton cultivars, grown on more than 92% of the hectarage in the Southern region of Kazakhstan, are PA-3031, PA-3044, M-4005, M-4007, M-4011, Bereke-07, Myrzashol-80, and M-4017.

Keywords: Medium-staple cotton (*Gossypium hirsutum* L.), salinity, drought, insect pests and diseases, seed cotton yield, fiber quality traits

Key findings: Long-time and extensive breeding work developed highly productive cotton cultivars of medium-staple size, grown only for 118–122 days, with a high rate of boll retention and opening, fiber yield (38.0%–39.4%), and fiber quality of type IV-IV that meets the requirements of the textile industry. In the cultivars' testing program, promising cotton cultivars, i.e., Maktaaral-4003, Maktaaral-4006, Maktaaral-4015, and Maktaaral-4017, excelled the standard cultivar in almost all the parameters. These cotton genotypes are sources of economically valuable traits widely used in long-term hybridization programs.

Communicating Editor: Prof. Naqib Ullah Khan

Manuscript received: March 18, 2023; Accepted: April 5, 2023.

Citation: Makhmadjanov SP, Tokhetova LA, Daurenbek NM, Tagaev AM, Kostakov AK (2023). Cotton advanced lines assessment in the Southern Region of Kazakhstan. *SABRAO J. Breed. Genet.* 55(2): 279-290. http://doi.org/10.54910/sabrao2023.55.2.1.

INTRODUCTION

Cotton provides the raw material for textile and edible oil industries, serves as a valuable cash crop, gives financial assistance to many people, and strengthens the countries' economy by exporting cotton fiber worldwide (Ahmad *et al.,* 2017; Wang *et al.,* 2022). Four countries, viz., India, China, the USA, and Brazil, produce around 75% of the world's cotton. Cotton classification can be a cosmopolitan crop, as it grows in tropical, subtropical regions and currently on all continents except Antarctica (Abdellatif *et al.,* 2012; Matniyazova *et al*., 2022; Makamov *et al*., 2023). According to Statista (2021), cotton, the most widely planted and profitable industrial crop, accounts for more than 20% of the global share of fiber use and is a source of income for more than 250 million people worldwide. The cotton industry has an estimated global economic impact of US$500 billion annually (Zhang *et al.,* 2021). In Australia, the Commonwealth Scientific and Industrial Research Organization (CSIRO) is the only cotton breeding enterprise engaged in developing high-yielding cotton cultivars for the local industry and also for requirements in North and South America and Europe. The said breeding program is unique compared with many other public and commercial breeding programs worldwide because it specifically focuses on diverse and complex research with the substantial commercial outcomes (Conaty *et al.,* 2022).

In the Republic of Kazakhstan, the Agricultural Experimental Station of Cotton and Melon Growing in Atakent, Kazakhstan, is the only scientific institution engaged in full-scale cotton breeding and holds the National Cotton Gene Pool amounting to 635 accessions. The cotton-growing zone in Southern Kazakhstan is the northernmost cotton-growing zone in the world. In this Turkestan region of Kazakhstan, about 115,000–125,000 ha grow medium-staple cotton (*Gossypium hirsutum* L.) annually.

The Turkestan region is the northernmost cotton growing location, with the early onset of low temperatures in autumn, cotton does not ripen. Therefore, the main task of breeders is to breed and develop the early maturing cotton cultivars (105–115 days). In Kazakhstan, the plant breeding program proceeds with the financial support of the Ministry of Agriculture within the framework of program-targeted funding. The main breeding strategies come from classical methods based on intraspecific hybridization followed by individual genotype selection. In the hybridization process, selecting effective and adapted parental cultivars is crucial; thus, maintaining germplasm diversity is a priority. The breeding programs use the germplasm from various resources, with even some of the most successful parental genotypes procured from the cotton gene banks in China, the USA, Uzbekistan, Pakistan, and India (Makhmadjanov *et al.,* 2022). Cotton is a facultative self-pollinating plant, and its biological response depends upon the population's genetic makeup, population homeostasis, as well as, the natural and artificial selection under specific growing conditions. Interspecific and intraspecific hybridization is one of the main approaches to producing elite cultivars in cotton, contributing to growth and development, and increasing heterosis capacity in the first and second generations. In this regard, more focus should pay attention to hybrid cotton, which is a good approach for significantly improving the genetic potential of yield and fiber quality (Kiani *et al.,* 2007; Khan *et al.,* 2009; Akhmedov, 2011; Sheidai *et al.,* 2018).

Past studies revealed that using both natural and artificial selection is more effective concerning hybrid populations, by having large plant forms due to heterozygous origin (Pedersen, 1973; Meirzhan, 2012; Baboev, 2015). The sharp differences of hybrid plants in the population composition in winter hardiness, foliage, bushiness, branchiness, disease resistance, nutrient content, growth rates, longevity, and, ultimately, productivity are usually a reflection of genotypic differences inherited from the parental forms. Therefore, a hybrid (with no established hereditary basis yet) carries the traits and properties of parental genotypes and their characteristics due to the specific combination of genes determining the appearance of new properties.

Researchers have developed new Russian cultivars adapted to the harsh conditions of Southern Russia to implement the genetic breeding material studied in various regions of Southern Russia and to meet the following requirements (Kasyanenko *et al*., 1999), i.e., resistant to low temperatures, drought, and strong winds; tolerant to pests and diseases; early maturing; high potential productivity; high fiber quality (fiber length and yield, strength, and micronaire); adaptability to various types of soil moisture availability and the mechanized cycle of cultivation; and absence of defects in processing, and manufacturability from raw cotton to fabric dyeing (Kotomenkova and Vinogradova*,* 2018).

Consequently, the need to develop new cotton cultivars that differed from the previous ones by high yield potential and having resistance to biotic and abiotic environmental factors is earnest (Amin and Gergis*,* 2006; Urazaliev, 2015). One of the critical factors while creating a new cultivar is the agroecological condition of growth. As a result, the cultivar must combine the traits of productivity and resistance to pests and diseases necessary for production. Compulsory to breeding is selecting parental forms, which will ensure success in obtaining the best hybrid combinations, and their evaluation through genotype by environment interaction is also crucial.

Modern genetics and breeding of crops, including cotton, have several theoretically and practically relevant fundamental and applied developments, methodological approaches, and techniques successfully employed by qualified breeders (Kim, 2009; Urazaliev, 2015; Goncharov and Goncharov, 2018). Thus, Umbetaev *et al.* (2021) believed that one of the methods for unlocking the genetic potential of cotton cultivars is to select parental pairs for crossing based on the origin of genotypes, intravarietal and intervarietal, and complex hybridization to develop new cultivars of medium fiber cotton, most adapted to the soil and climatic conditions of the Turkestan region.

The primary breeding material is a cultivar of mutation, genetic combination, and recombination of genes. Knowledge of genetics laws is the basis for developing and maintaining promising collections used by breeders and allocating valuable types from the species gene pool. Direct selection can also proceed with the knowledge of the mechanism of genetic processes in the populations of crop plants. High cotton productivity with fine fiber quality is achievable using appropriate cotton cultivars and agronomic techniques to regulate the plant growth, development, and maturity because efficient and rational regulation of plant senescence by cultivars and agronomic techniques will optimize the use of light, heat, water, and other natural resources during the limited growing season for cotton to develop a normal maturity (Chen and Dong*,* 2016).

Breeding work on creating and studying cultivars with high technological qualities of medium-fiber cotton occurs in many countries, such as Uzbekistan, Kazakhstan, Turkey, China, the USA, and Pakistan. The prime indicators of fiber quality are seed cotton yield, fiber length, micronaire, metric number, strength, and linear strength. The present stage of medium-fiber cultivars' selection has obtained cultivars with a high fiber yield of 44%–45%, fiber length of 40–43 mm, and microns (3.6–4.2 microns). The whole cultivar of cotton fiber divides into seven types, with I, II, and III providing cultivars with fine fiber and IV to VII producing the cultivars of medium-fiber cotton. The main indicators determining the industrial grade of the strand are its maturity and strength. Notably, improving the fiber quality indicators of medium-fiber cotton, which accounts for 95% of the world's sown areas occupied by this crop, is one of the major tasks of the world cotton breeding program. It, in turn, requires the production of new promising cotton cultivars by introducing innovative developments in cotton breeding, particularly marker-associated selection (MAC) technology (Asphandiyarova *et al.,* 2003; Darmanov *et al.,* 2019). The cotton fiber grown in Uzbekistan over the past 10 years has an increased micronaire index (4.6 to 5.0) to improve the growth quality in spinning production. This observed phenomenon worldwide requires the creation of new cotton breeding cultivars. New cotton fiber cultivars Porlok-1 and Porlok-2 met the expected cotton-growing criteria developed based on genetic engineering (Tojimirzaev, 2022).

Thus, the literature review showed that the ecological flexibility of *G. hirsutum* allows its growth worldwide (Wendel *et al.,* 2010). Nevertheless, the constant pressure of stern selection for desirable traits has led to limited genetic diversity, which may also lead to uniting cotton germplasm in the future (Wei *et al.,* 2020). In this regard, the conservation, use, and mobilization of genetic resources are several most relevant priorities in addressing food security. Therefore, the presented study aimed to assess the genetic potential of newly developed cotton cultivars compared with check cultivars.

MATERIALS AND METHODS

The research took place at the experimental site of the Agricultural Experimental Station of Cotton and Melon Growing, located in the Turkestan region of the Republic of Kazakhstan. Characteristics of climatic conditions of the Turkestan region are sharp fluctuations, with freezing winters that reach -25 ℃, and summers hot, up to +45 ℃. The annual precipitation ranges from 210 to 400

Table 1. Meteorological indicators of the growing seasons 2019–2021.

	Precipitation (mm)				Temperature (°C)			
Month	Monthly amount			Medium-long-term	Average daily air temperature			Medium-long-term
	2019	2020	2021		2019	2020	2021	
January	12.2	20.1	16.2	16.2	-2.0	-0.2	-1.1	-1
February	3.8	39.5	38.7	27.3	-0.1	4.3	2.1	2
March	0	1.2	1.1	0.8	10.5	8.5	9.5	10
April	0	48.6	48.1	32.2	13.9	14.6	14.3	14
May	0	0	0	0.0	19.5	22.4	21.0	21
June	0	0	0	0.0	24.7	26.3	25.5	26
July	0	0	0	0.0	26.9	26.8	26.9	27
August	0	0	0	0.0	23.0	23.3	23.2	23
September	0	0.2	0.3	0.2	17.5	16.3	16.9	17
Precipitation total and average temperature	16	109.6	104.4	76.7	14.9	15.8	15.4	15.4

mm. Spring has an intensive increase in temperatures and maximum precipitation, usually warm and short, and relatively wet. The air temperature in spring usually reaches +13 ℃ to 15 ℃, and in April, the temperature reaches +15.3 ℃. Relative humidity ranges from 55%–60%, while at the end of spring goes down to 52%–53%. In summer, the average daily temperature varies between +24.2 ℃ to 25.6 ℃, but in July, it reaches up to 47 ℃. In autumn, the air temperature is mostly +12.5 ℃, with the autumn frost ceasing the cotton crop growth in late October or early November.

According to the meteorological station at the LLP - Agricultural Experimental Station of Cotton and Melon Growing, during 2020–2021, the average air temperature and precipitation were 15.4 ℃ and 76.7 mm, respectively. Precipitation distribution by month was as follows: the most humid months were January, February, and April (16.2, 27.3, and 32.2 mm, respectively) (Table 1).

The table shows that 2020 and 2021 exhibited higher precipitation compared with 2019. There was very little precipitation in 2019, which favored early spring sowing in April. In 2019, the lowest temperature in April (13.9 ℃) affected the slow growth of plant development. In May, June, and July, the temperature was stable for all years, which favorably affected the growth and development of cotton. Generally, the climatic conditions of 2019–2021 showed that the air temperature and the amount of precipitation during the growing season were relatively uniform by months, favoring good cotton growth and development.

The presented research aimed to study the genetic potential of 15 high-yielding cotton (*Gossypium hirsutum* L.) cultivars with medium-staple compared with a standard cultivar (M-4005) during 2019–2021, at the Agricultural Experimental Station of Cotton and Melon Growing, Atakent, Kazakhstan. The following work proceeded in the competitive nursery on a total area of 1.8 ha, with sowing carried out on April 19, 22, and 26 in 2019, 2020, and 2021, respectively. The sowing scheme was 90 x 1–2 x 25, with rows and plant spacing of 90 cm and 25 cm, respectively. On one running meter, 9.25 plants x 11111 m ha^{-1}, with 90 cm row spacing = 102777 plants ha^{-1} (density).

The estimated area of the plots was 72 m^2, with four rows 20.0 m long, with the distance between the tiers at 2.0 m. The placement of variants in a randomized method was in threefold repetition. Row sowing utilized a selective seeder. Phenological observations proceeded in the following phases in plots: For the seedling emergence, the accounting ensued during 50% and 100% emergence on the plot in terms of the total sowing density. Noting the formation of true leaves and fruit branches and the appearance of the first buds was at the beginning of appearance in days. For flowering, the beginning of 50% and 100% flowering on checked plants included fruit formation - ripening and opening of bolls. Maturity was until the onset of 50% of plants with open bolls.

The yield determination by collecting from the plot of 72 m^2 in all three replications used the formula below:

$$\bigcup = \bigcup d \times 10000 / Sd \times 1000$$

Where:
Y = Yield (tons/ha)
Yd = Raw cotton yield from the plot (kg)

Sd = Plot area (m^2)
1000 = Conversion factor per ton/ha

The experimental data processing continued in an MS Excel sheet. Phenological observation assessment used the methodology of Simongulyan *et al.* (1980). Further processing of the recorded data was according to Dospekhov (1979).

During the three years of experimentation, the soils were light medium, loamy gray, and moderately saline (1–2 mg-eq. per 100 g of dirt in terms of chlorine), with a groundwater depth of 1.5–2.0 m. The experiment progressed on the 44th branch, the 3rd map, and the 5th year after the plowing of alfalfa in the field. Soil cultivation employed the standard methods: in autumn-winter, autumn plowing was at a depth of 35–38 cm using a double-depth plow, preparing the field for winter washing irrigation, furrow cutting, and temporary cart irrigation, with soil washing irrigation having an irrigation rate of more than 1800 m^3 of water. In the spring, furrow spreading and temporary kart irrigators for the first spring harrowing, 2-fold harrowing, and chiseling of the field ensued to a depth of about 15–18 cm.

During the experimentation periods on competitive cultivar testing, the following measures included, i.e., for weeding, inter-row cultivation: the first - without fertilizing to a depth of 10–12 cm, the second and third to a depth of the central organ of 15–18 cm, with the introduction of ammonium nitrate (220 kg/ha in fertilizers); the first thinning of cotton occurred with the formation of 1–2 true leaves, the second thinning according to the scheme 90 x 1–2 x 20, leaving 7–8 plants per linear meter, approximately 85,000–90,000 pieces/ha. All fiber quality parameters transpired after ginning on the J-10 device, with the fiber evaluated for technological qualities on the LPS-4, Micronaire, and KX-730 devices to determine the fiber length.

RESULTS AND DISCUSSION

Cotton cultivars must have high productivity, early maturity, natural resistance to pests and diseases, adapted to machine processing and harvesting, high yield and fiber length, technological qualities, and high oil content in cottonseed. Cotton cultivars should adapt well to changing environmental conditions and respond effectively to improving agricultural technology, particularly fertilizer doses, by increasing the economic yield. Therefore, all these requirements should be in focus when developing a new cultivar. Moreover, the breeder must consider the present conditions and the changes that may occur in agricultural production for the next decade or more. With this approach, the developed cotton cultivar could be cultivable for about 10–15 years, providing a long time high production (Simongulyan *et al.,* 1980).

The nursery of competitive cultivar testing is the final stage of the selection process. In this area, the vital signs need an accurate and comprehensive study. The best genotypes are those reliably exceeding the standard in yields, precocities, and technological indicators, such as, resistance to pests and diseases. Variants and samples, studied and distinguished for some years through economically valuable traits, gained evaluation under production testing conditions; if confirmed effective, those entries proceed to the state cultivar testing (Dospekhov, 1979).

Cultivar development that combines high productivity with early maturity is one of the leading tasks of cotton breeding. Its central directions are to determine the morphological, physiological, and quantitative components of the crop and plant contributing to an increase in the yield of cotton seeds per unit area (Sharma *et al.,* 2021; Ballester *et al.,* 2021; Kumar *et al.,* 2000). Since the cotton belt of Kazakhstan is the northernmost in the world, creating precocious cultivars is essential to the country. The yield and fiber quality variables of raw cotton crucially relate to the precocity of the cultivar. On crops of mature cultivars, it is easier to apply complex mechanization of cultivation, especially harvesting. The importance of the cultivar's precocity increases significantly in unfavorable years for cotton, with less effective temperatures during the growing season and early frosts (Makhmadjanov *et al.,* 2022). The combination of precocity and high yield in one cultivar is a very difficult task. In addition, there is a negative correlation between these. However, scientists (Shaheen *et al.,* 2021) have overcome this phenomenon. They created the *Bt*-cotton RH-647 cultivar at Cotton Research Institute CRI, Khanpur, recognized for its excellent plant characteristics and high yield potential in the harsh agro-climatic conditions of the Rahimyar Khan cotton-growing area in Bahawalpur region and southern Punjab in 2016. RH-647 boasts of its novel plant structure and improved fiber quality, heat- and drought-tolerant to successfully sustain yield in harsh, highly variable, hot, and dry climatic conditions in seasons. Moreover, RH-647 is early maturing, with plant morphogenetic traits like bushy cylindrical shape catching more radiation from sunlight and aeration than compact formed cultivars. Cotton cultivars earlier created in Uzbekistan include, i.e., Surkhan-9, Surkhan-14, Surkhan-16, Surkhan-18, Surkhan-102, and Surkhan-102, have an early maturity of 110–120 days and a yield of more than 5.0 t ha^{-1} (Kimsanboev *et al.,* 2017).

In the competitive cultivar testing nursery on an area of 1.8 ha, cotton samples numbered 15 pieces, with the cultivar Maktaaral-4005 used as the standard cultivar zoned in the Turkestan region. The growing season of the tested cotton cultivars was on 200 plants, considering all the phases of the development of cotton. The flowering phase of cotton cultivars was at the onset of 50% of flowering. Observing the cultivars M-4019, M-4015, M-4017, and M-4021, the flowering phase compared with the standard cultivar M-4005 was 2–6 days ahead, whereas cultivars M-4026, M-4006, and M-4010 lagged for 2–5 days. The remaining tested cultivars, i.e., M-4009, M-4012, M-4018, M-4025, M-4030, M-4001, M-4003, and M-4004, were at par with the standard cultivar (M-4005), with a value of 126 days (Table 2).

Observations further showed that the precocious cotton cultivars were M-4010 (117.0 days), M-4003 (117.0 days), M-4001 (120.0 days), and M-4026 (116.0 days). In terms of yield, the cultivars also had differences depending on biological traits. The most productive cultivars were M-4003 (4.45 t ha^{-1}), M-4019 (4.52 t ha), M-4009 (4.51 t ha^{-1}), and M-4017 (4.57 t ha^{-1}), which exceeded the standard cultivar M-4005 by 0.56–.62 t ha^{-1}. Cultivars M-4026, M-4018, M-4030, M-4025, M-4010, M-4015, and M-4006 also had an advantage over the standard by 0.21–0.46 t ha^{-1} more yield. The three cotton cultivars, M-4004, M-4012, and M-4021, with the standard cultivar M-4005, revealed an equal yield (3.95 t ha^{-1}).

During the growing season, data recording on phenological traits also took place. For standard cultivar M-4005, the main stem height was 107 cm, which exceeded the cultivars M-4003, M-4006, M-4012, and M-4030 by 3.0–10 cm. The remaining cotton-tested cultivars had a lag of 8.4–17.2 cm. Nearly all the samples versus the standard cultivar M-4005 exceeded the number of sympodial branches with shortened internodes. Cultivars M-4017, M-4019, and M-4009 on bush productivity exceeded the check cultivar M-4005; however, all other tested samples were at an identical range of the standard cultivar (Figure 1).

Table 2. Growing seasons and yield of cotton cultivars.

Cultivars	Growing season (days)				Yield (t/ha)			
	2019	2020	2021	3-years average	2019	2020	2021	3-years average
M-4001	120.0	121.0	119.0	120.0	4.32	4.24	4.21	4.25
M-4003	117.0	117.0	118.0	117.3	4.54	4.36	4.45	4.45
M-4004	123.0	124.0	126.0	124.3	3.99	3.94	3.82	3.91
M-4006	119.0	120.0	121.0	120.0	4.47	4.43	4.34	4.41
M-4009	124.0	124.0	123.0	123.7	4.55	4.47	4.5	4.51
M-4010	118.0	118.0	117.0	117.7	4.36	4.25	4.28	4.29
M-4012	124.0	127.0	126.0	125.7	4.1	4.03	3.97	4.03
M-4015	120.0	119.0	121.0	120.0	4.42	4.46	4.33	4.4
M-4017	120.0	121.0	119.0	120.0	4.64	4.57	4.52	4.57
M-4018	122.0	122.0	121.0	121.7	4.20	4.18	4.14	4.17
M-4019	121.0	123.0	120.0	121.3	4.56	4.52	4.48	4.52
M-4021	122.0	124.0	121.0	122.3	4.4	4.07	3.93	4.04
M-4025	120.0	120.0	122.0	120.7	4.31	4.39	4.26	4.32
M-4026	117.0	117.0	116.0	116.7	4.23	4.17	4.09	4.16
M-4030	128.0	126.0	127.0	127.0	4.07	4.25	4.17	4.16
M-4005 St	126.0	125.0	127.0	126.0	4.02	3.96	3.88	3.95
LSD$_{0.05}$				1.77				0.09
Exp. accuracy (%)				0.51				0.68

Maktaaral-4017 Maktaaral-4019 Maktaaral-4009

Figure 1. Cotton cultivars of the Agricultural Experimental Station of Cotton and Melon Growing, Atakent, Kazakhstan.

The rate of boll opening is one of the relevant indicators of the bush. The maturation, boll opening, and cotton harvesting are the final stages in the cotton growing season. This period exhibits a weakening of the intensity of plant life processes and a decrease in the accumulation rate of organic substances in the bolls. This period begins when the leaves of the first formed bolls dry out and open, while in many other bolls, the physiological processes like formation and maturation of seeds and fibers are ongoing. The process of cracking the flaps in biologically mature bolls is physical. The opening rate (maturation) of the bolls depends on the impact of a complex of environmental factors. Plant senescence and maturity performance are complex processes regulated by both internal and external factors. Like cereal crops with determinate growth, cotton can also have normal maturity, premature senescence, and late maturity performance (Chen and Dong*,* 2016).

Also, the forecast shows that in 2030, the growing demand for water and energy will reach 6.9 trillion cubic meters globally, exceeding 40% of the available water reserves. Currently, global warming has led to a shortage of water, which will reflect in decreased crop yields. Therefore, selection for drought resistance becomes highly relevant. Thus, studies to assess the drought resistance of Pima cotton (*Gossypium barbadense* L.) have shown that line T450 was the most promising under drought conditions in Uzbekistan (Shavkiev *et al.,* 2022).

Productivity is the economically important and most valuable property of cotton cultivars. The structural elements of cotton productivity include the number of full-fledged bolls per plant and their size. Usually, in cotton plants with great potency for accumulating bolls, even in the most optimal growing conditions, about half of the buds, flowers, and ovaries fall off. A precise irrigation regime, with low soil fertility and other unfavorable conditions, enhances the percentage of fruit falling. However, in the cotton plant, fruit falling off and the variations in accumulating fruit elements are hereditary. The number of preserved bolls on the plant determines the productivity of the cotton plant to a greater extent than their size. Cultivars with very large bolls have fewer bolls on the bush, and therefore, not advisable to create cultivars with a raw mass of one boll of more than 8–8.5 g. Large-seeded cultivars made sense when there was a high proportion of manual harvesting. However, in machine harvesting nowadays, the mass of the raw material of one boll (7–7.5 g) is optimal (Simongulyan *et al.,* 1980).

Cotton genotypes markedly differed in the number of open bolls, with a sizable number of full-fledged bolls observed in the cultivar M-4017 (Table 3). Cultivars M-4025, M-4006, and M-4019 also exceeded the standard cultivar opening by 8.9%, 14.5%, and 15.0%, respectively. Generally, the bolls opening rate was 67.6%, while the standard cultivar had this indicator twice less. In the experiments, in the plants with 6–7 bolls left on the bush, the raw cotton mass of one boll

Table 3. Valuable indicators among various cotton cultivars.

Cultivars	Boll weight (g)				Fiber yield (%)				Fiber length (mm)			
	2019	2020	2021	3-years average	2019	2020	2021	3-years average	2019	2020	2021	3-years average
M-4001	5.9	5.9	6.0	5.9	38.7	38.5	38.4	38.5	32.9	32.8	33.0	32.9
M-4003	5.9	5.8	6.0	5.9	37.9	38.3	38.1	38.1	33.0	33.0	33.1	33.0
M-4004	5.8	5.7	5.6	5.7	39.6	38.1	39.1	38.9	33.0	32.8	32.9	32.9
M-4006	6.0	6.1	5.9	6.0	38.7	38.0	38.3	38.3	34.1	33.4	33.3	33.6
M-4009	6.2	6.2	6.3	6.2	37.9	37.8	38.0	37.9	33.0	33.1	33.2	33.1
M-4010	6.0	6.1	6.1	6.0	38.9	38.6	38.4	38.6	33.1	32.9	33.0	33.0
M-4012	5.9	5.6	5.8	5.7	40.1	38.1	39.2	39.1	32.8	32.6	32.7	32.7
M-4015	6.1	6.0	5.9	6.0	40.3	38.6	39.7	39.5	33.7	33.1	33.4	33.4
M-4017	6.2	6.1	6.4	6.2	39.4	39.8	40.0	39.7	33.3	33.0	33.5	33.2
M-4018	6.0	5.9	6.1	6.0	38.7	38.9	38.6	38.7	34.1	32.9	33.3	33.4
M-4019	6.2	6.1	6.3	6.2	39.2	39.0	39.4	39.2	32.9	32.8	33.0	32.9
M-4021	5.9	5.7	5.7	5.7	38.1	38.4	38.2	38.2	33.4	32.7	33.1	33.0
M-4025	6.0	5.9	5.8	5.9	38.7	38.2	38.5	38.4	33.8	33.0	33.3	33.3
M-4026	5.9	5.8	5.7	5.8	38.9	38.0	38.4	38.4	32.9	32.9	33.1	32.9
M-4030	5.9	5.9	5.8	5.8	39.3	39.7	39.5	39.5	33.0	33.1	33.2	33.1
M-4005, St	5.8	5.7	5.9	5.8	37.8	37.8	38.0	37.8	32.8	32.7	32.9	32.8
$LSD_{0.05}$				0.17				0.67				0.37
Exp. accuracy (%)				1.01				0.59				0.39

increased by 7.5 g (66.7%) and in plants with 3–4 bolls, by 33.9 g (77.2%). According to the mass index of one boll, the cultivars M-4009, M-4019, and M-4017 were significantly higher than the same trait values in the standard cultivar M-4005. However, lesser rates for the parameter emerged in the cultivars M-4004 and M-4021, confirming their low productivity. Other cultivars were close to the standard cultivar with their values (Table 3).

Cotton cultivation is primarily for the sake of fiber, with the fiber yield determined by the total seed cotton yield and the ratio of fiber to the weight of raw cotton. With equal raw material, a cultivar with a higher fiber yield also produces a higher fiber yield. The fiber yield also depends on the seed weight and the fiber index. The low seed weight should not determine the high fiber yield but the density and length of fibers on the seed. Estimates show that an increase in fiber yield by 1% will give the country an additional 570 million meters of fabric (Simongulyan *et al.,* 1980). In terms of fiber yield, the cultivars M-4009, M-4003, M-4021, M-4006, M-4010, M-4001, M-4026, M-4025, and M-4018 were close to the standard; however, cultivars M-4004, M-4012, M-4019, and M-4030 noticeably excelled in this trait. The highest fiber yield appeared in cultivars M-4015 (39.5%) and M-4017 (39.7%), exceeding the standard cultivar by 1.7%–1.9% more fiber.

Regarding fiber length, the cultivars M-4015, M-4018, and M-4006 distinguished themselves, significantly exceeding the standard cultivar LSD. The remaining cultivars also slightly exceeded the standard or were close to it. High values of micronaire displayed in cultivars M-4003, M-4025, M-4001, M-4006, and M-4026, significantly excelling the standard cultivar by 20%–25%. However, in the cultivars M-4021 and M-4030, the trait was at the standard level. On fiber breaking load (fiber strength), the cultivars M-4003, M-4004, M-4015, and M-4017 led the standard cultivar by 0.6–1.0 g.s. However, the cultivars M-4012 and M-4019 showed at the level of the standard (Table 4).

Overall, the studied cotton cultivars were superior to the standard cultivar in almost all parameters. Thus, providing the textile industry with raw materials in the required assortment depends on which cultivars with what fiber quality needs cultivating for production. The fiber quality is the chief indicator for evaluating the breeding cultivars (Table 5). Hence, new medium-fiber cotton cultivars M-4003, M-4015, and M-4017 have positive economic and valuable indicators. Boll weight, fiber yield, length, strength, and technological qualities of these tested cultivars exceed the standard cultivar with a great advantage.

Table 4. Technological properties of the fiber in various cotton cultivars.

Samples	Micronaire readings				Breaking load (g.s.)			
	2019	2020	2021	3-years average	2019	2020	2021	3-years average
M-4001	4.5	4.6	4.6	4.5	4.8	4.9	4.8	4.8
M-4003	4.6	4.6	4.5	4.5	4.9	4.9	4.9	4.9
M-4004	4.6	4.8	4.7	4.7	5.0	4.8	4.9	4.9
M-4006	4.7	4.7	4.6	4.6	4.9	4.8	4.8	4.8
M-4009	4.8	4.6	4.7	4.7	4.8	4.9	4.8	4.8
M-4010	4.5	4.5	4.6	4.5	4.9	4.9	4.9	4.9
M-4012	4.8	4.8	4.7	4.7	4.7	4.7	4.7	4.7
M-4015	4.6	4.6	4.6	4.6	5.1	5.1	4.9	5.0
M-4017	4.8	4.6	4.6	4.6	4.9	4.9	4.9	4.9
M-4018	4.5	4.7	4.6	4.6	4.8	4.8	4.8	4.8
M-4019	4.7	4.7	4.6	4.6	4.8	4.8	4.7	4.7
M-4021	4.8	4.8	4.8	4.8	4.7	4.7	4.8	4.7
M-4025	4.6	4.6	4.5	4.5	4.9	4.9	4.9	4.9
M-4026	4.7	4.7	4.6	4.6	4.9	4.7	4.8	4.8
M-4030	4.8	4.8	4.8	4.8	4.8	4.8	4.8	4.8
M-4005, St	4.8	4.8	4.8	4.8	4.7	4.7	4.7	4.7
$LSD_{0.05}$				0.11				0.09
Exp. accuracy (%)				0.79				0.66

Table 5. Indications of technological qualities of the fiber in various cotton cultivars.

Samples	Degree of fineness indicators				Fiber maturity				Breaking length (km)			
	2019	2020	2021	3-years average	2019	2020	2021	3-years average	2019	2020	2021	3-years average
M-4001	5400	5300	5350	5350	2.1	2.1	2.1	2.1	25.9	26.0	25.6	25.8
M-4003	5340	5320	5360	5340	2.1	2.1	2.2	2.1	26.2	26.1	26.2	26.1
M-4004	5260	5390	5380	5343.3	2.1	2.1	2.2	2.1	26.3	25.9	26.3	26.1
M-4006	5320	5370	5360	5350	2.1	2.1	2.2	2.1	26.1	25.8	25.7	25.8
M-4009	5360	5310	5400	5356.6	2.1	2.1	2.1	2.1	25.7	26.0	25.9	25.8
M-4010	5270	5270	5300	5280	2.1	2.1	2.0	2.1	25.8	25.8	25.9	25.8
M-4012	5450	5430	5440	5440	2.0	2.0	2.1	2.0	25.6	25.5	25.5	25.5
M-4015	5180	5160	5320	5220	2.2	2.2	2.2	2.2	26.4	26.3	26.6	26.4
M-4017	5340	5310	5410	5353.3	2.1	2.1	2.1	2.1	26.2	26.0	26.5	26.2
M-4018	5400	5380	5380	5386.6	2.1	2.1	2.0	2.1	25.9	25.8	25.8	25.8
M-4019	5400	5360	5450	5403.3	2.1	2.1	2.1	2.1	25.9	25.7	25.6	25.7
M-4021	5460	5440	5300	5400	2.0	2.0	2.0	2.0	25.6	25.6	25.4	25.5
M-4025	5270	5310	5300	5293.3	2.1	2.1	2.2	2.1	26.3	26.0	25.9	26.0
M-4026	5320	5420	5400	5380	2.1	2.0	2.1	2.1	26.1	25.5	25.9	25.8
M-4030	5400	5380	5420	5400	2.1	2.1	2.0	2.1	25.9	25.8	26.0	25.9
M-4005 St	5410	5430	5420	5420	2.0	2.0	2.0	2.0	25.4	25.5	25.4	25.4
$LSD_{0.05}$				76.33				0.072				0.29
Exp. accuracy (%)				0.49				1.2				0.39

The association among the traits is highly relevant in choosing and selecting material for future breeding. Evaluation of genotypic and phenotypic correlations among the traits helps to initiate future breeding strategies. If the correlation between two attributes is positive and significant, improving one will positively impact the other. Therefore, selection for one trait will improve other related characteristics. For getting high-quality fibers, breeding programs must develop cotton cultivars that overcome the negative relationship between agronomic performance and fiber quality. Since 1935, the USDA-ARS Pee Dee Germplasm Improvement Program has prioritized improving fiber quality while maintaining and refining agronomic performance. These findings showed that the negative relationship between agronomic traits and fiber quality is often due to a genetic link that can be overcome (Campbell, 2021). Song's *et al.* (2015) findings enunciated a significant positive relationship among the fiber traits; however, fiber length showed a significant negative correlation with other fiber quality traits. The correlation analysis suggested that improving raw cotton yield and fiber yield can be combined with boll number and weight, independently of other fiber quality traits.

In the presented study, the seed cotton yield showed a high positive correlation with one boll weight, as well as, a significant relationship with the fiber strength and length. The growing seasons showed a medium and strong positive correlation with traits, such as, one boll weight, fiber length, micronaire, fiber strength, and fiber maturity coefficient. The one boll weight had a strong relationship with fiber yield, micronaire, fiber maturity coefficient, and an average positive relationship with fiber metric number and fiber strength. Fiber yield revealed a high correlation with fiber length, strength, metric number, and breaking length, while the above-average positive correlation with fiber maturity index.

Fiber length directly correlates with micronaire, fiber strength, fiber metric number, and a significant positive relationship with fiber elongation trait. The micronaire index had a high relationship with fiber strength and a significant relationship with fiber maturity ratio. Fiber strength had a high positive relationship with fiber metric number and an above-average relationship with fiber maturity ratio and fiber elongation. Observations also showed fiber metric number had a high correlation with fiber elongation, which positively correlates with the fiber maturity coefficient.

Long-term studies have established that plant height has the only positive correlation with the growing season duration; however, no significant correlation of this trait resulted in fiber quality. Specific attention should center on such a trait as ‘bush compactness,’ which also has a relevant positive relationship (*r* = 0.745) with the trait ‘accelerated and friendly boll opening.’ The more compact the plant, the greater the incidence of light rays on the leaf surface. With plant compactness, it is possible to increase the density of plants per hectare (170,000–180,000), while with standard sowing, the density was 120,000 ha^{-1}, which increased the yield to 6.0–7.0 t ha^{-1}.

Thus, the results further revealed a strong positive relationship (*r* = 0.779) between the boll weight and seed cotton yield, with a linear relationship expressed by the equation U = 0.0684× + 3.033. A positive mean correlation also emerged among the seed cotton yield, fiber length, and strength (Table 6). Shavkiev *et al.* (2022) studies revealed that the correlation between the studied traits and seed yield showed that all traits positively correlate with seed yield under normal and drought-stress conditions. In other studies, the seed yield positively correlated with plant height, the number of bolls per plant, the number of sympodial branches on the plant, fiber length, and fiber strength (Rehman *et al.*, 2020). The correlation between various traits also depends on external factors, and a positive relationship appeared between cotton productivity and the area used; however, when using chemical fertilizers, a strong inverse relationship of cotton yield surfaced (Muhammad *et al.*, 2022).

Table 6. Correlation analysis of qualitative and quantitative traits of the *Gossypium hirsutum* L.

Traits	Y	VP	WOB	FO	LF	M	BLF	MFN	CFM	BLF
VP	-0.491	-								
WOB	0.779**	0.732	-							
FO	0.146	0.354	0.797	-						
LF	0.345	0.437	0.345	0.785	-					
M	-0.376	0.785	0.726	0.218	0.774	-				
BLF	0.423*	0.435	0.341	0.745	0.718	0.724	-			
MFN	-0.332	0.382	0.424	0.728	0.712	0.325	0.727	-		
CFM	0.401	0.793	0.784	0.425	0.215	0.544	0.548	0.278	-	
BLF	0.426*	0.743	0.453	0.741	0.427	0.247	0.674	0.748	0.714	-

Note: r is the correlation coefficient (r < 0.3 – the correlation dependence between the traits is weak (with r = 0.3 - 0.7 – medium, with r > 0.7 – strong); Y – yield; VP – vegetation period; WOB – the weight of one boll; FO – fiber output; LF – length of the fiber; M – micronaire; BLF – breaking load of the fiber; MFN – metric fiber number; CFM – coefficient of fiber maturity; BLF – breaking length of the fiber.
Standard Error -1.34; **: Highly significant (*P* ≤ 0.01), *: Significant (*P* ≤ 0.05)

Therefore, these yield-related traits require high consideration as the main selection criteria for genotype to increase yield, in combination with improving fiber yield and quality. The remaining technological properties of the fiber of cotton cultivars weakly correlate with yield (r = 0.146). Generally, an analysis showed that lines M-4003, M-4006, M-4015, and M-4017 could benefit the hybridization programs to improve the yield and fiber quality traits. High economic and fiber-related features of the tested cotton cultivars will allow for obtaining high yields in the conditions of the Turkestan region, thereby increasing the profitability of cotton growing in the area with high production. Most tested cotton cultivars will be introduced into the breeding program to develop the new high-yielding cotton genotypes.

At present, in the Turkestan region, the total area under medium-staple cotton occupies about 120,000 ha, of which the domestic cultivars of Agricultural Experimental Station of Cotton and Melon Growing, i.e., Maktaaral-4017, Maktaaral-4005, Maktaaral-4019, Maktaaral-4009, Maktaaral-4011, and Maktaaral-5027 underwent into production on an area of 85,000 ha (71.0% of the total cotton area).

CONCLUSIONS

Based on practical developments, the study selected new forms of medium-sized, mature, highly productive, and fork-resistant cotton plants with a growing season of 118–122 days, a high rate of boll opening, fiber yield (38.0%–39.4%), and fiber quality of type IV-IV meeting the requirements of the textile industry. Selected breeding cotton cultivars Maktaaral-4003, Maktaaral-4006, Maktaaral-4015, and Maktaaral-4017 exceeded the standard cultivar (Maktaaral-4005) in almost all the parameters.

ACKNOWLEDGMENTS

The scientific research proceeded within the framework of program-targeted funding on the BR10765017 cipher, Contract No. 11-10, dated September 10, 2021.

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