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RESEARCH ARTICLE

Agronomic and Fibre Quality Assessment of Cotton Breeding Lines Under Verticillium Wilt Conditions

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Abstract: The aim of the study was to identify promising cotton samples with high yield, adaptability, and stable fibre quality. The present work presents the results of a comprehensive assessment of 91 breeding samples of cotton according to economically valuable and technological traits under the conditions of southern Kazakhstan and Uzbekistan in 2024. The comparative analysis identified several promising samples, with M-4010, M-4015, M-4017, M-4019, and M-4025 selected as priority lines. Across the station, competitive, and infectious trials, the breeding samples showed yields of 32.5-46.8 c/ha, fibre output of 36.3-39.8%, fibre length of 32.6-33.7 mm, and fibre breaking load of 4.4-5.6 gf. The study included samples with different genetic predispositions to stresses and to *Verticillium dahliae* infection, including the variety M-4005 as a control standard and the variety S-4727 as a susceptible benchmark. For the assessment of agronomic and technological characteristics, field and laboratory analyses were used, including measurement of the vegetation period, yield, boll structure, fibre output, fibre breaking load, micronaire, and maturity. At the station-trial stage, the samples had vegetation periods of 118-129 days, yields of 36.2-46.8 c/ha compared with 38.4 c/ha in M-4005, boll mass of 5.6-6.2 g, and fibre output of 36.4-39.1%. The evaluated lines had fibre length of up to 33.7 mm, micronaire values of 4.6-4.8, fibre breaking loads of 5.3-5.6 gf, and fibre metric numbers of 5,240-5,490 m/g. The reliability of the differences between genotypes was confirmed by the ANOVA method at a significance level of $p<0.05$. The infectious variety trial at a pathogen concentration of $\geq 10^5$ CFU/g of soil showed total wilt incidence of 0.0-0.9% in all 40 new breeding lines, compared with 0.7% in M-4005 and 37.4% in S-4727. Under the infectious background, fibre breaking load ranged from 4.4 to 5.0 gf, micronaire from 4.4 to 4.8, fibre metric number from 5,260 to 5,640 m/g, and fibre breaking length from 24.6 to 26.3 km. The practical value of this study lies in the identification of highly productive cotton samples showing a high level of field resistance under the tested Verticillium dahliae infectious background and suitable for further evaluation in breeding programmes.

Keywords: Yield, Fibre Length, Verticillium Wilt Resistance, Textile Quality, Vegetation Period

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Introduction

The relevance of this study was determined by the need to create new cotton varieties possessing a complex of adaptive traits high yield, earliness and resistance to wilt. In the southern regions of Kazakhstan and neighbouring cotton-growing areas of Uzbekistan, increasing heat and water stress create additional risks for agricultural production [1, 2]. Therefore, genetically stable varieties are needed to maintain high-quality fibre under stress-prone production conditions. The intensification of cotton growing requires varieties that combine stress resistance with high technological indicators. The problem of this study was caused by the insufficient effectiveness of traditional breeding approaches focused mainly on yield without due consideration of resistance to biotic stresses. The lack of a comprehensive assessment on an infectious background limits the introduction of promising varieties into practice. Therefore, comparative selection according to economically valuable and technological traits under different agroecological conditions becomes particularly important.

Within the framework of the study of the early phases of plant development, [3] recorded significant variability in the timing of the formation of the first sympodium in varieties and F1 hybrids. A relationship was established between earliness and the initial morphogenetic activity of plants under field conditions. In the study by [4], the adaptive qualities and technological characteristics of cotton were examined. The aim was to identify samples capable of maintaining yield and fibre quality under stressful climatic conditions.

As noted in the study by [5], an increase in the level of mechanisation, including the introduction of combine harvesting, proved to be an important factor contributing to the growth of yield and the stability of varieties. At the same time, the authors paid special attention to the link between the technical equipment of farms and the production efficiency of cotton. In the review by [6], special attention was paid to the importance of sequencing technologies for improving the agronomic traits of cotton. The authors substantiated the prospects of molecular methods as a tool for creating stress-resistant forms while preserving fibre quality. It was shown that the application of modern biotechnologies accelerated the breeding process and increased the efficiency of selection.

In the studies by [7], the influence of different harvesting methods on the contamination of cotton fibre and its technological properties was shown. The authors emphasised that even under intensive mechanised harvesting, it was possible to preserve such characteristics as fibre length and fibre breaking load, provided that selection was balanced.

In the retrospective study by [8], three decades of breeding work in Ethiopia were examined, which made it possible to assess the accumulated potential of local genetic resources. The directions were identified in which the combination of traditional breeding and farmers' practice provided a stable increase in yield and fibre quality. According to the conclusions of [9], the key challenge of modern cotton growing remained the need to combine biotechnological solutions with entrepreneurial activity. A lack of integration of scientific achievements into the practice of small and medium-sized producers was noted.

On the basis of the evolutionary analysis of the genus *Gossypium* carried out by [10], the role of archaic cotton forms in breeding for resistance to viruses and drought was underlined. Genomic sources of traits that had previously been ignored in intensive breeding were considered. In another direction, [11] examined biotechnological trends in the context of sustainable agriculture. The prospect of introducing genetic modification to enhance the stress tolerance of cultivated plants was indicated.

According to the generalised analysis presented by [12], the search for resistant forms of *Gossypium hirsutum* to the cotton leaf curl virus remained of great importance. Key approaches to maintaining productivity under viral infection were identified. Relying on interspecific methods, [13] studied the potential of distant hybridisation in improving cotton varieties. It was recorded that intra- and interspecific crosses contributed to the expansion of the gene pool without loss of fibre quality. In a number of works, however, no comprehensive assessment of varieties was carried out simultaneously for yield, resistance to wilt and technological fibre qualities under infectious conditions. Insufficient attention was also paid to the preservation of technological fibre properties under biotic stress and to the comparison of new samples with a susceptible benchmark.

The aim of the study was to carry out a comprehensive assessment of breeding samples of cotton in order to select resistant and high-yielding forms with high fibre quality under wilt conditions. The objectives of the study were to determine the economically valuable and technological indicators of breeding samples at different stages of variety testing, to compare the samples with control varieties, and to identify forms that retained fibre quality under wilt conditions.

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Material and Methods

The study was conducted in 2024 in an experimental field at the Agricultural Experimental Station for Cotton and Melon Growing in the Turkestan Region, Republic of Kazakhstan. The study evaluated the duration of the vegetation period, plant height, number of bolls, raw cotton mass, fibre output, and overall productivity under arid conditions with increased insolation. At the same time, in Uzbekistan at the research experimental stations located in the Tashkent and Jizzakh regions specialised trials on an infectious background were conducted, including the assessment of resistance to wilt, the analysis of the severity of wilt symptoms, as well as laboratory tests of technological fibre properties such as breaking load, length, maturity coefficient and micronaire index. The climatic conditions of the region were sharply continental and were characterised by high solar insolation, a dry summer and a wide range of diurnal temperatures from +20°C at night to +42°C during the day. The average air humidity in June-August was 35-50%. Similar agro-climatic parameters were observed at the experimental sites in Uzbekistan, especially in the Tashkent and Jizzakh regions, where hot and dry summer conditions also prevailed. This ensured the comparability of environmental factors during the variety trials and made it possible to identify genotypes with high adaptability within the entire zone of irrigated agriculture in Central Asia. For precise microclimate control, HOBO MX2300 digital sensors (Onset, USA) and a Sentek Drill & Drop soil-monitoring system (Australia) connected to the Field Climate software package (Pessl Instruments, Austria) were used.

The test objects were 91 breeding samples of cotton, including the standard variety M-4005 and the susceptible benchmark S-4727. The selection of these samples was determined by the functional importance within the framework of the comparative analysis. The variety M-4005 was used as a control owing to its stable yield, medium earliness and balanced fibre quality, which made it a reliable reference point when assessing new breeding lines. The variety S-4727, characterised by pronounced susceptibility to *Verticillium dahliae*, was applied in the infectious variety trial to record the activity of the pathogen objectively and to confirm the level of infection, as well as to assess the degree of resistance of the studied samples. For in-depth laboratory and pathophysiological analyses, 42 cotton varieties, which had previously passed field assessment for a number of agronomic traits including productivity, adaptability to stress conditions and presumed resistance to wilt were selected. The selection was carried out with the aim of subsequent comparison of the technological characteristics of the fibre under pathogen infection.

Sowing was performed on plots of 10 m² according to a randomised block design with threefold replication. The seed rate was about 100 thousand plants per hectare with 90 cm inter-row spacing. Crop management was carried out according to a unified technology.

In the station and competitive variety trials, which were conducted on a non-infectious background, the duration of the vegetation period (from sowing to 50% boll opening), yield (c/ha), mass of one boll (g), fibre output (%) and fibre length (mm) were evaluated. Yield was calculated according to formula (1):

$$Y = \frac{M_{\text{total}} \times 10{,}000}{S}, \tag{1}$$

Where: Y – yield, c/ha, M_{total} – mass of harvested raw cotton, g, S – area of the accounting plot, cm². Fibre output was determined according to formula (2):

$$W = \frac{M_{\text{fib}}}{M_{\text{raw}}} \cdot 100, \tag{2}$$

Where: W – fibre output, %, M_{fib}– mass of cleaned fibre, g, M_{raw}– mass of raw cotton, g.

The technological properties of the fibre were determined using the HVI Spectrum complex (Uster Technologies, Switzerland), certified according to international ICAC standards. The analysis included the determination of micronaire (fibre fineness and maturity), breaking load (gf), metric number (m/g), maturity coefficient, and breaking length of fibre (km). These indicators were selected because micronaire determines fibre fineness and processability; fibre breaking load and breaking length reflect resistance to rupture during spinning and weaving; the metric number characterises fibre fineness and yarn-count potential; and the maturity coefficient indicates fibre-wall development and behaviour during dyeing and finishing. Together, these parameters make it possible to select breeding lines that combine agronomic performance with suitability for textile processing. Fibre strength was calculated as the ratio of the breaking force to the cross-sectional area according to formula (3):

$$F = \frac{P}{A'} \quad (3)$$

Where: F– fibre strength, N/mm², P– breaking load, N, A– cross-sectional area of the fibre, mm². Fibre breaking load, reported in gf in Tables 2, 4, and 6, represents the directly measured force at rupture, whereas fibre strength calculated using Equation (3) is expressed in N/mm². The metric number of the fibre, reflecting its fineness, was determined according to formula (4):

$$Nm = \frac{L}{M'} \quad (4)$$

Where: Nm – metric number of the fibre, m/g, L – fibre length, m, M – fibre mass, g.

The infectious variety trial was carried out on an infected plot where the wilt pathogen (*Verticillium dahliae*) was present at a concentration of at least 10^5 CFU/g of soil, which was confirmed by PCR diagnostics on a Bio-Rad CFX96 platform (USA). The overall disease incidence (%) and the severity of damage (%) were recorded in the plants. Fibre samples were taken at the same dates from both the non-infectious and the infectious backgrounds, which made it possible to assess the resistance of the fibre's technological indicators to biotic stress.

All quantitative data were processed by the method of one-way analysis of variance (ANOVA) with the subsequent calculation of the standard deviation and confidence intervals. Statistical processing was carried out in the Statistica 13.0 software environment (StatSoft, USA). Differences between varieties and conditions were considered statistically significant at the significance level of $p<0.05$. The least significant difference ($LSD_{0.05}$) was calculated using the critical value of Student's t-distribution, the experimental error, and the number of replications. All measurements were performed in triplicate at each stage of the phenological development of plants from budding to boll opening at 10-14-day intervals, in accordance with standards of accuracy and representativeness.

Results

Evaluation of Economically Valuable Traits in the Station Variety Trial

The ripening time of cotton (from sowing to the opening of 50% of bolls) ranged from 118 to 129 days. The control variety showed 126 days. The greatest reduction in the vegetation period (−8 days) was recorded in M-4046, followed by M-4035 (−7 days) and several lines that matured 6 days earlier, including M-4013, M-4016, M-4023, M-4033, M-4036, M-4041, M-4043, M-4045, and M-4053. Conversely, some samples, such as M-4044, M-4049 and M-4055, were characterised by a longer vegetation period (127-129 days), which was probably connected with the potentially higher productivity.

Yield indicators varied widely from 36.2 to 46.8 c/ha, with an average value of 41.9 c/ha. The control variety demonstrated a yield of 38.4 c/ha, and most of the studied samples exceeded it in this indicator. Variety M-4027 was particularly distinguished, with the highest yield of 46.8 c/ha, which is 8.4 c/ha more than the control. A significant yield increase was also shown by M-4029 (+7.4), M-4039 (+7.2), M-4031 (+6.2) and M-4036 (+6.0). In total, 29 of the 32 new varieties had yields above M-4005.

The average mass of one boll was from 5.6 to 6.2 g. In the standard variety, this indicator was 5.9 g. A significant excess was observed in varieties M-4043 (6.2 g), M-4036 and M-4039 (6.1 g each), which indicated a pronounced effect of increasing the size of the fruiting organs. At the same time, in some samples the mass of the boll was 0.2-0.3 g lower than the control, for example, in M-4014, M-4027, and M-4052. These deviations could be compensated by a greater number of bolls or by the improvement of other traits, such as fibre output and quality.

Fibre output in the varieties ranged from 36.4% to 39.1%, compared with 37.9% in M-4005. The highest value was recorded in M-4034 (39.1%), followed by M-4020 and M-4035 (38.7% each). The lowest values were recorded in M-4037 (36.4%) and M-4051 (36.6%). Overall, 14 of the 32 new varieties exceeded the standard for fibre output.

Fibre length was from 32.7 to 33.7 mm. The standard variety M-4005 had a fibre length of 32.7 mm. Higher values were recorded in the majority of the studied samples. The maximum result (33.7 mm) was shown by variety M-4052, exceeding the standard by 1 mm. It is also worth noting M-4034, M-4033, M-4035 and M-4041, whose fibre length exceeded the control by 0.7-0.9 mm. The maximum advantage in fibre length over M-4005 was 1.0 mm (Table 1).

Table 1: Evaluation of economically valuable traits in the station variety testing

Varieties		Number of days from sowing to 50% ripening		Yield		Average mass of one boll		Fibre output		Fibre length	
		Abs.	Dev. from st	c/ha	Dev. from st	g	Dev. from st	%	Dev. from st	mm	Dev. from st
1		2	3	4	5	6	7	8	9	10	11
1	M-4005	126	0.0	38.4	0.0	5.9	0.0	37.9	0.0	32.7	0.0
2	M-4013	120	-6	42.6	+4.2	6.0	+0.1	38.4	+0.5	33.1	+0.4
3	M-4014	122	-4	39.3	+0.9	5.7	-0.2	37.6	-0.3	32.9	+0.2
4	M-4016	120	-6	43.5	+5.1	6.1	+0.2	38.3	+0.4	33.3	+0.6
5	M-4020	125	-1	40.7	+2.3	6.0	+0.1	38.7	+0.8	32.8	+0.1
6	M-4022	124	-2	40.3	+1.9	5.9	0.0	37.9	0.0	33.0	+0.3
7	M-4023	120	-6	44.2	+5.8	5.9	0.0	38.2	+0.3	32.9	+0.2
8	M-4027	123	-3	46.8	+8.4	5.8	-0.1	37.5	-0.4	32.8	+0.1
9	M-4028	126	-0.0	44.3	+5.9	5.7	-0.2	38.4	+0.5	32.9	+0.2
10	M-4029	128	+2	45.8	+7.4	6.0	+0.1	38.5	+0.6	33.1	+0.4
11	M-4031	124	-2	44.6	+6.2	5.9	0.0	37.9	0.0	33.4	+0.7
12	M-4033	120	-6	42.7	+4.3	5.9	0.0	37.5	-0.4	33.5	+0.8
13	M-4034	121	-5	41.6	+3.2	5.8	-0.1	39.1	+1.2	33.6	+0.9
14	M-4035	119	-7	41.9	+3.5	6.0	+0.1	38.7	+0.8	33.4	+0.7
15	M-4036	120	-6	44.4	+6.0	6.1	+0.2	38.4	+0.5	32.8	+0.1
16	M-4037	125	-1	43.9	+5.5	6.0	+0.1	36.4	-1.5	32.8	+0.1
17	M-4038	123	-3	41.6	+3.2	5.7	-0.2	38.0	+0.1	33.0	+0.3
18	M-4039	125	-1	45.6	+7.2	6.1	+0.2	37.6	-0.3	32.7	-0.0
19	M-4040	121	-5	42.7	+4.3	5.9	0.0	37.3	-0.6	33.1	+0.4
20	M-4041	120	-6	42.3	+3.9	6.1	+0.2	38.5	+0.6	33.5	+0.8
21	M-4042	124	-2	41.4	+3.0	5.9	0.0	38.2	+0.3	32.8	0.1
22	M-4043	120	-6	40.4	+2.0	6.2	+0.3	37.6	-0.3	32.7	0.0
23	M-4044	127	+1	40.8	+2.4	5.9	0.0	37.3	-0.6	33.0	+0.3
24	M-4045	120	-6	43.7	+5.3	6.0	+0.1	38.0	+0.1	33.2	+0.5
25	M-4046	118	-8	45.8	+7.4	5.8	-0.1	37.6	-0.3	33.4	+0.7
26	M-4048	122	-4	38.6	+0.2	5.7	-0.2	37.3	-0.6	32.7	0.0
27	M-4049	127	+1	41.4	+3.0	5.6	-0.3	37.0	-0.9	33.2	+0.5
28	M-4050	124	-2	37.8	-0.6	5.9	0.0	37.5	-0.4	33.3	+0.6
29	M-4051	125	-1	39.7	+1.3	5.7	-0.2	36.6	-1.3	33.2	+0.5
30	M-4052	123	-3	36.2	-2.2	5.9	0.0	37.4	-0.5	33.7	+1.0
31	M-4053	120	-6	41.6	+3.2	6.0	+0.1	38.6	+0.7	33.4	+0.7
32	M-4054	127	+1	39.2	+0.8	5.9	0.0	37.7	-0.2	32.8	+0.1
33	M-4055	129	+3	37.6	-0.8	5.8	-0.1	37.3	-0.6	33.0	+0.3
M=41.9 c/ha; P=2.6%; E=1.1 c/ha. $LSD_{0.05}$=2.0.											

Note: $LSD_{0\text{-}05}$ – least significant difference at $p<0.05$

Source: compiled by the authors

Out of the total number of 91 breeding samples, 33 varieties and hybrids were included, selected on the basis of the full availability of quantitative data for all key agronomic and technological indicators. Table 1 included both samples exceeding the standard in a number of indicators (for example, M-4046, M-4027, M-4036) and varieties with close or moderate values, which made it possible to present a wide range of variation within the studied sample. On the basis of the combination of traits, the most promising varieties were identified. Thus, M-4027 combined the highest yield, a short vegetation period and satisfactory fibre quality. Varieties M-4029, M-4031 and M-4039 were distinguished by consistently high productivity and balanced technological parameters. M-4034 and M-4052 demonstrated the best indicators for fibre length, and M-4036 and M-4043 – for boll mass and fibre output. Thus, the data of the variety trial confirmed that the majority of new samples possessed improved agronomic characteristics compared with the control variety, which made it possible to recommend these samples for further competitive testing and possible zonal adaptation.

Analysis of Technological Fibre Properties According to the Station Variety Trial

The micronaire indicator, which characterises fibre thickness and density, varied from 4.6 to 4.8. The control variety had a value of 4.8, which corresponds to mature fibre. The minimum micronaire values (4.6) were recorded in eight new varieties: M-4013, M-4027, M-4035, M-4039, M-4041, M-4045, M-4051 and M-4054. This indicates the presence of finer fibre, which may be preferable for the production of delicate and smooth fabrics. Most of the other samples were within the range of 4.7-4.8, which ensures technological stability and versatility in processing.

The breaking load of the fibre ranged from 5.3 to 5.6 gf, with the control variety at 5.4 gf. Twenty-five of the 32 new samples had fibre breaking loads of at least 5.4 gf. The highest values (5.6 gf) were observed in M-4013, M-4027, and M-4033, indicating higher fibre breaking load than in M-4005. It is especially important that high fibre breaking load was also retained in varieties with minimum micronaire this reflects a balanced combination of structure and reliability of the fibre, achieved through effective breeding.

The metric number of the fibre fluctuated within 5,240-5,490 m/g. In the standard variety, it was 5,430, while the maximum values were recorded in varieties M-4034 and M-4044 (5,490), which indicates high fineness and suitability for the production of fine-count yarn. High indicators were also shown by varieties M-4028, M-4042, M-4048 and M-4053. These parameters are particularly valuable for the light textile industry, focused on the production of strong and at the same time elegant fabrics.

The fibre maturity coefficient varied from 2.3 to 2.5, with the control variety having a value of 2.5. Most of the new samples showed values of 2.4 and higher, which indicates well-formed cell walls and a high level of maturity. This ensures fibre resistance during dyeing and wet processes, reducing the likelihood of deformation and damage. Varieties M-4013, M-4014, M-4031, M-4039, M-4040 and M-4052 were particularly mature, showing a maturity coefficient of 2.5.

The fibre breaking length was in the range of 26.0 to 26.5 km. In the control variety, this indicator was 26.1 km. The maximum values (26.5 km) were shown by varieties M-4016 and M-4045, which reflect high elasticity and the ability of the fibre to withstand stretching without breaking. This is especially important for the production of long-fibre yarn and fabric materials with increased wear resistance. More than 75% of the new varieties demonstrated fibre breaking lengths equal to or exceeding the standard.

As for fibre grading, the control sample M-4005 was assigned to the first category (I). Twenty-five of the 33 samples were assigned grade I, while eight varieties were assigned the selected grade (Sel.). This confirms the superiority in the aggregate of indicators: uniformity of structure, maturity, fibre breaking load, and absence of coarse inclusions. Such varieties are of the greatest interest for commercial use and for export supplies. The assignment of the selected category to several lines is a vivid sign of the success of breeding work to improve the quality of cotton fibre (Table 2).

Thirty-three cotton varieties were included from the total of 91 tested samples, selected on the basis of the high stability of agronomic and technological traits shown in previous stages of the study. In comparison with the control variety M-4005, which had a fibre breaking load of 5.4 gf, a fibre metric number of 5,430 m/g, a maturity coefficient of 2.5, and a fibre breaking length of 26.1 km, the improved samples demonstrated a fibre breaking load of up to 5.6 gf, a fibre metric number of up to 5,490 m/g, a maturity coefficient of up to 2.5, and a fibre breaking length of up to 26.5 km. The micronaire values remained in the range of 4.6-4.8, which indicates a balanced combination of fibre breaking load and fineness. Thus, according to the results of the analysis of technological fibre properties in the conditions of the 2024 station variety trial, 25 out of 33 studied new cotton varieties surpassed the control variety in

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key technological traits – in particular, in fibre breaking load, maturity coefficient, and fibre metric number. Lines were identified that combined fibre fineness with high fibre breaking load and maturity and also possessed the best grading indicators. Varieties M-4027, M-4041, M-4045 and M-4034 can be considered the most promising in terms of the combination of the studied technological parameters.

Table 2: Analysis of technological fibre properties according to the station variety trial

Variety		Micronaire	Grade	Fibre breaking load, gf	Fibre metric number, m/g	Fibre maturity coefficient	Fibre breaking length, km
1	M-4005	4.8	I	5.4	5430	2.5	26.1
2	M-4013	4.6	Sel.	5.6	5320	2.5	26.4
3	M-4014	4.7	I	5.5	5430	2.5	26.0
4	M-4016	4.8	I	5.5	5360	2.4	26.5
5	M-4020	4.7	I	5.3	5390	2.3	26.4
6	M-4022	4.8	I	5.3	5460	2.4	26.1
7	M-4023	4.7	I	5.3	5400	2.4	26.0
8	M-4027	4.6	Sel.	5.6	5240	2.3	26.4
9	M-4028	4.7	I	5.5	5460	2.4	26.4
10	M-4029	4.7	I	5.5	5380	2.3	26.4
11	M-4031	4.8	I	5.3	5420	2.5	26.4
12	M-4033	4.7	I	5.6	5380	2.4	26.0
13	M-4034	4.8	I	5.5	5490	2.4	26.2
14	M-4035	4.6	Sel.	5.4	5310	2.4	26.1
15	M-4036	4.7	I	5.4	5420	2.4	26.4
16	M-4037	4.7	I	5.4	5380	2.4	26.3
17	M-4038	4.8	I	5.4	5380	2.3	26.2
18	M-4039	4.6	Sel.	5.5	5270	2.5	26.0
19	M-4040	4.8	I	5.4	5430	2.5	26.2
20	M-4041	4.6	Sel.	5.4	5250	2.5	26.2
21	M-4042	4.8	I	5.5	5480	2.5	26.4
22	M-4043	4.7	I	5.3	5390	2.4	26.3
23	M-4044	4.7	I	5.4	5490	2.5	26.4
24	M-4045	4.6	Sel.	5.4	5250	2.3	26.2
25	M-4046	4.7	I	5.4	5390	2.3	26.1
26	M-4048	4.8	I	5.5	5470	2.3	26.4
27	M-4049	4.7	I	5.4	5390	2.4	26.4
28	M-4050	4.8	I	5.5	5400	2.4	26.3
29	M-4051	4.6	Sel.	5.5	5300	2.4	26.4
30	M-4052	4.7	I	5.3	5430	2.5	26.2
31	M-4053	4.8	I	5.5	5480	2.4	26.3
32	M-4054	4.6	Sel.	5.4	5330	2.4	26.2
33	M-4055	4.7	I	5.3	5390	2.4	26.0

Source: compiled by the authors

Results of Competitive Variety Trial for Economically Valuable Traits

The ripening time of cotton varied from 117 to 128 days. The standard variety had a vegetation period of 125 days. Most of the new samples demonstrated earlier ripening: in 13 out of 15 breeding lines, this indicator was lower than in the standard.

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The earliest varieties were M-4003 and M-4026 (117 days), as well as M-4010 and M-4015 (118-119 days), which indicated the presence in the collection of samples with a clearly pronounced earliness. Such varieties are especially relevant under conditions of a short vegetation period and when it is necessary to obtain a second harvest.

Yield ranged from 39.4 to 45.7 c/ha, with the average value in the sample being 42.7 c/ha. The control variety showed a yield of 39.6 c/ha. All breeding samples, except one (M-4004), exceeded the standard in this indicator. Particularly high results were recorded in varieties M-4017 (45.7 c/ha), M-4019 (45.2 c/ha), M-4015 (44.6 c/ha), M-4009 (44.7 c/ha) and M-4006 (44.3 c/ha). The yield advantage over M-4005 ranged from +2.8 to +6.1 c/ha and exceeded $LSD_{0.05}$ (2.0 c/ha).

The average mass of one boll in the control variety was 5.7 g. In the new samples, both moderate upward deviations and similar values were observed. The maximum indicators were recorded in varieties M-4006, M-4009, M-4010, M-4015, M-4017 and M-4019 – all these varieties had a boll mass of 6.0-6.2 g. These varieties exceeded M-4005 in boll mass by 0.3-0.5 g.

In terms of fibre output, 16 out of 33 new varieties exceeded the control variety M-4005. The control variety showed 37.8%, while the indicators in the new samples were in the range of 36.3 to 39.8%. The highest output was recorded in variety M-4017 (38.7%), which is 0.9% higher than the control, as well as in M-4019 and M-4015 (38.0-38.6%). At the same time, not a single variety showed a significant decrease in this indicator, which confirmed the stability of the fibre-forming ability in the new lines.

The fibre length in the control variety was 32.7 mm. Of the 15 new varieties included in the competitive variety trial, 14 samples demonstrated fibre length equal to or exceeding the control value (32.7 mm), reaching a maximum of 33.4 mm. The greatest fibre length was recorded in varieties M-4006 (33.4 mm), M-4015 and M-4030 (33.1 mm), as well as in M-4003 and M-4025 (33.0 mm). The maximum advantage in fibre length over M-4005 was 0.7 mm (Table 3).

Table 3: Results of the competitive variety trial of new varieties for economically valuable traits

Varieties		Number of days from sowing to 50% ripening		Yield		Average mass of one boll		Fibre output		Fibre length	
		abs.	Dev. from St	c/ha	Dev. from St	g	Dev. from St	%	Dev. from St	mm	Dev. from St
1	M-4005	125	0.0	39.6	0.0	5.7	0.0	37.8	0.0	32.7	0.0
2	M-4001	121	-4	42.4	+2.8	5.9	+0.2	38.5	+0.7	32.8	+0.1
3	M-4003	117	-8	43.6	+4.0	5.8	+0.1	38.3	+0.5	33.0	+0.3
4	M-4004	124	-1	39.4	-0.2	5.7	0.0	38.1	+0.3	32.8	+0.1
5	M-4006	120	-5	44.3	+4.7	6.1	+0.4	38.0	+0.2	33.4	+0.7
6	M-4009	124	-1	44.7	+5.1	6.2	+0.5	37.8	0.0	33.1	+0.4
7	M-4010	118	-7	42.5	+2.9	6.1	+0.4	38.6	+0.8	32.9	+0.2
8	M-4012	127	+2	40.3	+0.7	5.6	-0.1	38.1	+0.3	32.6	-0.1
9	M-4015	119	-6	44.6	+5.0	6.0	+0.3	38.6	+0.8	33.1	+0.4
10	M-4017	121	-4	45.7	+6.1	6.1	+0.4	39.8	+2.0	33.0	+0.3
11	M-4018	122	-3	41.8	+2.2	5.9	+0.2	38.9	+1.1	32.9	+0.2
12	M-4019	123	-2	45.2	+5.6	6.1	+0.4	39.0	+1.2	32.8	+0.1
13	M-4021	124	-1	40.7	+1.1	5.7	0.0	38.4	+0.6	32.7	0.0
14	M-4025	120	-5	43.9	+4.3	5.9	+0.2	38.2	+0.4	33.0	+0.3
15	M-4026	117	-8	41.7	+2.1	5.8	+0.1	38.0	+0.2	32.9	+0.2
16	M-4030	126	+1	42.5	+2.9	5.9	+0.2	39.7	+1.9	33.1	+0.4
M = 42.7 c/ha; E = 1.1 c/ha; R = 2.6%; $LSD_{0.05}$ = 2.0.											

Note: $LSD_{0.05}$ – least significant difference at p<0.05

Source: compiled by the authors

In the competitive variety trial for economically valuable traits, 15 new breeding samples and the control M-4005 were included that demonstrated promising agronomic characteristics. The selection of a limited number of varieties at this stage was due to the need for a more in-depth assessment of each sample in comparison with the control, as well as to preliminary screening at the early phases of the breeding process. Thus, on the basis of the combination of traits, the most productive and stable samples were identified. The varieties M-4017, M-4015, M-4019, M-4006 and M-4009 should be considered the most promising in terms of economically valuable traits. These lines combined earliness, high yield, good boll mass, increased fibre output, and optimal length. The results of the competitive trial confirmed the high breeding value of these samples and the readiness for further introduction into production or for submission to state trials.

Comparative Characteristics of Technological fibre Properties in the Competitive Trial

Micronaire, which characterises fibre thickness and density, varied in the new varieties from 4.5 to 4.8. The control variety M-4005 had a value of 4.8, corresponding to the standard of mature fibre. At the same time, half of the new samples demonstrated values below 4.8, which indicated a finer fibre structure. The lowest micronaire (4.5) was recorded in variety M-4010, which makes it particularly promising for the production of delicate fabrics. Such values indicate good processability while maintaining the necessary technological properties.

The fibre breaking load varied within 5.0 to 5.4 gf. In the control variety, this indicator was 5.4 gf, but some new samples showed even higher or comparable values. Thus, variety M-4015 reached the maximum – 5.4 gf, and M-4017, M-4019, M-4025 and M-4030 demonstrated indicators of 5.0 gf and higher. These values indicate a favourable combination of fibre breaking load and fineness.

The metric number of the fibre, reflecting the degree of its fineness, ranged from 5,160 to 5,440 m/g. The control variety had a value of 5,430, and most of the new samples were close to this level. The highest number (5,440) was noted in M-4021, which indicates the possibility of obtaining especially fine yarn from it. Conversely, in variety M-4015, the metric number was 5,160, which indicates a coarser but strong fibre suitable for dense and wear-resistant fabrics.

The fibre maturity coefficient ranged from 2.2 to 2.4. The control variety M-4005 had a value of 2.2. The highest coefficient, 2.4, was recorded in M-4004 and M-4015, while the remaining accessions had values of 2.2-2.3.

The fibre breaking length ranged from 26.0 to 26.4 km. The control variety M-4005 had a value of 26.0 km, while M-4015 had the maximum value of 26.4 km. M-4004 reached 26.3 km, and M-4001, M-4006, M-4017, M-4021, and M-4025 reached 26.2 km. These fibre breaking-length values indicate suitability for the production of yarn with minimal breakage. Particular attention should be paid to the fibre grade. The control variety was assigned grade I, whereas seven new samples received the designation “Sel.”: M-4001, M-4003, M-4009, M-4010, M-4015, M-4017, and M-4025. This confirms the high quality, uniformity, maturity, and absence of foreign inclusions. The assignment of the selected category increases the market value of the fibre and makes it particularly attractive for the high-level textile industry (Table 4).

This comparative characteristic of technological fibre properties included 16 new cotton varieties, selected according to the results of the preliminary stages of breeding. Such a number of samples was due to the task of focusing on the most promising lines that had demonstrated stable fibre quality indicators in previous trials. Thus, the competitive variety trial confirmed the presence in the group of new varieties of lines with improved or consistently high technological fibre properties. Varieties M-4015, M-4017, M-4019, and M-4025 stood out in particular, with fibre breaking loads of 5.1-5.4 gf, maturity coefficients of 2.2-2.4, and fibre breaking lengths of 26.0-26.4 km. M-4015, M-4017, and M-4025 were assigned the selected grade, whereas M-4019 was assigned grade I.

Evaluation of Economically Valuable Traits Under Infectious Conditions (Wilt)

In terms of the duration of the vegetation period of cotton, the values ranged from 117 to 129 days. The control resistant variety M-4005 had an indicator of 126 days, and the susceptible one 128. M-4016 matured in 117 days, M-4015 in 118 days, and M-4003 and M-4025 in 119 days, compared with 126 days in M-4005.

Yield analysis showed that the control variety M-4005, under pathogenic pressure, maintained a high level of productivity – 33.8 c/ha. At the same time, the susceptible variety S-4727 showed a sharp decrease to 30.6 c/ha. Most of the new varieties demonstrated yields close to or even exceeding the standard. The highest values were recorded in varieties M-4017 (37.6 c/ha), M-4015 (36.3), M-4016 (36.4), M-4021 (36.8), M-4019 and M-4003 (35.7-35.8 each). These results indicated that the new lines maintained a high productive potential under disease conditions and exhibited a high level of field resistance under the tested infectious background.

The average boll mass in most varieties remained within 5.6-6.0 g, without a sharp decrease compared with the non-infectious background. In the resistant varieties M-4017, M-4019, M-4010 and M-4006, the boll mass reached 6.0 g, which confirmed the adaptability and ability to maintain full growth. Conversely, in the susceptible control S-4727, this indicator remained unchanged (5.6 g), but its yield sharply decreased due to high disease incidence and plant death.

Table 4: Comparative characteristics of technological fibre properties of new cotton varieties in the competitive trial

Variety		Micronaire	Grade	Fibre breaking load, gf	Fibre metric number, m/g	Fibre maturity coefficient	Fibre breaking length, km
1	M-4005	4.8	I	5.4	5430	2.2	26.0
2	M-4001	4.6	Sel.	5.1	5300	2.3	26.2
3	M-4003	4.6	Sel.	5.2	5320	2.3	26.1
4	M-4004	4.8	I	5.0	5390	2.4	26.3
5	M-4006	4.7	I	5.1	5370	2.3	26.2
6	M-4009	4.6	Sel.	5.3	5310	2.2	26.1
7	M-4010	4.5	Sel.	5.0	5270	2.3	26.0
8	M-4012	4.8	I	5.2	5430	2.2	26.1
9	M-4015	4.6	Sel.	5.4	5160	2.4	26.4
10	M-4017	4.6	Sel.	5.3	5310	2.3	26.2
11	M-4018	4.7	I	5.2	5380	2.2	26.1
12	M-4019	4.7	I	5.1	5360	2.2	26.0
13	M-4021	4.8	I	5.2	5440	2.3	26.2
14	M-4025	4.6	Sel.	5.3	5310	2.3	26.2
15	M-4026	4.7	I	5.1	5420	2.2	26.0
16	M-4030	4.8	I	5.2	5380	2.3	26.1

Source: compiled by the authors

Fibre output ranged from 36.3 to 38.7%, while in the standard it was 36.9%. Several tested lines exceeded the control value: M-4017 38.7%, M-4015 37.8%, M-4016 38.2%, and M-4013 – 37.6%. At the same time, in the susceptible variety S-4727, a noticeable decrease to 32.6% was observed, which reflected fibre degradation under the influence of the pathogen.

In terms of fibre length, the range was from 32.6 to 33.6 mm. In the control variety M-4005, this indicator was 32.6 mm. Among the new samples, the best results were shown by M-4017 (33.6 mm), M-4015 and M-4019 (33.4-33.5 mm). M-4017, M-4015, and M-4019 maintained fibre lengths of 33.4-33.6 mm under the infectious background. In the susceptible variety S-4727, the fibre length was at the level of 32.3 mm, with a tendency to shorten, which negatively affects textile suitability.

The most indicative characteristic under infectious pressure was the degree of wilt incidence. In the resistant variety M-4005, the total incidence was only 0.7%, without a pronounced severe form. Almost all new breeding samples showed the same or even better results an absolute absence of disease symptoms was recorded in 25 of the 40 new breeding lines, including M-4003, M-4006, M-4009, M-4010, M-4015, M-4016, M-4017 and M-4025. At the same time, S-4727 had a total incidence of 37.4%, including severe symptoms in 17.3% of plants, confirming its substantially greater susceptibility under the tested infectious background (Table 5).

Table 5: Evaluation of economically valuable traits under infectious conditions (wilt)

Varieties		Number of days from sowing to 50% ripening	Yield, c/ha	Average mass of 1 boll, g	Fibre output %	Fibre length mm	Wilt incidence, %	
							total	in severe form
1	M-4005	126	33.8	5.6	36.9	32.6	0.7	0.0
2	S-4727	128	30.6	5.6	32.6	32.3	37.4	17.3
3	M-4001	120	34.8	5.8	37.2	32.7	0.7	0.0
4	M-4002	125	33.9	5.7	36.7	32.6	0.9	0.0
5	M-4003	119	35.8	5.8	37.8	33.0	0.0	0.0
6	M-4004	127	32.5	5.6	36.9	32.6	0.7	0.0

Varieties		Number of days from sowing to 50% ripening	Yield, c/ha	Average mass of 1 boll, g	Fibre output %	Fibre length mm	Wilt incidence, %	
							total	in severe form
7	M-4006	121	34.3	5.9	37.5	33.5	0.0	0.0
8	M-4008	124	33.9	5.6	36.7	32.7	0.8	0.0
9	M-4009	125	34.6	6.0	37.4	32.8	0.0	0.0
10	M-4010	122	35.7	5.9	36.9	32.7	0.0	0.0
11	M-4012	121	33.8	5.7	37.0	32.9	0.7	0.0
12	M-4013	120	35.9	5.9	37.6	33.2	0.0	0.0
13	M-4014	124	33.6	5.7	36.9	33.0	0.0	0.0
14	M-4015	118	36.3	5.9	37.8	33.4	0.0	0.0
15	M-4016	117	36.4	5.9	38.2	33.1	0.0	0.0
16	M-4017	120	37.6	6.0	38.7	33.6	0.0	0.0
17	M-4018	122	35.4	5.7	37.6	32.8	0.0	0.0
18	M-4019	128	35.7	6.0	38.0	33.1	0.0	0.0
19	M-4020	123	34.5	5.7	36.9	32.7	0.9	0.2
20	M-4021	125	36.8	5.6	37.0	32.8	0.7	0.0
21	M-4022	128	33.9	5.7	37.5	32.9	0.9	0.1
22	M-4023	127	32.8	5.8	37.4	32.6	0.0	0.0
23	M-4024	123	34.3	5.9	36.9	32.7	0.0	0.0
24	M-4025	119	34.3	5.9	37.6	32.9	0.0	0.0
25	M-4026	120	33.7	5.7	36.9	33.2	0.0	0.0
26	M-4027	121	34.3	5.9	37.8	33.5	0.9	0.2
27	M-4028	129	32.7	5.6	36.8	32.8	0.7	0.0
28	M-4029	126	34.5	5.9	37.2	32.9	0.0	0.0
29	M-4030	128	33.9	5.6	37.4	32.7	0.9	0.0
30	M-4031	126	34.6	5.7	36.4	32.6	0.8	0.1
31	M-4032	127	34.2	5.6	36.9	32.7	0.0	0.0
32	M-4033	129	35.4	5.8	37.4	33.0	0.0	0.0
33	M-4034	124	34.3	5.7	37.1	32.6	0.9	0.1
34	M-4035	123	35.7	5.6	37.5	33.0	0.0	0.0
35	M-4036	125	33.9	5.7	36.9	32.6	0.0	0.0
36	M-4037	127	34.9	5.7	36.9	32.8	0.0	0.0
37	M-4038	128	33.3	5.6	37.1	32.9	0.7	0.1
38	M-4040	122	34.9	5.6	36.3	32.7	0.0	0.0
39	M-4045	120	34.4	5.9	37.0	33.0	0.0	0.0
40	M-4046	127	35.8	5.8	37.8	32.6	0.0	0.0
41	M-4049	129	34.4	5.7	37.4	32.8	0.8	0.0
42	M-4050	125	35.6	5.9	37.2	32.9	0.0	0.0
M=34.6 c/ha; E=0.8 c/ha; R=2.3%; $LSD_{0.05}$=2.0.								

Note: $LSD_{0.05}$ – least significant difference at p<0.05

Source: compiled by the authors

Forty-two cotton varieties were selected that had passed preliminary assessment on agronomic indicators and potential resistance to wilt. The inclusion in the analysis under infectious conditions was due to the need for a deeper verification of resistance under stress conditions and the identification of genotypes capable of maintaining high yield and fibre quality under pathogenic impact. Such an approach made it possible to expand the comparative base and ensure the representativeness of the selection for further breeding decisions. Under the tested infectious background, M-4017, M-4015, M-4016, and M-4019 combined relatively high yield and fibre quality indicators with low wilt incidence. These lines therefore warrant further multi-year and multi-location evaluation.

Fibre Quality Under Pathogenic Infection

Analysis of the micronaire indicator, which characterises fibre thickness and maturity, showed that in the control variety M-4005 it was 4.7, while in the susceptible control it was 4.8. Most of the new varieties retained optimal values in the range of 4.5 to 4.7, despite pathogenic pressure. Thus, varieties M-4015, M-4016, M-4021 and M-4040 demonstrated a micronaire of 4.4-4.5, which indicates the formation of finer and mature fibre even under stress conditions. Such values are especially valuable for the textile industry focused on thin and uniform fibres. Conversely, in the susceptible variety S-4727, an increase in micronaire to 4.8 reflected a physiological disturbance in the processes of fibre formation, which is typical for plants subjected to biotic stress.

The fibre breaking load indicators ranged from 4.4 to 5.0 gf. In the control variety, this parameter was 4.6 gf, and in the susceptible one 4.5 gf. The breeding samples demonstrated a wide range of values, and a significant part of these samples (more than 25 varieties) retained or exceeded the standard level. The maximum values were recorded in M-4016, M-4017, and M-4025 (4.8-4.9 gf), exceeding M-4005 by 0.2-0.3 gf.

The metric number of the fibre, reflecting the degree of fineness, was in the range of 5,260 to 5,640 m/g. The control variety had a value of 5,470, which corresponded to fine and mature fibre. Almost all resistant varieties demonstrated similar indicators: M-4012, M-4013, M-4020, M-4022, M-4026, M-4036 and M-4040 had values from 5,550 to 5,640, which even exceeded the standard. At the same time, in the susceptible variety S-4727, the metric number was lower (5,530), but this was accompanied by a decrease in fibre breaking load and length, which indicates a deterioration in quality.

The fibre breaking length under infectious conditions ranged from 24.6 to 26.3 km. In the standard variety, this indicator was 25.2 km. The best values were shown by varieties M-4010 and M-4019 (26.3 and 26.1 km respectively), as well as M-4016, M-4025, M-4045 and M-4035. This meant that even under pathogenic load, the fibre retained the ability to withstand prolonged stretching without destruction, which is important for spinning processes. The breaking length of the susceptible variety S-4727 was the lowest – 24.9 km, which indicates the degradation of the internal fibre structure under the influence of the disease.

Summarising the obtained data, it can be noted that the majority of the new breeding samples showed high stability of technological characteristics. Despite the stress conditions caused by wilt infection, the indicators of micronaire, fibre breaking load, fibre metric number, and fibre breaking length in a significant part of the lines remained at the level of or exceeded the standard. Varieties M-4016, M-4017, M-4019, M-4021, and M-4040 stood out in particular, demonstrating high fibre breaking load, maturity, and fibre metric number. These samples combined resistance to the disease with the preservation of key technological parameters, which indicates the versatility and high breeding value (Table 6).

Technological fibre quality under pathogenic infection was assessed in 42 varieties selected after the preceding agronomic and wilt-incidence evaluation. The comparison included micronaire, fibre breaking load, fibre metric number, and fibre breaking length under the tested infectious background.

Table 6: Fibre quality under pathogenic infection

Variety		Micronaire	Fibre breaking load, gf	Fibre metric number, m/g	Fibre breaking length, km
1	M-4005	4.7	4.6	5470	25.2
2	S-4727	4.8	4.5	5530	24.9
3	M-4001	4.6	4.6	5480	25.2
4	M-4002	4.7	4.5	5560	25.0
5	M-4003	4.5	4.7	5450	25.6
6	M-4004	4.8	4.6	5480	25.2
7	M-4006	4.6	4.7	5470	25.7

Variety		Micronaire	Fibre breaking load, gf	Fibre metric number, m/g	Fibre breaking length, km
8	M-4008	4.7	4.6	5480	25.2
9	M-4009	4.8	4.7	5430	25.5
10	M-4010	4.5	5.0	5260	26.3
11	M-4012	4.6	4.5	5570	25.1
12	M-4013	4.5	4.7	5440	25.6
13	M-4014	4.7	4.6	5520	25.4
14	M-4015	4.5	4.7	5430	25.5
15	M-4016	4.4	4.8	5400	25.9
16	M-4017	4.6	4.9	5340	26.2
17	M-4018	4.6	4.7	5420	25.5
18	M-4019	4.5	4.9	5330	26.1
19	M-4020	4.6	4.5	5570	25.1
20	M-4021	4.5	4.4	5590	24.6
21	M-4022	4.7	4.5	5550	25.0
22	M-4023	4.6	4.6	5510	25.3
23	M-4024	4.7	4.6	5500	25.3
24	M-4025	4.5	4.8	5410	25.9
25	M-4026	4.4	4.7	5410	25.4
26	M-4027	4.8	4.5	5550	25.0
27	M-4028	4.8	4.5	5580	25.1
28	M-4029	4.7	4.6	5510	25.3
29	M-4030	4.6	4.6	5480	25.2
30	M-4031	4.5	4.6	5470	25.2
31	M-4032	4.6	4.6	5470	25.2
32	M-4033	4.4	4.5	5560	25.0
33	M-4034	4.6	4.6	5500	25.3
34	M-4035	4.5	4.7	5420	25.5
35	M-4036	4.7	4.5	5570	25.1
36	M-4037	4.6	4.6	5480	25.2
37	M-4038	4.5	4.5	5550	25.0
38	M-4040	4.4	4.4	5640	24.8
39	M-4045	4.5	4.7	5440	25.6
40	M-4046	4.5	4.7	5410	25.4
41	M-4049	4.6	4.5	5540	24.9
42	M-4050	4.7	4.4	5600	24.6

Source: compiled by the authors

Climatic differences between regions played an important role in the formation of differences in technological traits. In Kazakhstan, the vegetation period was accompanied by more pronounced continentality: daytime temperatures often exceeded +40 °C, night time ones dropped to +20 °C, and the average air humidity fluctuated within 35-45%. In Uzbekistan, weather conditions were slightly milder the average daytime temperature reached +37°C, night time +25°C, and air humidity was consistently higher (40-55%). These differences contributed to a differentiated reaction of plants, especially at the phase of boll filling and the biosynthesis of the fibre cell wall. Yield in Uzbekistan was slightly higher (an average of 36.8 c/ha against 35.4 c/ha in Kazakhstan), which was probably associated with lower thermal stress and greater water-holding capacity of the soils. However, in Kazakhstan, a better expression of technological fibre indicators was noted: the average micronaire was 4.6 against 4.7 in Uzbekistan, the breaking load was 4.8 gf against 4.6 gf, and the fibre breaking length was 25.8 km against 25.3 km, respectively.

The micronaire indicator under the drier and hotter climate of Kazakhstan showed a decrease to 4.4-4.6 in most samples, which indicates the formation of finer fibre. The lowest values were recorded in varieties M-4016, M-4026 and M-4040 grown in Kazakhstan. This may have been associated with short-term stress during the active fibre formation, which stimulated the differentiation of the cell wall with reduced thickness. At the same time, the breaking load remained at a high level. Varieties M-4010, M-4015 and M-4017 grown in Kazakhstan showed fibre breaking loads of up to 5.0 gf, which exceeded the control level (4.6 gf) and the average values for Uzbekistan. These genotypes were characterised by a balanced combination of fibre breaking load and maturity coefficient, which is especially valuable under conditions of limited irrigation and high temperatures.

The fibre maturity coefficient also varied: in Kazakhstan it was on average 2.3, in Uzbekistan –2.2. Most varieties in both locations showed maturity coefficients above 2.0, while the average value was slightly higher in Kazakhstan (2.3) than in Uzbekistan (2.2). The fibre breaking length was also higher in varieties grown in Kazakhstan. The value of 25.8 km against 25.3 km indicated more elastic fibre that is less prone to breakage. Particularly stable results in both zones were shown by varieties M-4010 and M-4015 with maximum length values (26.3 and 26.1 km respectively), which makes these varieties universal in terms of adaptability.

The analysis of fibre grading showed that eight samples received the status “Sel.” in both regions. These are varieties M-4010, M-4015, M-4001, M-4003, M-4006, M-4009, M-4025 and M-4026. The varieties were distinguished by stable indicators of micronaire, maturity, fibre breaking load and metric number. These varieties retained comparable values for the evaluated fibre-quality indicators at both study locations (Table 7).

The comparative analysis showed that M-4010, M-4015, and M-4017 retained comparable micronaire, fibre breaking load, maturity coefficient, and fibre breaking length values at the two study locations. These lines should therefore undergo further multi-year and multi-location validation before zoning or large-scale introduction.

Table 7: Results of the comparative analysis of cotton samples under the conditions of Kazakhstan and Uzbekistan

Indicator	Kazakhstan	Uzbekistan	Comparative assessment
Average temperature	+40 °C (day), +22 °C (night)	+37 °C (day), +25 °C (night)	Sharper diurnal fluctuations in Kazakhstan
Average air humidity	35-45%	40-55%	Humidity is slightly higher in Uzbekistan, which affects growth and maturity
Average yield, c/ha	35.4	36.8	Slight advantage under the conditions of Uzbekistan
Average micronaire	4.6	4.7	Finer fibre in Kazakhstan
Fibre breaking load, gf	4.8	4.6	Higher fibre breaking load in Kazakhstan under drier conditions
Fibre breaking length, km	25.8	25.3	Greater length under the conditions of Kazakhstan
Fibre metric number, m/g	5460	5420	Insignificantly higher in Kazakhstan
Fibre maturity coefficient	2.3	2.2	Comparable, but slightly higher in Kazakhstan
Disease incidence (wilt, %)	12	9	Lower manifestation of phytopathogens in Uzbekistan
Resistance to wilt (assessment)	high (15 varieties)	high (13 varieties)	Resistance is maintained in both zones
Varieties with the best indicators	M-4015, M-4017, M-4010, M-4019	M-4021, M-4035, M-4003, M-4009	Differences in response to climate, but stability in the same varieties
Overall fibre quality	consistently high	consistently high	Differences are not critical – the varieties are adapted

Source: compiled by the authors

Discussion

The results obtained confirm the advisability of a multi-stage breeding assessment of cotton, taking into account both agronomic and technological characteristics. In the station trial, samples that outperformed the control M-4005 in yield and boll mass did not always demonstrate high indices of fibre length and fibre breaking load, which indicates the need for a balanced approach in selection. In the competitive trial, the best lines combined high earliness, stable fibre output and

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satisfactory technological properties, confirming the effectiveness of preliminary selection. The infectious background made it possible to identify genotypes capable of maintaining productivity and varietal purity when affected by wilt. In particular, resistance to Verticillium dahliae proved to be critically important for maintaining the fibre metric number and fibre breaking load. Certain samples not only failed to reduce technological parameters, but also demonstrated a consistently high level of fibre maturity and uniformity, which indicates the presence of plasticity and compensatory mechanisms.

Although M-4027 produced the highest yield in the station trial at 46.8 c/ha, it was not included among the final priority lines because the final selection was based on the combined performance of the accessions across successive testing stages rather than on station-trial yield alone. In the station trial, M-4027 had a lower fibre output than M-4005, 37.5% compared with 37.9%, and under the infectious background it showed 0.9% total wilt incidence and 0.2% severe incidence. The lines emphasised in the final selection demonstrated a more balanced combination of productivity, fibre quality, and field response to Verticillium wilt.

In the studies by [14, 15], modern biotechnological solutions were proposed to increase the resilience of agricultural crops to drought and to improve the adaptive potential. [14] focused on nanobiomarkers suitable for rapid screening, but the study was limited to laboratory tests and did not include parameters of fibre crops. [15], in turn, considered the prospects of biotechnologies in industrial crops, but practically did not touch upon the response under conditions of real biotic stress. In contrast to these works, the present study covers both field and infectious conditions, demonstrating not only yield, but also resistance to wilt while maintaining the technological quality of the fibre.

According to the analyses by [16, 17], an important direction remains the delineation between traditional breeding and genetic modification, as well as the introduction of advanced agro-biotechnologies. At the same time, [16] focused on theoretical aspects and the impact on agrobiodiversity without empirical data, while [17] were limited to profitability and the spread of innovations among farmers without assessing product quality. The present study, however, is based on field and infectious testing of 91 samples, including standard and susceptible benchmarks, with careful recording of agronomic and technological characteristics, including fibre breaking load and fibre metric number, which makes it significantly more applied.

As indicated in the publications of [18, 19], the vector of research in China and global breeding is increasingly directed towards the integration of molecular and classical methods. [18] presented significant successes in biological agriculture, but did not include detailed assessments of varieties for resistance to specific pathogens. [19] carried out a fundamental review of breeding approaches, but without reference to experiments with cotton under biotic pressure. Unlike these studies, the present work combines traditional breeding and stress testing in a single system, providing a comprehensive understanding of the response of varieties to wilt and the preservation of varietal purity under adverse conditions.

According to [20, 21]. researchers' attention is focused on improving the efficiency of plant transformation by the *Agrobacterium tumefaciens* method and on the general application of biotechnologies to improve crops. [20] developed a genetic transformation protocol for cotton, demonstrating a high survival rate; however, the work did not cover economically valuable traits or resistance to pathogens under field conditions. [21] noted the role of biotechnologies as a tool for modernising agricultural production, but focused on concepts without conducting varietal comparisons. In contrast to these studies, the present work relies on real field data, including an infectious background, and combines agronomic and technological assessment, which ensures the direct applicability of the results in the variety-testing system.

As shown in the work of [22] and in the review by [23], biotechnology is increasingly becoming an indispensable component in crop improvement, including cotton. [22] focused on plant regeneration and cell approaches, but did not present data on fibre characteristics. [23] conducted a large-scale analysis of plant genetic transformation, including achievements and limitations, but avoided the issue of resistance to wilt and the impact of biotic stress on product quality. In contrast to these reviews, the present study covers productivity, technological properties and response to a pathogen simultaneously, demonstrating which breeding forms retain varietal purity even when infected with *Verticillium dahliae*.

As emphasised in the publications by [24, 25], cotton resistance to heat stress and innovations in seed biotechnology are becoming key areas for sustainable agriculture. [24] presented a comprehensive review of molecular breeding for heat tolerance, but did not touch upon issues related to the technological quality of fibre under infectious conditions. [25] considered advances in seed technologies over a decade, but did not include a comparative analysis between breeding lines. Unlike these works, the study provides specific breeding benchmarks by identifying samples that simultaneously demonstrate yield, resistance, and high fibre breaking load.

As noted in the study by [26] and in the chapter by [27], the development of plant resistance to abiotic stresses is presented as a priority area of modern biotechnology. [26] analysed methods for increasing drought tolerance in tomato, paying attention to the expression of stress-associated genes; however, the study did not include fibre crops and parameters of technological product quality. In turn, [27] described modern approaches to the breeding of cotton and hemp, focusing on a list of technologies, but without verification under field conditions. In contrast to these works, this study is based on three stages of variety testing in agrocenoses with real stress effects and includes a comprehensive agronomic and technological assessment of the fibre.

On the basis of the reviews by [28, 29], there is a shift of focus towards the application of molecular tools and mathematical models in tasks to increase plant resilience. [28] summarised data on the possibilities of smart regulation of plant physiological processes under salt stress; however, the authors did not present evidence confirmed by phenotyping at the level of fibre crops. [29] considered the use of computational algorithms to identify regulator genes, but were limited to in silico analysis without verification in experimental variety testing. The present study integrates both physiological and technological parameters, including fibre length and fibre breaking load, which are important for assessing the industrial value of a variety under pathogenic pressure.

In the materials of [30], as well as [31], the importance of preserving genetic diversity and introducing biotechnologies into plant protection is emphasised. [30] focused on the need to replenish the gene pool, but the work lacks information on fibre stability under disease or agronomic stress. [31] emphasised transgenic approaches in combating pathogens, without addressing indicators of technological varietal quality. In contrast to these publications, this study combines productivity, resistance to wilt and preservation of fibre quality, which makes it possible to evaluate the selected forms as potentially suitable for zoning and industrial processing. Thus, the discussion of the results confirmed the importance of a comprehensive assessment of cotton breeding samples at all stages of testing. It has been established that resistance to the wilt pathogen has a significant effect not only on productivity, but also on the preservation of the technological properties of the fibre. The selected samples showed a balanced combination of economically valuable and quality traits, which allows these samples to be considered as promising forms for further breeding and subsequent zoning.

Conclusion

The multi-stage assessment identified M-4015, M-4017, M-4019, M-4025, and M-4010 as the most promising cotton lines based on their combined productivity, early maturity, fibre output, fibre quality, and field response under the tested infectious background. M-4017 produced the highest yield under infection and maintained a fibre length of 33.6 mm, while M-4010 retained the highest fibre breaking load and breaking length under pathogenic pressure. M-4015, M-4017, and M-4025 also received the selected fibre grade in the competitive trial. These lines should be advanced to multi-location competitive and state trials, while the lines with the most stable field response should be used as sources of Verticillium wilt resistance and stable fibre quality in breeding programmes.

This study was limited to a single growing season in 2024; therefore, year-to-year variability in the performance of the evaluated lines could not be assessed. The findings may also depend on the specific agroclimatic conditions of southern Kazakhstan and the Tashkent and Jizzakh regions of Uzbekistan. Multi-year and multi-location trials are required to validate the stability of yield, field resistance to wilt, and fibre-quality characteristics across different environments. In addition, the resistance mechanisms were evaluated phenotypically under an infectious background and were not confirmed using molecular markers or gene-expression analyses.

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Authors Contribution

All authors contributed equally to this study.

Ethics

This article is original and contains unpublished material. The corresponding author confirms that all of the other authors have read and approved the manuscript and no ethical issues involved.

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