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Breeding of Drought-resistance and Salt-tolerance, Suitable for Machine Picking New Cotton Variety Hengmian HD008

Dai Maohua [1], Liu Liying [1], Li Yuan [2], Liu Chao [2], Wu Zhenliang [1]

1 Hebei Key Laboratory of Crops Drought Resistance/Dryland Farming Institute, Hebei Academy of Agricultural and Forestry Sciences, Hengshui, 053000, China

2 Hebei Seed Management General Station, Shijiazhuang, 050031, China

Corresponding author email: wuzhenliang123@163.com

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Abstract Under the background of improving agricultural quality and efficiency, the new requirements for cotton varieties were put forward. Dryland Farming Institute, Hebei Academy of Agricultural and Forestry Sciences took 'Hengmian 4' (resource material of middle-early maturity and disease-resistant upland cotton) as female parent and RILNnXu0022HF (resource material of high quality upland cotton) as male parent to carry out hybrid combinations. After years of continuous directional selection, Hengmian HD008 was selected under disease stress, pest stress, salt stress and drought stress. Hengmian HD008 has the outstanding performance of drought and salt tolerance, high quality and yield, suitable for machine picking，which was approved by Hebei Province in August 2019 (Approved number: Jishenmian 20199003) and was suitable for planting in Hebei Province and similar ecological and spring sowing cotton areas in the Yellow River Basin.

Keywords Upland cotton (*Gossypium hirsutum*); Hengmian HD008; Drought-resistance and salt-tolerance; Machine picking cotton

Cotton (*Gossypium* spp.) is an important economic crop in China and an important material related to the people's livelihood (Yu, 2018). Hebei Province is a traditional cotton planting province in China. The cotton planting area and yield in Hebei Province are stable at about 10% of the national cotton planting area and yield all the year round. And the development of cotton production in this area is of great significance to promote the local farmers' income and agricultural efficiency.

Hebei Province is one of the provinces with serious shortage of water resources in China, with only 311 m^3 per capita, which is 1/7 of the national average. The loss of crops caused by drought stress ranks first among all abiotic stresses (Ullah et al., 2019; Tahir et al., 2020). The yield and quality of most cotton varieties promoted in production will be greatly reduced under severe drought conditions at seedling and bud stages, which seriously restricts the development of cotton production (Ullah et al., 2019). Cotton Drought-resistance has become an important trait that cannot be ignored (Zhang et al., 2018). The area of saline-alkali land in Hebei Province is more than 600 000 hm^2, which is mainly distributed in the traditional cotton planting cities in middle and south of Hebei, like Hengshui, Cangzhou, Xingtai, etc. And the soil salinization seriously reduced the yield and quality of cotton in this area (Hasanuzzaman et al., 2018; Xie et al., 2019). Salt-tolerance is an important trait for cotton varieties in saline-alkali soil (Barajas-Lopez et al., 2018).

The labor cost of cotton is high, and the benefit is low. Compared with other crops, cotton has more labor input, about 25 workers per mu, 10 times more than wheat and corn in two seasons (Shaban et al., 2018). With the transfer of a large number of agricultural labor force to non-agriculture, the problems such as seasonal labor shortage and labor cost increase have become increasingly prominent. Therefore, it is an inevitable trend for the development of cotton production to develop machine picking cotton, gradually realize the full mechanization of cotton planting, and reduce the labor cost of cotton production (Guo et al., 2018). And the mechanization of cotton picking is bound to put forward corresponding requirements for the characteristics of cotton varieties. Suitable for machine picking cotton variety is one of the key technologies to realize mechanized cotton harvest (Lu et al., 2018).

At present, the planting area of cotton in Hebei Province is seriously declining, and the land competition for grain and cotton and the high labor cost are the two main limiting factors restricting the development of cotton industry. The main way to save the continuous decline of cotton area is to develop cotton planting in saline-alkali land and realize the full mechanization of cotton planting. And the breeding and spreading of drought-resistance and salt-tolerance, suitable for machine picking new cotton variety will be the most direct, economic and effective way (Yu et al., 2015). Based on the goal of drought and salt tolerance, high quality and yield, suitable for machine picking, after years of continuous directional selection, Hengmian HD008 was selected by Hebei Academy of Agricultural and Forestry Sciences.

1 Results and Analysis

1.1 Agronomic and economic trait index

Hengmian HD008 is a transgenic insect - resistant conventional cotton variety, which is suitable for planting in spring sowing cotton areas in Hebei Province. Its stems and leaves have medium hair, leaves are small and dark green. The single plant has good boll bearing ability, the boll is medium, oval type, with few messy branch buds. Boll opening smooth, concentrated, suitable for machine picking. The average growth duration is 119 d, the plant height is 92 cm, the node position of the first fruit branch is 6.9 nodes, the height is 24.0 cm, the number of fruit branches per plant is 11.6, the angle between fruit branches is 66.4°, the number of bolls per plant is 11.3, and the percentage of open bolls is 80.7%. The boll weight is 5.8 g, the sub-finger is 12.7 g, and the lint percentage is 39.2%.

1.2 Yield performance

The comparison test of new varieties in the institute from 2010 to 2011 showed that Hengmian HD008 had excellent comprehensive characters and outstanding performance. In 2010, the pre-frost lint yield of 1 605.0 kg/hm^2, was 17.6% higher than that of the control 'Jimian958'. In 2011, the pre-frost lint yield of 1 474.5 kg/hm^2, was 11.4% higher than that of the control 'Jimian958'.

In the spring sowing cotton areas in Hebei Province from 2016 to 2017, the 2-year average seed cotton yield and lint yield were 3 744.0 kg/hm^2 and 1 468.5 kg/hm^2, respectively, which increased by 5.1% and 10.1% respectively compared with the control variety 'Shikang126'. The differences were significant (Table 1). In the cotton variety production experiment in Hebei Province in 2018, the seed cotton yield and lint yield were 3 859.5 kg/hm^2 and 1 486.5 kg/hm^2, respectively. which increased by 7.0% and 11.6% respectively compared with the control variety 'Shikang126'. The differences were significant (Table 1). Hengmian HD008 was planted in a large area in Xintun Town, Zaoqiang County in 2019. The field measured seed cotton yield was 4 813.5 kg/hm^2, which increased by 753.0 kg per hectare compared with the local production control, with rate of growth of 18.5%.

Table 1 Yield of Hengmian HD008 in regional and production trial of cotton varieties in Hebei Province during 2016-2018

Type of trial	Year	Seed cotton yield		Lint yield		Lint percentage (%)
		Yield (kg/hm^2)	Rate of growth (%)	Yield (kg/hm^2)	Rate of growth (%)	
Regional trial	2016	3 802.5	8.2	1 483.5	14.4	39.0
	2017	3 685.5	2.0	1 453.5	5.8	39.4
	Mean	3 744.0	5.1	1 468.5	10.1	39.2
Production trial	2018	3 859.5	7.0	1 486.5	11.6	38.5

1.3 Fiber quality

The fiber quality is tested by the Cotton Quality Supervision and Testing Center of Ministry of Agriculture. The results of regional tests in 2016 and 2017 (Table 2) showed that the upper half mean length was 29.5 mm, the fiber strength was 31.3 cN/tex, the micronaire was 85.2%, and the spinning consistency index was 142.0. The fiber quality of Hengmian HD008 is excellent (Ministry of Agriculture of the People's Republic of China, 2007).

Table 2 Fiber quality of Hengmian HD008 in regional trial of cotton varieties in Hebei Province during 2016-2017

Year	Upper half mean length (mm)	Fiber strength (cN/tex)	Micronaire	Uniformity (%)	Elongation rate (%)	Reflectance degree (%)	yellowness	Spinning consistency index
2016	29.3	31.9	5.1	86.1	5.5	74.2	6.6	148.0
2017	29.7	30.7	5.2	84.2	5.5	76.0	7.0	136.0
Mean	29.5	31.3	5.2	85.2	5.5	75.1	6.8	142.0

1.4 Disease resistance

Disease resistance was identified by Plant Protection Institute, Hebei Academy of Agricultural and Forestry Sciences. In 2016, fusarium wilt disease index was 0.38, verticillium wilt relative disease index was 14.86. In 2017, fusarium wilt disease index was 0.37, verticillium wilt relative disease index was 33.70. The average fusarium wilt disease index in 2016 and 2017 was 0.38, and the verticillium wilt relative disease index was 24.28, which belongs to the type of high resistance to fusarium wilt and resistance to verticillium wilt (Table 3).

Table 3 Disease resistance of Hengmian HD008 in regional trial of cotton varieties in Hebei Province during 2016-2017

Year	Fusarium wilt		Verticillium wilt	
	Disease index	Reactive type	Relative disease index	Reactive type
2016	0.38	HR	14.86	R
2017	0.37	HR	33.70	T
Mean	0.38	HR	24.28	T

1.5 Drought-resistance and salt-tolerance

According to the identification standards of drought-resistance of local standard crop varieties in Hebei Province (Hebei Provincial Administration of Quality and Technical Supervision, 1999, Identification Standards of Drought-resistance of Crop Varieties, DB13T 398.5-1999), the Dry-Land Farming Institute of Hebei Academy of Agricultural and Forestry Sciences identified the drought-resistance of Hengmian HD008 under artificial simulated drought environment. The results showed that the drought-resistance index of Hengmian HD008 was 1.18, which was significantly higher than that of the control variety 'Zhong H177' (drought-resistance index was 1.00). According to the technical specification for evaluating crop germplasm resources (Ministry of Agriculture of the People's Republic of China, 2013), Institute of Cotton Research of CAAS used 0.4% salt stress method at seedling stage to identify salt-tolerance. The results showed that the relative survival percentage of Hengmian HD008 was 62.21%, which was significantly higher than that of salt-tolerance control variety 'Zhong 9807' (relative survival percentage was 51.22%).

1.6 Key points of cultivation techniques

Hengmian HD008 is suitable for planting in Hebei Province and similar ecological and spring sowing cotton areas in the Yellow River Basin. And it is suitable for machine picking, also can be cultivated in regular way. The suitable sowing time is from mid-late April to early May. The suitable density of machine picking is 90 000 plants/hm^2, conventional cultivation of land with high water and fertilizer is 45 000 plants/hm^2, medium water and fertilizer land is 52 500 plants/hm^2, and poor dry land is 60 000 plants/hm^2. Apply enough base fertilizer, heavy flower and boll fertilizer, supplement top fertilizer according to growth trend, and don't take off fertilizer at later stage. Machine picking cultivation, combined with chemical control, can reduce the pruning process. While conventional cultivation, as long as pruning once. In mid-July, before ridge closure, non-target pests such as thrips, aphids and mirids should be controlled in time, and cotton bollworm should be controlled according to the occurrence of the third or fourth generation.

2 Discussion

Under the background of the national supply-side reform, the cotton area of Hebei Province moved eastward, and the natural conditions of the cotton area of Hebei Province were saline-alkali, seasonal drought, and lack of rain. Fresh water was limited, and salt water was surplus, which restricted the high, stable, and efficient development of cotton yield. Combined with the reality of cotton production in Hebei Province with more labor and high labor

cost, the characteristics of drought-resistance and salt-tolerance identification techniques (Hebei Provincial Administration of Quality and Technical Supervision, 1999, Identification Standards of Drought-resistance of Crop Varieties, DB13T 398.5-1999) were used to synchronize with drought, saline-alkali, and disease stress (Wu et al., 2015, Chinese Patent, ZL 2015 1 0623505.8). The conventional breeding technology, molecular marker-assisted selection technology and transgenic technology were effectively integrated to realize the polymerization and recombination of excellent characters such as saline-alkali tolerance, drought-resistance and water saving, high yield, high quality, and suitable for machine picking, and enrich the cotton breeding germplasm resources in Hebei Province, improve the drought-resistance and salt-tolerance of the varieties suitable for machine picking. New Cotton Variety Hengmian HD008 with drought-resistance and salt-tolerance, high yield, and good quality, suitable for machine picking was bred, which provide variety support for the development of mechanized cotton planting in saline-alkali dryland in Hebei Province.

3 Materials and Methods

3.1 Parent materials

Parent materials: 'Hengmian 4'×RILNnXu0022HF. The selection of parents with stress-resistance, high yield and good quality is the key to the cultivation of good varieties (Li, 2019; Richard et al., 2020). In 2007, the transgenic *Bt* 'Hengmian 4 ' was selected as female parent, which showed moderate plant type tightness, clear appearance, large boll, oval, strong boll setting per plant and easy picking. The growth duration is 128 d, with middle-early maturity. High and stable yield, good quality, upper half mean length is 30.4 mm, fiber strength is 28.2 cN/tex, micronaire is 4.5, good drought-resistance and salt-tolerance, strong resistance to verticillium wilt. RILNnXu0022HF, a high-quality resource material with rich genetic background provided by Cotton Research Institute of CAAS, was selected as male parent, which showed lighter leaf color, strong stem, few buds of messy branches, large boll, strong boll setting per plant. The fiber is of good quality, with a cashmere length of 31.3 mm, fiber strength of 31.2 cN/tex and a micronaire of 4.4. Good drought-resistance is good, but the resistance to verticillium wilt is slightly poor. Boll opening early and smoothly. Parents had complementary or enhanced advantages in many traits, such as fiber quality, yield, stress resistance and so on (Abdelraheem et al., 2019).

3.2 Breeding process

In 2007, 'Hengmian 4' as female parent and RILNnXu0022HF as male parent to carry out hybrid combinations, and the F_1 generation was planted in Hainan Experimental Station, Dryland Farming Institute, Hebei Academy of Agricultural and Forestry Sciences, Sanya City, Hainan Province in the winter of 2007. In 2008, F_2 generation was planted in the Mixed Disease Nursery of Fusarium wilt and Verticillium wilt in the Dryland Farming and Water-saving Agricultural Experimental Station of Hebei Academy of Agriculture and Forestry Sciences. Under the natural conditions with no control of cotton bollworm, single plant selection with disease resistance, insect resistance, high quality and high yield was carried out. In the winter of 2008, the generation was propagated in Hainan. In 2009, the F_4 generation was planted in the Dryland Farming and Water-saving Agricultural Experimental Station of Hebei Academy of Agricultural and Forestry Sciences for the identification and selection of stress resistance, high yield, quality and machine picking. From 2008 to 2009, through 2 years and 4 generations of identification and selection of individual plant, line and strain. The comparison test of new varieties in from 2010 to 2011 showed that Hengmian HD008 had outstanding performance in early maturity, stress resistance, high and stable yield, quality, and machine picking. From 2012 to 2013, the adaptability and stability of stress resistance, high yield, good quality and machine picking were identified in Nangong City, Zaoqiang County, Quzhou County and Haixing County in Hebei Province. Participated in the regional trial of spring sowing machine cotton picking group in Hebei Province from 2016 to 2017, and participated in the production trial in 2018, and was approved by Hebei Crop Variety Approval Committee in August 2019.

3.3 Trait indexes determination

The traits were determined as follows: growth duration, plant height, number of fruit branches, node position of the first fruit branch, boll number of per plant, boll weight of per plant, seed index, lint percentage, seed cotton yield, lint yield, disease index of Fusarium wilt, disease index of Verticillium wilt, upper half mean length,

uniformity index, fiber strength, elongation rate and micronaire. Among them, Fusarium and Verticillium wilt was identified by the Plant Protection Institute of Hebei Academy of Agricultural and Forestry Sciences, and the fiber quality was tested by the Cotton Quality Supervision and Testing Center of Ministry of Agriculture.

3.4 Stress resistance identification

The drought-resistance of Hengmian HD008 was identified according to the drought resistance index (DRI) in the drought resistance identification standards of crop varieties (Hebei Provincial Administration of Quality and Technical Supervision, 1999, Identification Standards of Drought-resistance of Crop Varieties, DB13T 398.5-1999). $DRI=(Y_a)^2\cdot(Y_m)^{-1}\cdot Y_M\cdot(Y_A)^{-2}$, in which: DRI-drought resistance index of the tested variety, Y_a-dryland yield of the tested variety, Y_m-wetland yield of the tested variety, Y_A-dryland yield of the control variety, Y_M-wetland yield of the control variety. In the experiment, 'Zhong H177' was used as the control variety for drought resistance identification. The salt-tolerance of Hengmian HD008 was identified according to the relative survival percentage (LP) in the technical specification for evaluating crop germplasm resources (Ministry of Agriculture of the People's Republic of China, 2003). $LP=P\cdot0.5\cdot P_{CK}^{-1}\cdot100$, in which: LP-relative survival percentage, P-survival percentage, P_{CK}-control survival percentage. In the experiment, ‘Zhong9807’ was used as the control variety for salt-tolerance identification.

Authors’ contributions

DMH was the designer and executor of this study, completed the data analysis, drafted the manuscript. LLY, LY, and LC participated in the data collation and the analysis of the test results. WZL conceived of the project, directed the design of the study, data analysis, draft and revision. All authors read and approved the final manuscript.

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