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Evaluation of the Production Potential of Mung Bean Cultivar "Zhonglv 5"

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Abstract: High yields, high stress resistance, and wide adaptability are important cultivar traits, especially for crops sensitive to the photoperiod and temperature. Mung bean (*Vigna radiata*) is a typical short-day plant, traditionally cultivated in Asian countries, and consumed all over the world. However, there has long been relatively little research regarding its genetic improvement until in recent decades. Zhonglv 5 is a mung bean cultivar that was developed via crossbreeding in China in the early part of this century. It has since played an important role in improving mung bean production in the country because of its high yields, high stress tolerance, and wide adaptability. We herein describe the development of Zhonglv 5, summarize its yield performance and adaptability in diverse eco-regions within China, and predict its potential future uses to provide information relevant for mung bean breeding, production, trade, and related industries.

Keywords: mung bean; development; Zhonglv 5; high yield; adaptability

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1. Introduction

Mung bean (*Vigna radiata* L.), which is a legume formerly grown mainly in Asia, has spread to countries outside of Asia primarily because of its multiple uses (e.g., nutrient source for humans, soil fertilization, animal forage crop, and even medicinal component) [1,2]. As an economically important crop, mung bean is usually cultivated under rain-fed conditions as a monoculture or part of a crop rotation, but intercropping with diverse cereals is also common [3–5] because it increases the N and C availability in the soil for subsequent crops [6]. Notably, the occurrence of pest infestations reportedly decreases when wheat is intercropped with mung bean [7].

In the past few decades, delays in systematic breeding and the extensive cultivation of mung bean using traditional systems has led to the misconception that mung bean is a low-yielding crop [2,8]. With the development and release of a series of breeding lines with an erect growth habit and high yields, mung bean production has increased significantly in recent decades [9–11]. However, mung bean production has been adversely affected by both abiotic stress (especially drought) and biotic stress (diseases and pest infestations). To address both climate changes and the development of mechanized production technology, there are now strict requirements for the characteristics of mung bean cultivars (e.g., stable erect growth habit, early flowering, and consistent maturation). As a typical short-day species, most mung bean cultivars are sensitive to photoperiod and temperature, which substantially affects stable production.

Mung bean has been grown in China for thousands of years, during which internationally famous mung bean brands were cultivated, including Mingguanglvdou in Anhui, Yulinlvdou in Shaanxi, and Zhangjiakoulvdou in Hebei [12]. The systematic selection of Zhonglv 1 and Zhonglv 2 by the Asian Vegetable Research and Development Center

(AVRDC) and the subsequent rapid spread of these cultivars throughout China in the final 20 years of the previous century considerably improved local mung bean production, including the aforementioned famous brands. However, the mung bean planting area has gradually decreased, and both the total production and the international market share of these brands diminished at the beginning of this century, mainly because of the rapid development of major crop production via high-efficiency farming. Because mung bean is highly tolerant to stresses, such as salinity and drought [13–16], its production in China mainly occurs in diverse eco-regions, especially areas under drought or semi-drought conditions, which are not suitable for the large-scale cultivation of major crops.

To enhance mung bean cultivar traits (e.g., early maturity, erect growth habit, and adaptability), various strategies have been used in mung bean breeding programs in China, which has resulted in the development and release of a series of new cultivars [12,17]. For example, Zhonglv 5, which is one of the most famous and widely used cultivars, was developed by crossbreeding parents exhibiting the desired traits. The stability, uniformity, distinctness, and other characteristics of Zhonglv 5 were evaluated to optimize the use of this cultivar. After it was first released in the year of 2004 by the national department, Zhonglv 5 was evaluated in successive years in different regions to confirm its adaptability to diverse eco-regions in China. Zhonglv 5 is still a popular choice for monoculturing and intercropping systems. It is especially useful as a crop for post-disaster replanting owing to its relatively short growth period.

2. Materials and Methods

2.1. Zhonglv 5 Development

Zhonglv 5 was originally derived from a cross between VC1973A and VC2768A. The maternal line (VC1973A) is a commonly grown cultivar from Thailand [18] and has been widely used for mung bean production and breeding or as the plant material in genetic studies [19–21]. The paternal line (VC2768A) is another cultivar developed by AVRDC [18]. After hybridization, bulk selection was performed from the F_2 generation to the F_6 generation in Beijing. When the phenotype of the selected line was stable, distinct, and uniform, a planting test was conducted locally for two seasons before the cultivar was approved by national organizations in 2004 [22].

2.2. Basic Agronomic Characteristics of Zhonglv 5

Years of cultivation and tests revealed that Zhonglv 5 is an early maturing cultivar with a growth period of approximately 70 and 85 days in the summer and spring growing seasons, respectively. It is erect with a height of 60–70 cm and its young stem lacks anthocyanin coloration. When grown in Beijing during the summer growing season, Zhonglv 5 usually has three branches on the main stem and produces about 25 pods per plant. The mature pod is black, 10 cm long, and contains 10–13 seeds. Most pods are set on the upper part of the plant and mature similarly, making Zhonglv 5 suitable for mechanized harvesting. Zhonglv 5 seeds are green and glossy, with a 100-seed weight of about 6.5–7.5 g. On the basis of reports from the Quality Testing Center of the Ministry of Agriculture, Zhonglv 5 seeds have a protein content of 23.1–25.1% and a starch content of 50.5–51.9%. Moreover, Zhonglv 5 is suitable for the production of sprouts with a high protein content [23], congee, and bean paste with a high phenolic acid content [24].

3. Results

3.1. Assessment of Disease Resistance and Drought Tolerance

Leaf spot is an important mung bean disease that usually occurs in the late plant development stage, resulting in substantial decreases in yield and seed quality [25]. According to a field investigation organized by researchers from the China Agricultural Research System of Pulse Crops (CARS-08), leaf spot of mung bean has increased in terms of frequency and severity. During experiments in which plants were inoculated under greenhouse conditions, only Zhonglv 5 was moderately resistant to leaf spot from among the thousands of tested

germplasms. Of the cultivars included in field tests conducted by CARS-08, Zhonglv 5 was the most resistant to leaf spot in Hubei province in 2011. It was also resistant to leaf spot in Xinjiang and Guangxi. Additionally, Zhonglv 5 was observed to be resistant to powdery mildew during large-scale production. However, a new fungus *Paramyrothecium foliicola* able to cause leaf spot of Zhonglv 5 was recently identified in north of China [26].

Drought tolerance is another distinct characteristic of Zhonglv 5. Among 19 new cultivars identified in northern Xinjiang, where the annual rainfall is no more than 200 mm, Zhonglv 5 was revealed to be the most tolerant to drought conditions. The average yield for Zhonglv 5 was 2100.0 kg/ha without irrigation, except for during the sowing stage, in Qitai (Xinjiang) in 2012, whereas it was 1545.0 kg/ha under similar field management at Zepu (Xinjiang). Moreover, Zhonglv 5 was the most drought-tolerant variety among 303 mung bean lines grown in Qitai (Xinjiang) in 2019 without irrigation, except during the seedling stage. Furthermore, Zhonglv 5 was recently demonstrated to be highly tolerant to drought conditions in Datong, Yangyuan, Nanning, and other eco-regions.

3.2. Evaluation of the Yield and Adaptability of Zhonglv 5 in Different Eco-Regions

During a field test in 2000, Zhonglv 5 had the highest average yield (2565.0 kg/ha), which was 11.7% higher than that of the control cultivar Zhonglv 1, which was the most famous cultivar at the end of the last century, and is still widely used today for diverse analyses [27,28]. In the national regional tests of 2001–2002, although the yields varied greatly among regions, compared with the yield of the control cultivar Jilv 2, an early and famous cultivar released in Hebei province in 1996, the Zhonglv 5 yield was higher at 11 of 20 locations (Table 1), but it was slightly lower at nine locations. Regarding large-scale mung bean production in 2003, Zhonglv 5 yields were 3.7–17.6% higher than Jilv 2 yields in Shanxi, Xinjiang, Liaoning, and Yunnan. In regional tests of new cultivars conducted by CARS-08 researchers in 2016 and 2017, Zhonglv 5 was used as the control, and its average yield was among the top five in Nanjing, Harbin, Nanyang, and Nanning. In recent years, yields of 2511.8 kg/ha (2020) and 2565.0 kg/ha (2021) were reported for the large-scale production of Zhonglv 5 at Chifeng, which is the main area for mung bean cultivation in eastern Inner Mongolia.

Table 1. Zhonglv 5 yield performance in National Regional Trials conducted in 2001 and 2002.

Locus (City/Province)	Yield Performance (kg/ha)		Yield Increase (%)
	Zhonglv 5	Control (Jilv 2)	
Harbin (Heilongjiang)	631.5	547.5	15.4
Baicheng (Jilin)	1183.5	1017.0	16.3
Shenyang (Liaoning)	1743.0	1347.0	29.3
Wengniuteqi (Inner Mongolia)	1074.0	1023.0	5.1
Fangshan (Beijing)	2227.5	2122.5	4.9
Yulin (Shaanxi)	1573.5	1296.0	21.4
Datong (Shanxi)	1717.5	1251.0	37.2
Shihezi (Xinjiang)	2323.5	1923.0	20.9
Taixing (Jiangsu)	1989.0	1915.5	3.9
Changsa (Hunan)	1414.5	1375.5	2.8
Lijiang (Yunnan)	1249.5	1080.0	15.6
Average	1557.0	1354.5	15.0

From 2013 to 2015, the Zhonglv 5 yields were high in different regions in which precision field management practices were applied. For example, the Zhonglv 5 yield was 2511.0 kg/ha in Chongqing and 3625.5 kg/ha in Qitai county, Xinjiang. The Zhonglv 5 yield was highest (3640.5 kg/ha) in Mingguang, Anhui province in 2013, but several high yields, from 2589.0 kg/ha in Nanyang to 3190.5 kg/ha in Nanjing, were recorded in 2014 and 2015.

In addition to monocultures, intercropping with Zhonglv 5 has resulted in economic benefits. The intercropping of Zhonglv 5 with various crops, including sugarcane, maize, and fruits, in different provinces has increased mung bean yields by 750–1350 kg/ha (Table 2, Figure 1).

Table 2. Zhonglv 5 yields in intercropping systems from 2013 to 2019.

Locus	Yield (kg/ha)	Year	Inter Crop	Locus	Yield (kg/ha)	Year	Inter Crop
Nanning (Guangxi)	1540.5	2013	Sugarcane (D *)	Chongzuo (Guangxi)	1369.5	2014	Sugarcane (D)
	964.5	2014	Sugarcane (S **)		1080.0	2014	Sugarcane (S)
	900.0	2015	Sugarcane (S)		1024.5	2016	Sugarcane (S)
	1297.5	2015	Sugarcane (S)		1074.0	2014	Sugarcane (D)
	1794.0	2015	Sugarcane (D)		1131.0	2014	Sugarcane (S)
	1248.0	2016	Sugarcane (S)		1200.0	2014	Sugarcane (D)
	1417.5	2016	Sugarcane (D)		897.0	2016	Sugarcane (S)
	966.0	2015	Cassava (S)		750.0	2019	Sugarcane (S)
	1428.0	2015	Cassava (D)		1342.5	2017	Maize (S)
	1528.5	2016	Cassava (S)		1837.5	2013	Young peach tree
	1473.0	2016	Cassava (D)	Hefei (Anhui)	886.5	2014	Maize (S)
	825.0	2017	Wild grape		954.0	2015	Maize (S)
Beihai (Guangxi)	1057.5	2015	Dragon fruit tree	Nanyang (Henan)	346.5	2015	Maize (S)
	1102.5	2016	Dragon fruit tree	Siyang (Jiangsu)	1875.0	2018	Peach tree
	979.5	2017	Cassava (S)	Jiaonan (Shandong)	513.0	2014	Pine tree
Hechi (Guangxi)	1387.5	2017	Maize (S)	Qingdao (Shanodng)	1086.0	2014	Maize (S)
Yulin (Guangxi)	888.0	2014	Dragon fruit tree		655.5	2015	Maize (S)
	1209.0	2014	Wild grape	Linfen (Shanxi)	621.0	2014	Maize (S)

Note: data were collected by CARS-08 during the 12th and 13th Five-Year Plan period. D * and S ** indicate mung bean plants were cultivated in double and single lines, respectively, in the intercropping system.

Figure 1. *Cont.*

Figure 1. Intercropping of mung bean with sugarcane.

4. Discussion

The progress in mung bean breeding over the last few decades in China has enabled local organizations to release more than 100 cultivars, of which 36 were developed by crossbreeding, including Zhonglv 5 [12]. Owing to its distinct, excellent characteristics (e.g., erect growth, high yields, and wide adaptability), Zhonglv 5 is commonly used for mung bean production, especially in northwestern and southern China. Although its yield advantage is not obvious in the northeastern and eastern provinces of China, the drought tolerance of Zhonglv 5 during periods of drought or high temperatures in these regions has been verified. Zhonglv 5 is still currently the main cultivar grown in northwestern and central China. Moreover, the revival of both Mingguanglvdou and Nanyanglvdou was mainly the result of the production of this cultivar [29,30]. On the basis of its wide distribution and stable productivity, Zhonglv 5 was recognized with a China Agricultural Science and Technology Award in 2015.

Because of climate change, natural disasters are a frequent occurrence and outbreaks of diseases and insect infestations have increased in severity [31], with detrimental effects on the sustainable production of crops, including mung bean. There are several reasons why we predict that Zhonglv 5 will continue to be used for mung bean production until improved cultivars are developed and released for commercial use. First, Zhonglv 5 is still the only mung bean cultivar resistant to leaf spot and moderately resistant to powdery mildew. Second, drought, which is one of the most important consequences of global climate changes, has been a problem for agricultural production worldwide. The high drought tolerance of Zhonglv 5 has been validated by breeders and farmers in diverse environments. Third, Zhonglv 5 can tolerate salt and alkali stresses [32] and does not accumulate large amounts of heavy metals in its seeds [33]. Finally, the financial benefits of including Zhonglv 5 in intercropping systems throughout China have been confirmed [34,35]. Owing to the elite characters of Zhonglv 5, the whole genome of Zhonglv 5 was sequenced recently in order to elaborate on its genetic structure (not published).

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