Resistance To Pokkah Boeng Disease In New And Main Cultivated Sugarcane Varieties

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Research Article

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Abstract

Pokkah boeng is an epidemic fungal disease that seriously affects development of the sugarcane industry in China. Resistance to pokkah boeng disease differs among sugarcane varieties. Breeding and planting resistant cultivars is the most economic and effective measure for controlling this disease. In this study, new sugarcane varieties bred by the China Sugarcane System and the main varieties cultivated in various sugarcane areas, were screened to find new elite pokkah boeng resistant varieties for application in sugarcane production. The natural field resistance to pokkah boeng disease of 60 new varieties was evaluated in regionalized experiment. Meanwhile, the field resistance of the 31 main cultivated varieties was analyzed in Lincang city, Puer city, Yuxi city, Yunnan Province, and in Yizhou district, Guangxi Province, where the incidence of pokkah boeng is particularly high. Field surveys showed that 35 (58.33%) of the 60 new sugarcane varieties were highly resistant to moderately resistant, and 25 (41.67%) were susceptible to highly susceptible. Of the 31 main cultivated varieties, 15 (48.39%) were highly resistant to moderately resistant, and 16 (51.61%) were susceptible to highly susceptible. The results suggested that, in wetter and rainy sugarcane areas with high incidence of pokkah boeng disease, it is necessary to increase efforts to eliminate the susceptible main cultivated varieties and promote the application of resistant new varieties. This will help to achieve a reasonable distribution of varieties, fundamentally control the outbreak of pokkah boeng disease, and facilitate the high-quality development of the sugarcane industry in China.

Introduction

Pokkah boeng is an important fungal disease that affects sugarcane (*Saccharum officinarum*) worldwide. *F. verticillioides* and *F. proliferatum* are two major *Fusarium* species that cause sugarcane pokkah boeng disease in China, with *F. verticillioides* accounting for over 90% of the recorded disease (Lin et al. 2014). Many cultivated plants act as middle hosts of the pathogen, including rice, sorghum, maize, banana, and pumpkin (Huang et al. 2018; Rott et al. 2000). The main symptoms of pokkah boeng disease were yellowing, shriveling and twisting of young leaves. Seriously infected plants exhibited growth cessation, and the top becomes very small, ultimately resulting in death by growing tip rot (Figure 1) (Huang et al. 2018). Pokkah boeng disease was first found in Java in 1890 (Rott et al. 2000). In 1921, with the breeding and popularization of the sugarcane variety POJ2878, pokkah boeng disease became epidemic and caused varying degrees of economic losses worldwide (Mohamed et al. 2008; Raid and Rott 2015; Singh et al. 2006; Vishwakarma et al., 2013).

In China, this disease has been reported in Fujian, Taiwan, Guangdong, Guangxi, Yunnan, Sichuan, and Hainan (Huang 1993; Huang and Li 2016; Liu et al. 1991; Lu 2007). In the 1980s, a severe outbreak of pokkah boeng occurred in Guangxi. The diseased plant rate reached 52.4% in Guitang 11, and the cane yield and brix were reduced by 14% and 7%, respectively (Liu et al. 1991). In 1989, the disease occurred suddenly in the Pearl River Delta, where Yuetang 57-423 and Yuetang 54-176 were highly susceptible varieties. The infected area covered over 400 hm², and the incidence rate was 30–50%. In some areas the incidence rate reached 80%, which had a significant impact on local sugarcane production (Huang et al. 1990). Since 2000, with the promotion of susceptible varieties ROC 1, ROC 10, ROC 16, ROC 22, ROC 25, and Yuetang 93-159 throughout the sugarcane regions of China, pokkah boeng disease occurred frequently. This has led to an increasingly serious situation and pokkah boeng is becoming an important disease in the growing stage (Huang and Li 2016; Huang et al. 2018).

In recent years, there has been more rainfall and high moisture, and the susceptible varieties Yuetang 93-159, ROC 25, ROC 1, and Chuantang 79-15 which have high yield and high sugar-content have been planted across large areas. This has led to the outbreak of pokkah boeng disease in Lincang, Puer, Yuxi, Honghe, and Banna, and has caused severe reductions in sugar and yield. Therefore, sugarcane production is increasing under threat (Li et al. 2017a). Investigations have shown that in susceptible varieties the disease is serious and causes the death of a large number of stalks. The diseased plant rate was found to be 81.1% on average and 100% in seriously infected fields. The measured yield loss was 38.42% on average, reaching 48.5%. The sugar content was reduced by 3.14% on average, with reductions as great as 4.21% (Shan et al. 2018).

At present, the research on pokkah boeng disease is mainly focused on the taxonomy, biological characteristics, phylogenetic relationship, and metabolites of the pathogen (Guo et al. 2016, 2019; Hilton et al. 2017; Lin et al. 2014, 2015; Liu et al. 2019; Viswanathan et al. 2011; Vishwakarma et al. 2016). There have also some investigations and studies on the occurrence of the disease, variety resistance, and its control techniques (Feng 2000; Goswami et al. 2013; Luo et al. 2017; Long et al. 2019; Wang et al. 2017a, 2017b). Outbreaks of pokkah boeng disease are caused by several main factors including the planting of susceptible varieties across large areas, high temperatures, a wet climate, the accumulation of pathogens, and improper cultivation and management measures (Shan et al. 2018).

Resistance to pokkah boeng disease differs among sugarcane varieties. Screening and planting resistant varieties is the most economic and effective method to control the disease. In recent years, under support from the China Sugarcane System, several new elite sugarcane varieties have been bred via a national joint research effort. However, these new varieties have not yet been evaluated their resistance to pokkah boeng disease. The results could provide a scientific basis for the breeding and selection of elite resistant varieties for commercial cultivation. This will benefit the control of pokkah boeng disease in sugarcane production via the rational distribution of varieties.

This study combined the regionalization experiment of new sugarcane varieties with disease investigation in sugarcane planting areas. A field resistance screening was conducted to identify the resistance of pokkah boeng disease in 60 new elite sugarcane varieties and 31 main cultivated varieties from 2016 and 2019. The determined resistance levels of the different varieties will provide a scientific basis for the selection of varieties for sugarcane production.

Material And Methods

Tested varieties

A total of 60 new elite sugarcane varieties bred in China in recent years (Table 1) and 31 of the main varieties cultivated in Yunnan and Guangxi sugarcane fields (Table 2) were tested in this study. ROC 22 was used as the control varieties of the regional experiment. Cultivar ROC 20 was used as a resistant control and ROC 25 as a susceptible control.

Disease occurrence and field resistance evaluation of new varieties under natural condition

The 60 new varieties was planted in in two successive batches at regionalization experimental station in Kaiyuan and Lincang, Yunnan Province, China in March 2016–2017 and 2018–2019 respectively.. ROC 22 was used as a control varieties of the regionalization experiment, and ROC 20 and ROC 25 were used as the pokkah boeng- resistant and pokkah boeng- susceptible control varieties, respectively. A randomized complete block design with three repeats was used. Each plot consisted of five rows (6 m in length and 5 m in wide; total area of 30 m²) with 1 m spacing between rows. The varieties were infected by naturally occurring populations of the pathogen of pokkah boeng disease in the field. To maximize infection, cultivar ROC 25, which is highly susceptible to pokkah boeng disease, was planted along the borders surrounding the trial fields. Two rows of ROC 25 were also planted repeatedly between every two test varieties.

When pokkah boeng incidence peaked in the susceptible control variety (October to November each year), pokkah boeng incidence of each new variety in the newly-planted and ratoon field was analyzed to evaluate the field resistance. For each variety, the number of diseased plants were recorded in three replicates by observe the main symptoms refer to Figure 1, and 100 successive millable stalks were investigated per replicate. Therefore, a total of 300 plants/stalks were surveyed per variety. The total number of surveyed plants and the number of diseased plants were recorded to calculate the natural diseased incidence. The field disease incidence (%) = (the number of diseased plants / total number of surveyed plants) × 100%. Referring to the classification method of Laboratory of Diseases and Insect Pests of the Technology System of National Sugar Industry (2012), and making modifications, the field resistance to pokkah boeng disease was graded 1 to 5 by the natural diseased incidence in each variety. Grade 1, 2, 3, 4, and 5 represented highly resistant, resistant, moderately resistant, susceptible, and highly susceptible, respectively and the corresponding ranges of disease incidence were 0.0%, 0.1–10.0%, 10.1–20.0%, 20.1–40.0%, and 40.1–100.0%

Disease occurrence and field resistance evaluation of main cultivated varieties under natural condition

From 2017 to 2019, from October to November, ineach year, pokkah boeng incidence of each new variety in the newly-planted and ratoon field was analyzed to evaluate the field resistance. The main cultivated varieties were from Lincang city, Puer city, and Yuxi city in Yunnan Province, and Yizhou district in Guangxi Province. These sugarcane varieties were infected by natural pathogen population of pokkah boeng disease in the field. For each main cultivated variety, a three points sampling method was used in the fields of newly-planted and ratoon cane. The diseased plant was recorded by three professional sugarcane pathologists with visual inspection of main symptoms. 100 successive plants were assessed at each sampling points in. Therefore, a total of 300 plants were surveyed per variety. The total number of surveyed plants and the number of diseased plants were recorded to calculate the field diseased incidence. The field resistance of the main cultivated varieties to pokkah boeng disease was graded 1 to 5 and evaluated as described in section 2.2.

Date analysis

DPS 9.01 data processing system was used for statistical analysis, and Duncan's new multiple range method was used for difference significance analysis (P < 0.05).

Results

Field resistance of new varieties

The resistance control variety ROC 20 was highly resistant to pokkah boeng disease, and the susceptible control variety ROC 25 was highly susceptible in the three replicate samples of newly-planted and ratoon cane grown in the field in Kaiyuan and Lincang. The pokkah boeng resistance of these controls was stable and consistent. The pokkah boeng resistance of each of 60 new varieties was stable and relatively consistent, with 35 (58.33%) found to be highly resistant to moderately resistant, and 25 (41.67%) to be susceptible to highly susceptible. Among them, five new varieties (8.33%), Yuegan 49, Funong 11-2907, Mintang 11-610, Mintang 12-1404, and Guitang 11-1076 were found to be highly resistant. Furthermore, 15 new varieties (25%), Yuegan 46, Yuegan 47, Funong 09-2201, Funong 09-6201, Funong 09-7111, Funong 10-14405, Mintang 06-1405, Guitang 40, Guitang 44, Guitang 06-1492, Guitang 06-2081, Guitang 08-1180, Guitang 08-1589, Yunzhe 11-1074, and Dezhe 07-36, were found to be resistant. Another 15 new varieties (25%), Yuegan 48, Yuegan 50, Funong 07-3206, Funong 09-4095, Funong 09-12206, Funong 10-0574, Mintang 07-2005, Guitang 08-120, Liucheng 09-15, Zhongzhe 1, Yunzhe 11-1204, Yunzhe 11-3898, Yunrui 10-187, Haizhe 22, and Zhongzhe 1202 were found to be moderately resistant. In total, 18 new varieties (30%), Yuegan 43, Yuegan 51, Yuegan 52, Funong 08-3214, Guitang 08-1533, Guitang 13-386, Liucheng 07-150, Zhongzhe 6, Zhongzhe 10, Yunzhe 08-1095, Yunzhe 08-1609, Yunzhe 11-3208, Yunrui 11-450, Yunrui 12-263,

Dezhe 09-78, Dezhe 12-88, Haizhe 28, and Zhongtang 1201 were susceptible. Finally, there were seven new varieties (11.67%), Yuegan 53, Liucheng 07-506, Liucheng 09-19, Zhongzhe 13, Yunzhe 09-1601, Yunrui 10-701, and Zhongtang 1301 that were found to be highly susceptible (Table 1).

Table 1 Evaluation of field resistance to pokkah boeng disease in new sugarcane varieties under natural infection conditions

Varieties	Kaiyuan				Lincang				Comprehensive
	Newly-Planted Disease incidence ^a	Ratoon Disease incidence ^a	Grade	Resistance response ^b	Newly-Planted Disease incidence ^a	Ratoon Disease incidence ^a	Grade	Resistance response ^b	Resistance response ^b
	(%)	(%)			(%)	(%)			
Yuegan 49	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	HR
Funong 11-2907	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	
Mintang 11-610	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	
Mintang 12-1404	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	
Guitang 11-1076	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	
Yuegan 46	(7.0±0.6)nop	(8.0±1.1)klm	2	R	(6.0±0.9)jk	(9.0±0.6)ijkl	2	R	R
Yuegan 47	(5.0±0.2)pq	(6.0±0.2)mn	2	R	(7.0±0.6)jk	(8.0±0.9)jklm	2	R	
Funong 09-2201	(6.0±0.3)op	(7.0±0.4)lmn	2	R	(6.0±0.7)jk	(8.0±0.2)jklm	2	R	
Funong 09-6201	(3.0±0.1)pq	(5.0±0.4)mn	2	R	(4.0±0.2)k	(3.0±0.3)mn	2	R	
Funong 09-7111	(5.0±0.1)pq	(6.0±0.2)mn	2	R	(6.0±0.5)jk	(5.0±0.3)lmn	2	R	
Funong 10-14405	(2.0±0.8)pq	(3.0±0.1)no	2	R	(4.0±0.4)k	(3.0±0.2)mn	2	R	
Mintang 06-1405	(7.0±0.5)nop	(8.0±0.9)klm	2	R	(6.0±0.2)jk	(7.0±0.1)klm	2	R	
Guitang 40	(5.0±0.4)pq	(6.0±0.5)mn	2	R	(7.0±0.5)jk	(8.0±0.7)jklm	2	R	
Guitang 44	(3.0±0.2)pq	(4.0±0.4)mno	2	R	(5.0±0.5)k	(6.0±0.8)lm	2	R	
Guitang 06-1492	(4.0±0.8)pq	(5.0±0.3)mn	2	R	(7.0±0.3)jk	(9.0±0.9)ijkl	2	R	
Guitang 06-2081	(7.0±0.4)nop	(6.0±0.4)mn	2	R	(9.0±0.1)ij	(7.0±0.5)klm	2	R	
Guitang 08-1180	(6.0±0.1)op	(3.0±0.5)no	2	R	(5.0±0.0)k	(4.0±0.6)lmn	2	R	
Guitang 08-1589	(2.0±0.4)pq	(3.0±0.1)no	2	R	(4.0±0.0)k	(5.0±0.7)lmn	2	R	
Yunzhe 11-1074	(5.0±0.8)pq	(4.0±0.6)mno	2	R	(6.0±0.1)jk	(5.0±0.8)lmn	2	R	
Dezhe 07-36	(6.0±1.2)op	(4.0±0.2)mno	2	R	(5.0±0.3)k	(7.0±0.7)klm	2	R	
Yuegan 48	(13.0±0.1)lm	(12.0±0.7)jk	3	MR	(14.0±1.8)h	(15.0±0.3)h	3	MR	MR
Yuegan 50	(14.0±1.5)lm	(13.0±1.8)j	3	MR	(12.0±1.3)hi	(13.0±1.7)hij	3	MR	
Funong 07-3206	(11.0±1.0)mno	(12.0±1.8)jk	3	MR	(13.0±1.0)h	(15.0±0.6)h	3	MR	
Funong 09-4095	(12.0±1.0)lmn	(11.0±0.4)jkl	3	MR	(13.0±1.2)h	(14.0±0.4)hi	3	MR	
Funong 09-12206	(16.0±1.0)klm	(15.0±1.5)ij	3	MR	(14.0±1.5)h	(12.0±1.1)hijk	3	MR	

Funong 10-0574	(12.0±1.5)lmn	(11.0±1.0)jkl	3	MR	(14.0±1.1)h	(13.0±1.8)hij	3	MR	
Mintang 07-2005	(15.0±0.6)lm	(14.0±0.3)j	3	MR	(14.0±1.4)h	(16.0±2.1)h	3	MR	
Guitang 08-120	(15.0±1.8)lm	(13.0±0.5)j	3	MR	(14.0±0.3)h	(13.0±0.9)hij	3	MR	
Liucheng 09-15	(13.0±0.6)lm	(12.0±0.0)jk	3	MR	(14.0±1.5)h	(15.0±0.3)h	3	MR	
Zhongzhe 1	(12.0±1.2)lmn	(11.0±0.1)jkl	3	MR	(13.0±0.8)h	(14.0±1.0)hi	3	MR	
Yunzhe 11-1204	(12.0±0.1)lmn	(11.0±0.7)jkl	3	MR	(13.0±1.0)h	(14.0±1.7)hi	3	MR	
Yunzhe 11-3898	(12.0±1.0)lmn	(12.0±0.2)jk	3	MR	(14.0±1.0)h	(13.0±0.3)hij	3	MR	
Yunrui 10-187	(11.0±0.1)mno	(13.0±0.1)j	3	MR	(12.0±1.8)hi	(15.0±0.8)h	3	MR	
Haizhe 22	(12.0±1.0)lmn	(11.0±0.7)jkl	3	MR	(13.0±1.2)h	(14.0±1.0)hi	3	MR	
Zhontang 1202	(17.0±1.1)jkl	(18.0±0.7)hi	3	MR	(15.0±1.1)h	(16.0±1.2)h	3	MR	
Yuegan 43	(21.0±0.6)ijk	(23.0±1.2)g	4	S	(22.0±0.3)fg	(25.0±1.3)g	4	S	S
Yuegan 51	(22.0±0.6)ij	(23.0±3.0)g	4	S	(25.0±1.5)f	(24.0±1.2)g	4	S	
Yuegan 52	(21.0±0.2)ijk	(22.0±1.1)g	4	S	(23.0±0.2)fg	(25.0±2.0)g	4	S	
Funong 08-3214	(23.0±1.3)hi	(24.0±1.4)g	4	S	(22.0±1.1)fg	(23.0±0.5)g	4	S	
Guitang 08-1533	(21.0±0.2)ijk	(22.0±0.2)g	4	S	(23.0±3.5)fg	(24.0±2.2)g	4	S	
Guitang 13-386	(23.0±1.0)hi	(22.0±1.9)g	4	S	(21.0±0.2)g	(23.0±0.2)g	4	S	
Liucheng 07-150	(25.0±0.8)hi	(24.0±0.6)g	4	S	(24.0±0.5)fg	(25.0±0.8)g	4	S	
Zhongzhe 6	(23.0±2.1)hi	(24.0±2.6)g	4	S	(21.0±0.2)g	(23.0±0.5)g	4	S	
Zhongzhe 10	(21.0±0.3)ijk	(23.0±1.5)g	4	S	(22.0±0.4)fg	(21.0±1.9)g	4	S	
Yunzhe 08-1095	(23.0±1.6)hi	(21.0±1.3)gh	4	S	(22.0±1.9)fg	(24.0±1.2)g	4	S	
Yunzhe 08-1609	(24.0±0.4)hi	(25.0±2.5)g	4	S	(23.0±0.9)fg	(25.0±0.0)g	4	S	
Yunzhe 11-3208	(21.0±1.5)ijk	(23.0±1.2)g	4	S	(22.0±1.0)fg	(24.0±1.4)g	4	S	
Yunrui 11-450	(23.0±1.8)hi	(25.0±0.5)g	4	S	(21.0±0.7)g	(24.0±1.1)g	4	S	
Yunrui 12-263	(25.0±1.2)hi	(24.0±1.6)g	4	S	(24.0±1.4)fg	(26.0±1.6)g	4	S	
Dezhe 09- 78	(23.0±2.6)hi	(25.0±1.0)g	4	S	(22.0±2.0)fg	(26.0±1.6)g	4	S	
Dezhe 12- 88	(22.0±0.5)ij	(23.0±0.7)g	4	S	(23.0±1.2)fg	(25.0±1.3)g	4	S	
Haizhe 28	(23.0±0.8)ijk	(25.0±1.8)g	4	S	(21.0±0.2)g	(24.0±1.9)g	4	S	
Zhontang 1201	(21.0±0.8)hi	(23.0±0.0)g	4	S	(22.0±0.4)fg	(24.0±1.0)g	4	S	

Yuegan 53	(42.0±1.9)fg	(48.0±1.0)e	5	HS	(46.0±1.3)d	(51.0±1.6)e	5	HS	HS
Liucheng 07-506	(46.0±2.9)ef	(51.0±2.1)de	5	HS	(49.0±2.9)d	(54.0±2.0)e	5	HS	
Liucheng 09-19	(41.0±2.2)g	(50.0±2.5)de	5	HS	(47.0±2.8)d	(55.0±2.1)e	5	HS	
Zhongzhe 13	(61.0±2.1)b	(70.0±1.4)b	5	HS	(67.0±2.7)c	(75.0±2.8)b	5	HS	
Yunzhe 09-1601	(51.0±1.0)cd	(60.0±1.8)c	5	HS	(57.0±1.1)c	(65.0±1.8)c	5	HS	
Yunrui 10-701	(50.0±1.6)de	(53.0±1.4)d	5	HS	(57.0±0.6)c	(50.0±1.2)e	5	HS	
Zhontang 1301	(55.0±2.0)c	(61.0±1.2)c	5	HS	(57.0±1.7)b	(60.0±1.6)d	5	HS	
ROC 22 (CK)	(28.0±0.6)h	(32.0±1.6)f	4	S	(32.0±1.2)e	(37.0±1.0)f	4	S	S
ROC 20 (PC)	(0.0±0.0)q	(0.0±0.0)o	1	HR	(0.0±0.0)l	(0.0±0.0)n	1	HR	HR
ROC 25 (NC)	(90.0±0.8)a	(95.0±0.5)a	5	HS	(90.0±0.7)a	(100.0±0.0)a	5	HS	HS

^aThe values in the table are the mean±SE. Different lowercase letters indicate significant differences among disease incidence of different varieties at 0.05 level.

^bHR: Highly resistant; R: Resistant; MR: Moderately resistant; S: Susceptible; HS: Highly susceptible

Field resistance of main cultivated varieties

The resistance of the newly-planted and ratoon cane of each of the 31 main cultivated varieties, which from different sugarcane areas in the field, was stable and relatively consistent. Of the 31 main cultivated varieties, 15 (48.39%) were highly resistant to moderately resistant and 16 (51.61%) were susceptible to highly susceptible. There were five (16.13%) highly resistant main cultivated varieties, namely ROC 20, Yuetang 83-88, Chuantang 61-408, Yunyin 10, and Guitang 21. There were also five (16.13%) resistant main cultivated varieties: Yuetang 79-177, Yunzhe 05-51, Liucheng 03-182, Guitang 36, and Guitang 44. A further five (16.13%) main cultivated varieties, Yuetang 60, Liucheng 05-136, ROC 16, Mintang 69-421, and Guitang 29 were found to be moderately resistant. Seven (22.58%) main cultivated varieties, ROC 22, Yuetang 86-368, Yuetang 00-236, ROC 10, Yunzhe 05-49, Dezhe 03-83, and Yunyin 3, were found to be susceptible. Meanwhile, nine (29.03%) varieties, ROC 25, Yuetang 93-159, Yingyu 91-59, Liucheng 03-1137, Yunzhe 03-258, Chuantang 79-15, ROC 1, Guitang 11, and Guitang 42, were highly susceptible (Table 2).

Table 2 Evaluation of field resistance to pokkah boeng disease in main cultivated sugarcane varieties under natural infection conditions

Sugarcane fields	Varieties	Newly-Planted Disease incidence ^a (%)	Ratoon Disease incidence ^a (%)	Grade	Resistance response ^b	Comprehensive resistance response ^b
Yunnan lincang	ROC 20	(0.0±0.0)u	(0.0±0.0)s	1	HR	HR
	Yuetang 83-88	(0.0±0.0)u	(0.0±0.0)s	1	HR	
	Chuantang 61-408	(0.0±0.0)u	(0.0±0.0)s	1	HR	
	Yuetang 79-177	(7.0±0.7)t	(9.0±0.1)qr	2	R	R
	Yunzhe 05-51	(8.0±0.3)st	(9.0±0.7)qr	2	R	
	Liucheng 03-182	(6.0±0.4)t	(5.0±0.4)rs	2	R	
	Yuetang 60	(16.0±1.1)pqr	(18.0±1.3)mnop	3	MR	MR
	Liucheng 05-136	(12.0±0.2)rs	(13.0±1.0)pq	3	MR	
	ROC 22	(32.0±1.8)jk	(37.0±1.5)fgh	4	S	S
	Yuetang 86-368	(35.0±0.9)ij	(31.0±0.8)hij	4	S	
	Yuetang 00-236	(21.0±0.8)mno	(25.0±0.3)ijklm	4	S	
	ROC 25	(90.0±0.2)a	(100.0±0.0)a	5	HS	HS
	Yuetang 93-159	(75.0±1.3)d	(90.0±1.6)b	5	HS	
	Yingyu 91-59	(49.0±1.9)f	(60.0±1.2)c	5	HS	
	Liucheng 03-1137	(42.0±0.0)gh	(44.0±0.2)ef	5	HS	
Yunnan Puer	ROC 20	(0.0±0.0)u	(0.0±0.0)s	1	HR	HR
	Yunyin 10	(0.0±0.0)u	(0.0±0.0)s	1	HR	
	Guitang 21	(0.0±0.0)u	(0.0±0.0)s	1	HR	
	Yunzhe 05-51	(4.0±0.1)tu	(5.0±0.1)rs	2	R	R
	ROC 16	(14.0±1.1)pqr	(13.0±0.8)pq	3	MR	MR
	Yuetang 60	(17.0±1.9)opq	(15.0±1.3)opq	3	MR	
	ROC 10	(36.0±1.8)ij	(39.0±1.5)fg	4	S	S
	ROC 22	(35.0±0.7)ij	(32.0±0.8)ghi	4	S	
	Yuetang 86-368	(25.0±2.0)lm	(30.0±0.3)hijk	4	S	
	Yuetang 00-236	(23.0±0.2)m	(21.0±0.3)lmnop	4	S	
	Yunzhe 05-49	(33.0±0.2)jk	(31.0±0.9)hij	4	S	
	Dezhe 03-83	(24.0±0.5)m	(22.0±0.3)lmno	4	S	HS
	Yuetang 93-159	(85.0±0.8)c	(100.0±0.0)a	5	HS	
	Yunzhe 03-258	(46.0±1.8)fg	(42.0±1.7)f	5	HS	
	Chuantang 79-15	(59.0±2.4)e	(65.0±2.5)c	5	HS	
Yunnan Yuxi	Yunzhe 05-51	(5.0±0.3)tu	(4.0±0.4)rs	2	R	R
	ROC 16	(13.0±1.2)qr	(16.0±1.0)nopq	3	MR	MR

	Mintang 69-421	(18.0±1.8)nop	(19.0±1.3)mnop	3	MR	
	ROC 10	(29.0±0.3)kl	(27.0±0.5)ijkl	4	S	S
	ROC 22	(22.0±0.3)mn	(21.0±0.6)lmnop	4	S	
	Yuetang 00-236	(21.0±0.1)mno	(23.0±0.3)klmno	4	S	
	Yunyin 3	(39.0±0.7)hi	(37.0±0.3)fgh	4	S	
	ROC 1	(90.0±0.3)b	(100.0±0.0)a	5	HS	HS
	Yuetang 93-159	(85.0±1.3)c	(90.0±1.5)b	5	HS	
	Guitang 11	(49.0±1.9)f	(52.0±1.1)d	5	HS	
Guangxi Yizhou	ROC 20	(0.0±0.0)u	(0.0±0.0)s	1	HR	HR
	Guitang 21	(0.0±0.0)u	(0.0±0.0)s	1	HR	
	Guitang 36	(4.0±0.2)tu	(5.0±0.4)rs	2	R	R
	Guitang 44	(5.0±0.5)tu	(9.0±0.9)qr	2	R	
	ROC 16	(12.0±0.3)rs	(15.0±0.6)opq	3	MR	MR
	Guitang 29	(16.0±0.8)pqr	(17.0±1.0)mnopq	3	MR	
	Liucheng 05-136	(18.0±1.3)nop	(15.0±1.0)opq	3	MR	
	ROC 22	(22.0±1.1)mn	(24.0±1.1)jklmn	4	S	S
	Guitang 42	(49.0±1.9)f	(50.0±1.5)de	5	HS	HS
	Liucheng 03-1137	(42.0±0.1)gh	(41.0±0.5)f	5	HS	
Susceptibility control	ROC 25	(95.0±0.1)b	(100.0±0.0)a	5	HS	HS
Resistant control	ROC 20	(0.0±0.0)u	(0.0±0.0)s	1	HR	HR

^aThe values in the table are the mean±SE. Different lowercase letters indicate significant differences among disease incidence of different varieties at 0.05 level.

^bHR: Highly resistant; R: Resistant; MR: Moderately resistant; S: Susceptible; HS: Highly susceptible

Discussion

Pokkah boeng disease is an important epidemic fungal disease that is prone to outbreaks. Screening and planting resistant varieties is the most economic and effective method that can be used to control this disease. As pokkah boeng disease has become an important disease that seriously affects the development of the sugarcane industry in China, disease-resistant sugarcane breeding strategies should be implemented in the future. Pokkah boeng disease resistance should be regarded as one of the main economic indices in variety breeding programs. The evaluation and screening of sugarcane varieties that are resistant to pokkah boeng disease should be strengthened. In addition, disease-resistant resources should be explored and utilized, the breeding of intermediate material should be improved, and parental combinations should be rationally matched. This will aid in the selection and breeding of stable resistant new varieties for popularization and application in sugarcane production.

Yunnan Province is an important distribution center of wild sugarcane resources in China and one of the global origins of wild sugarcane (Chen et al. 2001; Fan et al. 2001). Wild sugarcane resources are an importance source of resistance genes in modern sugarcane breeding. Some studies have shown that the wild germplasm resources preserved in the National Nursery of Sugarcane Germplasm Resources in China contain excellent disease-resistance genes, which is promising for the breeding of disease-resistant sugarcane varieties (Huang et al. 2012; Li et al. 2013, 2015, 2017b; Xu et al. 2014). The new and main cultivated varieties that displayed resistance to pokkah boeng in this study may be used for breeding resistant sugarcane varieties. These varieties can be used as a disease-resistance parent to hybridize with wild germplasm resources. The heritability of the disease resistance should then be analyzed and a disease-resistant germplasm gene bank may be established. This will allow further selection of new sugarcane varieties with pokkah boeng resistance for application in the sugarcane industry.

The main factors that induce pokkah boeng disease outbreaks are planting susceptible varieties in large areas, and high rainfall and humidity. The most economic and effective control measure against pokkah boeng disease is to select and plant resistance varieties (Huang et al. 2018; Shan et al.

2018). The results of this study showed that nine main cultivated varieties that are planted over large areas, including ROC 25, Yuetang 93-159, Yingyu 91-59, Liucheng 03-1137, Yunzhe 03-258, Chuantang 79-15, ROC 1, Guitang 11, and Guitang 42, were highly susceptible to pokkah boeng disease. In contrast, 20 elite new varieties bred in recent years, including Yuegan 49, Funong 11-2907, Mintang 11-610, Mintang 12-1404, Guitang 11-1076, Yuegan 46, Yuegan 47, Funong 09-2201, Funong 09-6201, Funong 09-7111, Funong 10-14405, Mintang 06-1405, Guitang 40, Guitang 44, Guitang 06-1492, Guitang 06-2081, Guitang 08-1180, Guitang 08-1589, Yunzhe 11-1074, and Dezhe 07-36 displayed strong pokkah boeng disease resistance. These results suggest that in wetter and rainy sugarcane planting areas with high incidence of pokkah boeng disease, it is necessary to eliminate the susceptible main cultivated varieties and promote the application of resistant new elite varieties. This will help to achieve a reasonable distribution of varieties, fundamentally controlling the outbreak of pokkah boeng disease, and providing guarantee for the high-quality development of the sugarcane industry in China.

Declarations

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Conflict of interest

The authors declare that they have no conflict of interest.

Availability of data and material

All data generated or analyzed during this study are included in this article.

Authors' contributions

Yingkun Huang and Wenfeng Li conceived and designed the study; Hongli Shan, Xiaoyan Cang, Wei Qin, Xiaoyan Wang, and Rongyue Zhang conducted this research; Hongli Shan wrote original draft; Yingkun Huang and Wenfeng Li reviewed and edited the draft.

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Figures

Figure 1

Symptoms of pokkah boeng disease infected sugarcane plants in the field. a, plant with typical diseased showing shriveling and twisting of young leaves; b, a cluster of diseased plants with typical symptoms; c, the apical growth points showing necrosis and decay; d, a view of a seriously diseased field.