Relationships between sucrose content and resistance of corn to stalk rot*

LONG Shu-sheng[1], LI Ya-ling[1], SHI Chun-xi[1],
LI En-cai[2], ZHANG Yu-hong[1], LI Ming-lei[1]

(1 Key Laboratory of Plant Protection Resources and Pests Management, Chinese Ministry of Education, College of Plant Protection, Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi 712100, China;
2 Station of Plant Protection and Quarantine of Baoji, Baoji, Shaanxi 721001, China)

[**Abstract**] The relationship between sucrose content and corn resistance to corn stalk rot caused by *Fusarium graminearum* was investigated. The incidence of corn stalk rot was closely related to sucrose content in the pith tissues of the second internode above the ground at the physiological maturity stage. Corn hybrids resistant to stalk rot had higher sucrose contents in the pith tissues of the second internode above the ground than hybrids susceptible to the disease. In addition, disease incidence was negatively correlated with sucrose content in the pith tissues of the second internode above the ground at the physiological maturity stage. The results suggested that sucrose content could be used as an indicator of corn stalk rot resistance and for selecting corn hybrids for resistance to corn stalk rot.

[**Key words**] sucrose content; resistance; corn stalk rot; *Fusarium graminearum*
[CLC number] S435.131; S513.01 [Document code] A [Article ID] 1671-9387(2003)04-0113-06

Corn stalk rot, caused by *Fusarium graminearum* Schwabe, is a serious disease that affects corn worldwide. The disease has been studied extensively but there have been few reports of relationships between sugar content in corn tissues and resistance to corn stalk rot. Craig and Hooker found that a decrease in the total sugar content (sucrose and reducing sugars) within the stalk caused senescence of pith tissue which increased the plant's susceptibility to corn stalk rot[1]. In the same study, total sugar content within the stalk was more closely correlated with stalk rot reaction than the quantity of individual component sugars (sucrose and reducing sugars). Moretimore and Ward reported that under any condition of stress which restricts corn plant's photosynthesis or alters any of the subsequent processes of carbohydrate metabolism of corn plant, the amount of carbohydrate produced is not enough to satisfy the plant's physiological demands. A reduction in sugar content in the stalk caused an increase in the incidence of corn stalk rot. The removal of stress factors resulted in the maintenance or an increase of sugar in the stalk and the disease did not occur in either resistant or susceptible hybrids. They also found that marked and consistent differences in the total sugar of the tissues (leaf, internode rind, internode pith) between resistant hybrid and susceptible hybrid were only evident at physiological maturity (kernel moisture 35% - 37%) of the plant. Reducing sugars and sucrose alone did not show this consistent relationship[2]. Timti concluded that corn stalk rot was associated with nitrogen, potassium and the sugar content of stems[3]. Various

* [收稿日期] 2002-11-15
[基金项目] 陕西省自然科学基金项目(96SM22)
[作者简介] 龙书生(1964-),男,陕西靖边人,副研究员,主要从事玉米病害研究。

workers have shown that resistance to corn stalk rot was positively correlated with the sugar content of stalk tissues[4~7]. However Czaplinska et al found that there was no relationship between sugar content and intensity of corn stalk rot. They concluded that sugar content could not be used as a reliable indicator of resistance to corn stalk rot or to predict severity of infection[8]. Zhu and Liu showed that the effects of sugar content on incidence and severity of stalk rot varied at different growing stages[9]. Long et al found that during the grain filling stage resistant hybrids had higher reducing sugar levels than hybrids that were susceptible to corn stalk rot. At the physiological maturity stage, total sugar content in the resistant hybrids was higher than that in susceptible hybrids. Their results also showed that there was a significant negative correlation between the incidence of corn stalk rot and content of reducing sugars in the second internode above the ground at the grain filling stage. And they also concluded that incidence of corn stalk rot had a significant negative correlation with total sugar content in the second internode above the ground at the physiological maturity stage[10].

Although relationships between total and reducing sugars and plant resistance to corn stalk rot have been studied, the role of sucrose in stalk rot resistance has not been defined. This study investigated relationships between sucrose content in the pith tissues of corn stalks and corn plant resistance to stalk rot.

1 Materials and methods

1.1 Experimental design

Four corn hybrids were selected to study their differences in resistance or susceptibility to corn stalk rot. These were: Shanda 931 (high resistance, with an average stalk rot incidence of 4.55%); Shanda 9 (moderate resistance, with an average stalk rot incidence of 25.00%); Xinong 11 (moderate susceptibility, with an average stalk rot incidence of 45.00%) and H4vb × 9372 (high susceptibility, with an average stalk rot incidence of 55.50%). Disease resistance or susceptibility (expressed as incidence of stalk rot) of each of these hybrids had previously been assessed by Long et al[10]. Field experiments were carried out over summer in 1998 at the Northwest Sci-Tech University of Agriculture and Forestry, Yangling, Shaanxi. The four hybrids were planted in randomized blocks design using three replications. Each plot was 10 m long × 3 m wide. Planting density is 675 000 plant/hm^2 (The distance between rows was 0.67 m and the distance between plants within each row was 0.33 m).

1.2 Sampling and determination of sucrose content

Samples for sucrose analysis were collected at three separate stages of plant development. These were tassel emergence stage (TE), grain filling stage (GF, about 4 weeks after TE) and physiological maturity stage (PM, about 8 weeks after TE). At each stage three specimens of each hybrid were collected. Sucrose content was measured in the pith tissues, from the first internode below the ear and the second internode above the ground, using the Shaffer-Somogyi (SS) micro-analysis method as described in Li HE[11]. The results were expressed as percentage of sucrose in pith tissue on a dry weight basis.

1.3 Data analysis

Analyses of variance (ANOVA) of all data were performed using Statistical Analysis System software, version 8.1 for Windows (SAS Institute Inc., Cary, NC). For sucrose contents were percentage data, statistical analysis were based on angular or inverse sine (arcsin) transformation.

2 Results

Sucrose contents in pith tissue at the first internode below the ear and at the second internode above the ground were obtained (Table 1). Results of analysis of variance (ANOVA) were shown in Table 2.

2.1 Sucrose content in pith tissue at the first internode below the ear

At the tassel emergence stage, sucrose content was very low in the pith tissues at the first internode below the ear in all four hybrids. The highest sucrose content was measured in Xinong 11 (moderate susceptibility) (Fig. 1). Analysis of variance showed that there were highly significant differences ($P < 0.01$) between hybrids (Table 2) and Duncan's test confirmed that the sucrose content of Xinong 11 was significantly ($P < 0.05$) higher than the other three hybrids Shanda 931 (high resistance), Shanda 9 (moderate resistance) and H4vb × 9372 (high susceptibility). However, differences between Shanda 931, Shanda 9 and H4vb × 9372 were not significant (Fig. 1).

Table 1 Levels of sucrose in the pith tissues of corn stalk internode %

Varieties	Sampling stage	Sucrose content							
		First internode below ear				Second internode above ground			
		1	2	3	Mean	1	2	3	Mean
Shanda 931	TE	4.29	5.59	3.67	4.52	3.75	4.56	6.06	4.79
	GF	25.96	22.97	25.17	24.70	7.46	8.13	8.62	8.07
	PM	35.00	42.58	46.05	41.21	37.43	37.75	36.87	37.35
Shanda 9	TE	3.66	2.86	4.71	3.74	4.54	4.98	2.48	4.00
	GF	26.30	23.79	24.46	24.85	8.27	9.05	8.67	8.66
	PM	37.71	36.72	36.43	36.95	31.75	31.67	32.13	31.85
Xinong 11	TE	8.24	8.34	10.19	8.92	4.56	4.57	4.55	4.56
	GF	27.93	27.59	26.66	27.39	13.19	12.98	13.28	13.15
	PM	27.98	25.60	19.70	24.43	9.99	16.73	11.86	12.86
H4vb × 9372	TE	4.40	4.72	4.49	4.54	5.57	4.77	5.47	5.27
	GF	25.19	25.38	25.67	25.41	6.72	5.87	6.68	6.42
	PM	21.52	21.94	22.06	21.84	9.41	8.13	9.30	8.95

Note: TE. Tassel emergence stage; GF. Grain filling stage; PM. Physiological maturity stage.

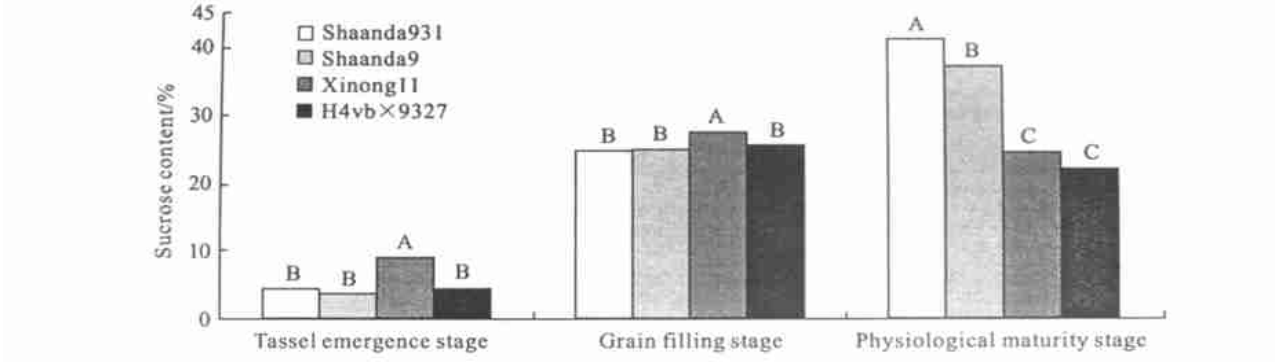

Fig. 1 Sucrose content in the first internode below the ear at different growth stages

Each value represents the average of three replicates

The same letters above each column indicate that the values at each growth stage are not significantly different ($P = 0.05$) according to Duncan's New Multiple-range test

Table 2 Analysis of variance for sucrose contents in pith tissues of corn stalk internode

Sampling stage	F		$F_{0.05}$	$F_{0.01}$
	First internode below ear	Second internode above ground		
TE	15.55**	0.76		
GF	5.28*	102.65**	4.76	9.78
PM	16.41**	112.88**		

Note: Data of sucrose contents were analyzed after angular or inverse sine transfomation.

Between the tassel emergence stage and the grain filling stage the sucrose content increased rapidly in each of the four hybrids. At the grain filling stage there were significant differences ($P < 0.05$) among the hybrids (Table 2). Xinong 11 had significantly ($P < 0.05$) higher sucrose content than the other three hybrids. However, differences among the other three hybrids were not significant (Fig. 1).

The sucrose content in resistant hybrids peaked at the physiological maturity stage but de-

creased in susceptible hybrids. Analysis of variance showed that there were significant differences among the hybrids at this growth stage ($P < 0.01$) (Table 2). These differences were significant ($P < 0.05$) between all hybrids except for between Xinong 11 and H4vb × 9372.

2.2 Sucrose content in pith tissue at the second internode above the ground

At the tassel emergence stage the sucrose content of pith tissues at the second internode above the ground was low in all hybrids and there were no significant differences between any of the hybrids (Table 2 and Fig. 2).

Sucrose content increased moderately between the tassel emergence stage and the grain filling stage. Analysis of variance showed that at the grain filling stage differences in sucrose content among the hybrids were highly significant ($P < 0.01$) (Table 2). The lowest sucrose content was measured in H4vb × 9372 and the highest sucrose content was measured in Xinong 11. The sucrose content in Shanda 931 and Shanda 9 were significantly higher than that in H4vb × 9372. However, Xinong 11 had significantly higher sucrose content than all the other three hybrids (Fig. 2).

By the physiological maturity stage sucrose content in the second internode above the ground of resistant hybrids had increased significantly. Sucrose content in the susceptible hybrids increased only marginally or in the case of Xinong 11 decreased slightly. Differences in sucrose content among hybrids were highly significant ($P < 0.01$) (Table 2). Duncan's test showed that these differences were significant ($P < 0.05$) between each of the four hybrids (Fig. 2).

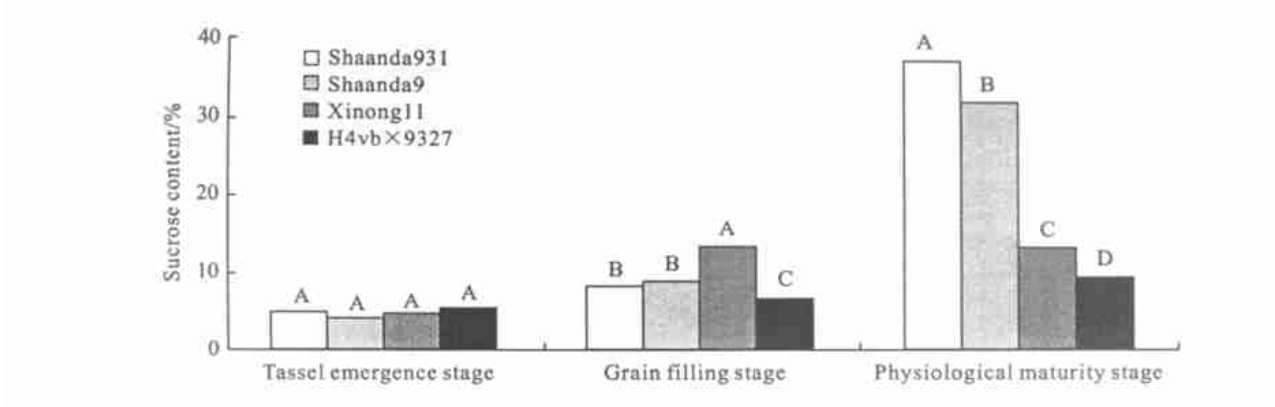

Fig. 2 Sucrose content in the second internode above the ground at different growth stages

Each value represents the average of three replicates

The same letters above each column indicate that the values at each growth stage are not significantly different ($P = 0.05$) according to Duncan's New Multiple-range test

2.3 Relationship between sucrose content and disease incidence

The results from a linear correlation analysis showed that there was a significant negative correlation ($r = -0.972\,6$) between incidence of corn stalk rot and sucrose content in pith tissue of the second internode above the ground at the physiological maturity stage. A hypothesis test for r showed that this was a real linear correlation. The regression equation was $Y = 68.238\,5 - 1.570\,2X$ (Table 3).

Table 3 Linear correlation analysis between corn stalk rot incidence and content of sucrose in pith tissue of second internode above ground at physiological maturity stage

Varieties	Disease incidence (Y)	Sucrose content (X)	Correlation coefficient (r)	t test for r		Regression equation
				$\|t\|$	$t_{0.05}$	
Shanda 931	4.55	37.35	-0.972 6	5.92*	4.30	$Y = 68.238\,5 - 1.570\,2X$
Shanda 9	25.00	31.85				
Xinong 11	45.00	12.86				
H4vb × 9372	55.50	8.95				

3 Discussion

During this study, relationships between sucrose content and resistance of corn to stalk rot caused by *F. graminearum* were investigated. The results from this study are the first to provide evidence suggesting that there is a strong relationship between sucrose content and resistance of corn to stalk rot.

Different trends of sucrose content occurred between resistant hybrids and susceptible hybrids in the pith tissues of the second internode above the ground from grain filling stage to physiological maturity stage. The sucrose content increased significantly in the resistant hybrids but only minor changes were measured in susceptible hybrids. Sucrose contents between each of the four hybrids at the physiological maturity stage were significantly different. These results are comparable with the findings of Mortimore et al. and Craig et al. who reported similar relationships of total sugar content between resistant hybrids (or inbred lines) and susceptible hybrids (or inbred lines) at physiological maturity stage. Long et al. also demonstrated that the resistant hybrids used in this study had significant higher total sugar contents in the pith tissues of the second internode above the ground at physiological maturity stage and significant higher reducing sugar contents in the pith tissues of the second internode above the ground at grain filling stage than susceptible hybrids. These results could indicate that sugar (including total sugar, reducing sugar and sucrose) contents in the pith tissues of corn stalk varied at different growth stages. There was a correlation between resistance of corn to stalk rot and sucrose content only at a suitable period in the whole life of corn plant. This may explain why Craig and Hooker found that total sugar content more closely correlated with stalk rot incidence and intensity than sucrose content, and why Czaplinska et al. reported that no relation was found between sugar content and intensity of stalk rot. Craig and Hooker took their last measurement four weeks after the silking stage. Czaplinska et al. examined sugar content at 6 weeks and then again at 13 weeks after inoculation that was carried out at the silking stage. Their sampling time might be not suitable. This suggests that the time of sampling for measuring sucrose content is an important factor in determining the resistance of a particular corn cultivar to corn stalk rot.

Another important factor may be the type of tissue that is sampled for analysis. Previously, Mortimore and Ward compared six different tissues and found that the difference of total sugar content in resistant or susceptible corn cultivars occurred in internode pith tissues. In the present study, although there were significant differences in sucrose content at the first internode below the ear, there were no significant differences between either of the resistant hybrids or either of the susceptible hybrids. However, the greatest differences in sucrose content were found in the pith tissue at the second internode above the ground and these differences were significant between each of the hybrids.

The greater the resistance of the hybrid had, the higher the sucrose content was when measured in the pith tissue at the second internode above the ground at the physiological maturity stage. This was confirmed by a linear correlation coefficient analysis, which showed that there was a strong negative correlation (r= - 0.972 6) between disease incidence and sucrose content. A possible explanation for this phenomenon is that resistant hybrids may have a lower capacity to metabolise sucrose into grain than susceptible hybrids. More sucrose maintaining in plant stalk could keep plant cells vigour enough to defend diseases invading. This may also explain why Koehler[12] found that corn hybrids that are susceptible to stalk rot are the highest yielding in seasons or locations where there is a low incidence of corn stalk rot.

This study has demonstrated that sucrose content can be used as an indicator of resistance to stalk rot in corn. However, it must be measured in the second internode above the ground at physiological maturity stage. Then by applying the re-

gression equation $Y = 68.238\,5 - 1.570\,2X$ (where Y = expected incidence of stalk rot expressed as a percentage and; X = sucrose content) resistance to stalk rot can be assessed. However, it is known that high sucrose content in plant stalk is associated with lower yields. Therefore, hybrids with moderate resistance may be more economically viable than highly resistant varieties. Further work is required to determine the optimal level of sucrose content that indicates resistance to stalk rot while maintaining high yields.

Acknowledgements: This project was funded by Shaanxi Science and Technology Foundation. We thank Mr B. P. Keen (NSW Agriculture, Australia) for help in writing the paper and Dr P. T. W. Wong (NSW Agriculture, Australia) for commenting on the manuscript.

[References]

[1] Craig J, Hooker A L. Relation of sugar trends and pith density to Diplodia stalk rot in dent corn[J]. Phytopathology, 1961, 51: 376-382.

[2] Mortimore C G, Ward G M. Root and stalk rot of corn in southwestern Ontario Ⅲ. Sugar levels as a measure of plant vigor and resistance[J]. Canadian Journal of Plant Science, 1964, 44: 451-457.

[3] Timti IN. Investigations on corn (*Zea mays* L.) stalk rot incited by pathogenic fungi in different environments[J]. Dissertation Abstracts International, 1978, 39(1): 17B-18B.

[4] Bunting E S, Gunn R E. Maize breeding——Progress Reports on Research and Development (1972-1973)[M]. Home Grown Cereals Authority: London, UK. 1973. 13-16.

[5] May Hacher M, Grossmann F. Indirect methods for determining resistance of maize to stalk rot[J]. Mitteilungen aus der Biologischen Bundesanstalt fur Land und Forstwirtschaft Berlin Dahlem, 1981, 203: 207.

[6] Widstrom N W, Carr M E, Bagby M O, et al. Distribution of sugar and soluble solids in the maize stalk[J]. Crop Science, 1988, 28(5): 861-863.

[7] Feng F F, Sun S H, Jiang J C, et al. Study on corn resistance to corn stalk rot and screening of resistance resouce[J]. Maize Science, 1995, Supplement: 53-58(in Chinese).

[8] Czaplinska S, Cebrat J, Jasa S, et al. Search for methods of estimating the resistance of maize to stalk rot[J]. Biuletyn Instytutu Hodowlii Aklimatyzacji Roslin, 1979, 136: 79-90.

[9] Zhu Y L, Liu J L. A prilimtary study on the resistance to Fusarium stalk rot in corn inbred lines[J]. Acta Agronomica Sinica, 1990, 16(2): 131-138(in Chinese).

[10] Long S S, Li Y L, Zhang Y H, et al. Studies on sugar levels used as a breeding index of variety resistant to maize stalk rot[J]. Journal of Shandong Agricultural University, 1999, 30(4): 372-376, 380(in Chinese).

[11] Li H E. Handbook of Quality Testing Technics for Agricultural Products[M]. Shenzhen: Hai Tian Publish House, 1997(in Chinese).

[12] Koehler B. Cornstalk rots in Illinois[R]. University of Illinois: Agricultural experiment station bulletin, 1960. 658.

蔗糖含量与玉米对镰刀菌茎腐病的抗病性的关系

龙书生[1], 李亚玲[1], 时春喜[1], 李恩才[2], 张宇宏[1], 李鸣雷[1]

(1 西北农林科技大学 植物保护学院 教育部植保资源与害虫管理重点实验室, 陕西 杨陵 712100;
2 宝鸡市植保植检站, 陕西 宝鸡 721001)

摘 要: 就玉米茎秆蔗糖含量与玉米对由禾谷镰刀菌(*Fusarium graminearum*)引起的茎腐病(corn stalk rot)的抗性间的关系进行了研究。结果表明, 在玉米生理成熟期地上第二茎间髓部组织内蔗糖的含量与玉米对茎腐病的抗性密切相关, 抗病的玉米杂交种的蔗糖含量明显高于感病的玉米杂交种。蔗糖含量与茎腐病的发病率呈显著的负相关关系。研究结果表明, 在生理成熟期地上第二茎间髓部组织内蔗糖含量可作为选育抗镰刀菌茎腐病玉米杂交种的生化指标。

关键词: 蔗糖含量; 抗病性; 玉米茎腐病; 禾谷镰刀菌