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Review

Sweetpotato viruses in China

Qingmei Wang[a,1], Liming Zhang[a,1], Biao Wang[b], Zhenfang Yin[b], Chaohong Feng[b], Qiaochun Wang[b,*]

[a] Institute of Field Crops, Shandong Academy of Agricultural Science, Jinan 250100, Shandong, PR China

[b] Key Laboratory of Genetic Improvement of Horticultural Crops of Northwest China, College of Horticulture, Northwest Agricultural and Forest University, Yangling 712100, Shaanxi, PR China

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ABSTRACT

China is the largest sweetpotato producer country in the world, with its total growing area and yield reaching 5.5 million ha and 106 million metric tones, respectively. Viral diseases constitute a major hindrance to the development and highly profitable production of the sweetpotato industry. The present article provides updated comprehensive information on type of virus, yield loss caused by viruses, increased yield and benefits by cultivation of virus-free plants. By analyzing data on changes in vegetative growth and physiology of plants infected by viruses, the authors attempted to elucidate the mechanisms by which infection of viruses caused significant losses of the root tuber yield. Meristem culture techniques for production of virus-free sweetpotato plants and propagation system of virus-free seed tubers have been well developed in China. At present time, virus-free sweetpotato seed tubers have been widely used in major sweetpotato-growing areas in China. Usage of virus-free seed tubers has brought great benefits to the sweetpotato industry in China.

1. Significance of sweetpotato in China

Sweetpotato (*Ipomoea batatas*) is the fifth largest staple crop next to rice, wheat, maize and soybean in China, and mainly used as food, vegetables, feed and industrial materials (Zhang et al., 2009). Today, China is the biggest sweetpotato producer country in the world. The total growing area and yield reached about 5.5 million ha (FAO, 2005) and 106 million metric tons (FAO, 2004), which accounted for 70% and 85% of total area and yield of the world, respectively. Sweetpotato is widely grown in China, from south (Hainan) to north (Inner Mongolia) and from east (Zhejiang) to west (Tibet) with its extensive producing areas concentrated in the Yellow River and the Yangtze River Basins (Gao et al., 2000; Zhang et al., 2009). Five major sweetpotato regions were distinguished according to the climatic conditions and the cropping systems (Anonymous, 1984). Sichuan, Henan, Chongqing, Anhui, Guangdong and Shandong were among the major producer provinces. With development of processing techniques in the last decade, various processing products emerged, for example, sweetpotato noodles, vermicelli and sheet jelly, chips, starch and organic products including ethanol (Zhang et al., 2009). About 5–10% of total yield of sweetpotato tubers are used for this purpose. Nevertheless, sweetpotato is still considered as a crop ensuring food security in many of less-developed regions of China (Zhang et al., 2009). Because of its high content of vitamins, minerals, dietary fibre and non-fibrous carbohydrates, an increased trend in consumption of sweetpotato as a nutritional food has been recently observed in China (Zhang et al., 2009). A recent study reported that orange-fleshed sweetpotato has a high content of β-carotene, a pro-vitamin A, which has antioxidant activities (Suda et al., 2003; Komaki and Yamakawa, 2006). These novel findings are expected to further promote consumption of sweetpotato in China (Zhang et al., 2009).

2. Types of viruses and their influences on sweetpotato production in China

2.1. Types of sweetpotato viruses

Three sweetpotato viruses have been detected since the 1950s: *Sweetpotato feathery mottle virus* (SPFMV), *Sweetpotato latent virus* (SPLV) and *Sweetpotato chlorotic fleck virus* (SPCFV) (Zhang and Wang, 1995; Song et al., 1997; Gao et al., 2000). With the introduction of sweetpotato genetic resources to China and development of new techniques for virus detection during the last decade, 11 of the about 20 sweetpotato viruses reported in the world have been detected in China (Table 1). *Sweetpotato chlorotic stunt virus* (SPCSV), which caused sweetpotato virus disease (SPVD) when co-infecting with SPFMV (Schaefers and Terry, 1976), was for the first time

* Corresponding author. Tel.: +86 29 87080295; fax: +86 29 87081305.
E-mail address: qiaochunwang@nwsuaf.edu.cn (Q.C. Wang).

[1] These two authors contributed equally to the present study.

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Table 1
A list of sweetpotato viruses in China.

Type of virus	Genus	Original location	Reference
C-6 virus	*Carlavirus* (a putative member)	Jiangsu and Anhui	Zhang et al., 2006
SPCFV	Not clarified yet	Jiangsu and Anhui	Zhang et al., 2006
SPCSV	*Crinivirus*	Shandong	Zhang et al., 2005, 2006
SPCV	Not clarified yet	Not specified	Gao et al., 2000
SPFMV	*Potyvirus*	Shandong, Jiangsu and Anhui	Zhang et al., 2006
		Guangdong	Colient and Kummert, 1993; Colient et al., 1993, 1997, 1998; Ateka et al., 2007
SPLCV	*Begomovirus*	Not specified	Lotrakul et al., 2001
		Liaoning	Luan et al., 2006
		Not specified	Li et al., 2004
SPLV	*Potyvirus*	Shandong, Jiangsu and Anhui	Zhang et al., 2005, 2006
		Guangdong	Colient et al., 1997, 1998
		Not specified	IsHak et al., 2003
SPMMV	*Ipomovirus*	Jiangsu and Anhui	Zhang et al., 2006
SPMSV	*Potyvirus*	Jiangsu and Anhui	Zhang et al., 2006
SPVG	*Potyvirus*	Guangdong	Colient et al., 1996, 1998
SPV-2	*Potyvirus* (a tentative member)	Guangdong	Ateka et al., 2007

detected in Shandong province with about 9% of occurrence frequency (Zhang et al., 2005; 2006). Fortunately, until now plants affected with SPVD have not been detected yet. SPFMV and SPLV were recognized to be the most two popular and damaging viruses in China. A survey conducted in three major sweetpotato-producing provinces showed that frequencies of occurrence ranged 21–100% for SPFMV and 21–90% for SPLV (Zhang et al., 2005, 2006). About 16% plants were co-infected by SPFMV and SPLV. Occurrence frequencies of viruses in five major sweetpotato-growing provinces of China are summarized in Table 2.

2.2. Yield and economical losses caused by viruses

Viral diseases have been recognized to be a major factor limiting sustainable sweetpotato production in China (Gao et al., 2000; Zhang et al., 2005, 2006, 2009). A survey conducted in the main sweetpotato-growing provinces including Jiangsu, Sichuan, Shandong and Anhui showed that sweetpotato viruses caused an average yield loss of about 20–30% (Gao et al., 2000), with the most severe loss up to 78% (Shang et al., 1996). Furthermore, virus-infected sweetpotato plants were found to be much more susceptible, than the healthy plants, to fungi *Monilochaetes infuscans* and *Ceratocystis fimbriata*, and nematodes *Pratylenchus coffeae* (Yang et al., 1998; Wang et al., 2000), thus causing much greater yield losses. It was estimated that sweetpotato viral diseases caused annually economical losses of 4 billion RMB Yuan (6.8 RMB Yuan ≈ 1 US $) to the sweetpotato industry in China (Zhang and Guo, 2005).

3. Virus-induced changes in growth and physiology of sweetpotato plants

Over the last two decades, great efforts have been made to investigate virus-induced changes in vegetative growth and physiology of virus-infected sweetpotato plants, in order to reveal

Table 2
Frequencies of incidence of sweetpotato viruses from 5 major sweetpotato-producing provinces in China.

Province	SPFMV (%)	SPLV (%)	SPMMV (%)	SPCFV (%)	SPMSV (%)	C-6 (%)	SPCSV (%)	C-8 (%)
Shandong	81	13	–	–	–	–	11	
Jiangsu	100	90	70	40	60	40	–	
Anhui	37	18	9	14	14	10	–	
Henan	72	60	42	54	–	60	–	59
Sichuan	13	7						

mechanisms by which viral diseases cause significant losses of tuber yield. Wang et al. (2000) found that virus-free (SPFMV and SPLV) plants had much better vegetative growth than virus-infected plants, in terms of shoot number, shoot length, fresh weight of plants, fresh weight of leaves and leaf area index (Table 3). Better vegetative growth is a prerequisite for production of high yield of tuberous roots (Wang et al., 2000). In fact, these data were supported by a study of Loebenstein (1959), who found that the respiration rate of the SPFMV-infected sweetpotato plants was significantly higher than that of the healthy ones. This increased rate remained higher (at least 50%) even 70 days after infection. High respiration rate led to poor vegetative growth of virus-infected plants. Furthermore, Loebenstein and Linsey (1961) demonstrated that peroxidase activity was involved in this increased respiration rate of the diseased plants. Root formation was earlier and root system developed better in SPFM-free seed tubers than in virus-infected ones (Table 4, Du et al., 1999). Root activity, which was determined by measuring the content of exogenous P^{32}, was found to be higher in the virus-free plants than in virus-infected ones. Well-developed root system is beneficial to uptake of water and nutrients, and their transport to sink organs (tuberous roots), thus resulting in increased tuber yield (Du et al., 1999). Tubers of virus-free plants developed earlier and expanded faster at early stage of tuber development in virus-free plants than in virus-infected ones (Zhang et al., 2003). Earlier development and faster expansion of tubers at early stage were recognized as a key factor for production of high yield of root tubers (Nie et al., 2000; Zhang et al., 2003). Photosynthetic rate [20.4 mg $(CO_2)/dm^2\,h$] of virus-free plants was significantly higher than that [13.8 mg $(CO_2)/dm^2\,h$] of virus-infected ones, while transpiration rate (0.64 $\mu g/cm^2\,s$) of the former was significantly lower than that (0.76 $\mu g/cm^2\,s$) of the latter (Du et al., 1999). Chen et al. (2001) also reported that leaf area index (4.4), chlorophyll content (1.1 mg/g), net photosynthetic rate (52.9 $\mu mol/m^2\,s$) and starch phosphorylase (49 mg/mg min) of virus-free plants were higher than those (4.2, 1.0 mg/g, 47.5 $\mu mol/m^2\,s$ and 43 mg/mg min) of virus-infected ones (Table 5, Chen et al., 2001). Larger leaf area index, higher chlorophyll content, higher photosynthetic ability and low transpiration rate enhance efficient utilization of water and enhance photosynthesis and drought resistance of the plants. All of these physiological characteristics in virus-free plants favorite production of high tuber yield (Du et al., 1999; Chen et al., 2001). Furthermore, proline level, total nitrogen level and activity of nitrate reductase were found higher in virus-free plants than in virus-infected ones (Table 5), reflecting a high level of nitrogen metabolic activity in virus-free plants. Sweetpotato has in general high requirements for nitrogen and maintenance of a high level of nitrogen metabolic activity is necessary for obtaining high yield of tuberous roots (Hill et al., 1990; Ankumah et al., 2003). Starch phosphorylase is an essential enzyme for starch biosynthesis of tubers (Brisson et al., 1989; Oluoha and Ugochukwu, 1995). High activity of this enzyme is associated with rapid expansion of tubers, resulting in production of large root tubers (Brisson et al., 1989; Oluoha and Ugochukwu, 1995). All of the above discussed differences in vegetative growth and physiology between virus-infected and