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# Diseases of Peach and Nectarine in China

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## ABSTRACT

*Prunus persica* originated from China, where it has been cultivated for more than 3,000 years. Many diseases on peach and nectarine, both infectious and non-infectious, have been identified in China. Leaf curl, brown rot, anthracnose, gummosis, Leucostoma canker, scab, bacterial spot and crown gall are among the common ones. *Tobacco mosaic virus*, *Prunus necrosis ring spot virus*, *Prune dwarf virus*, *Apple chlorotic leaf spot virus* and *Peach latent mosaic viroid* have also been detected in China. The commonly used chemicals for disease control on peach and nectarine are bordeaux mixture, lime sulfur, mancozeb, carbendazim, and thiophanate-methyl. With increasing living standard, the consumer demand for higher quality and safer fruit is increasing, and more and more effort has been put into searching for effective biocontrol agents and active ingredients in herbal extracts.

**Keywords:** disease management, infectious disease, *Prunus persica*, stone fruit

## CONTENTS



## INTRODUCTION

Peaches and nectarines are important fruit crops worldwide. Both originated from China where they have been cultivated for more than 3,000 years (Qu and Sun 2000; Long 2000). "Tao" is a general term used in Chinese to represent peach (*Prunus persica* (L.) Batsch) and its variants, such as nectarine (*Prunus persica* (L.) Batsch var. *nucipercica*) and flat peach (*Prunus persica* (L.) Batsch var. *compressa* Bean). Although all of them have been cultivated in China for a long time, the commercial varieties of nectarine were not available until the 1990's. The breeding programs started in the 1980's using materials introduced mainly from the USA, Japan and some local varieties and nectarine varieties developed by the Institute of Forestry and Pomology, Beijing Academy of Agriculture and Forestry Sciences and Zhengzhou Institute of Pomology, Chinese Academy of Agricultural Science were released to growers in the 1990's. Meanwhile, flat peach varieties with good quality and better adaptation were selected from local materials and started to grow in many provinces. Currently, the "tao" grown in China in large quantities includes peach, nectarine, flat peach, and flat nectarine (**Fig. 1**). As "Tao" was used in Chinese references in most cases, we use the term "peach and nectarine" to represent it in this paper except when a specification was made in a Chinese reference.

Over the past 20 years, not only the production area, but also the total yield increased greatly in China. During the 1960s-1980s, the national annual production of peach and nectarine was 0.3-0.5 million ton (http://faostat.fao.org/site/567/Desktopdefault.aspx). Compared with 1986, the cultivation area and yield of peach and nectarine in 2006 increased about 2- and 10-fold, respectively. The total cultivation area and yield of these two crops reached 0.3 million ha and 7.5 million tons, respectively. These values are likely to remain stable or increase slightly in the next few years. Now, the total production of peach and nectarine in China ranks No. 1 in the world (http://www.fao.org/es/ess/top/commodity.html, http://faostat.fao.org/site/567/Desktop Default.aspx)

During production, crop losses from diseases are often encountered by growers. More than 80 diseases have been identified on stone fruit worldwide (Ogawa *et al*. 1995), and more than 30 of them have been identified in China. The research and the status of diseases of peach and nectarine in China are reviewed in this paper.

## DISEASES OF PEACH AND NECTARINE

Many infectious and non-infectious diseases have been identified in China. However, few reports are related to non-infectious disease. They were usually treated as nutrient disorders resulting from inadequate management. Therefore, in this paper, we will focus exclusively on the infectious diseases.

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Invited Review


**Fig. 1 Different peaches and nectarines grown in China.** (**A**) Peach 'Lvhua9'; (**B**) Nectarine 'Ruiguang19'; (**C**) Flat peach 'Ruipan2'; (**D**) Flat nectarine 'Youpan9'.

## Diseases caused by fungi

More than 25 fungal diseases have been identified on peach and nectarine in China. Among them, leaf curl, brown rot, anthracnose, gummosis, Leucostoma canker (Valsa canker) and scab are the most common ones (**Table 1**). Leucostoma occurs mainly in the northern part of China, such as Liaoning, Hebei, Shandong, and Shaanxi, where cold damage occurred more often due to the low temperature in winter. Scab is more severe in Liaoning, Shandong, Jiangsu and Chengdu area where it is more humid in the growing season (Wang and Zhuang 2001). However, very little information on these two diseases is documented.

**Leaf curl** caused by *Taphrina deformans* (Burk.) Tulasne is one of the important diseases on peach and nectarine (Cao 1997) occurring in many provinces in China (**Table 1**). It usually causes the dieback of new sprouts and early defoliation in summer (Li and Mou 1996; Cao 1997), leading to a reduction of yield and affecting the formation of flower buds in the following year. When the disease is severe, more than 80% (sometimes 100%) of leaves are infected and about a 50% reduction in yield had been reported (Liu and Ren 1991; Li and Mou 1996; Yang 1997; Zhang and Wang 1999; He *et al*. 2003; Zhao 2004; Wang *et al*. 2006; Ban *et al*. 2007).

In orchards, leaf curl occurs first on the early maturing varieties as their leaves expand earlier. In the southern part of China, such as Zhejiang province, the dieback of new sprouts occurs from late April to early May on the early maturing varieties, but in mid June on late maturing varieties. This disease is more severe on early maturing varieties than late maturing varieties (Liu and Ren 1991; Cao 1997; Zhang and Wang 1999; Wang *et al*. 2006) and it is also more severe on younger trees (Ban *et al*. 2007). The incidence of the disease was positively correlated with the amount of rainfall (Liu and Ren 1991; Li and Mou 1996; Yang 1997; Zhang and Wang 1999; He *et al*. 2003; Zhao 2004).

**Brown rot** caused by *Monilinia* spp. occurs widely in China (**Table 1**). The incidence of fruit rot ranges from 20 to 100% (Sun 2006; Mao *et al*. 2007). Although, several species, including *M. fructicola*, *M. laxa*, *M. fructigena* and *Monilia Polystroma* (Byrde 1977; van Leeuwen *et al*. 2002) have been reported to cause brown rot on pome and stone fruit worldwide, before 1998, only *M. laxa* and *M. fructigena* had been documented in China (Wang *et al*. 1998). *M. fructicola* was recently reported on peach and nectarine in China (Zhu *et al*. 2005). A recent survey showed that 53 isolates collected from peach with brown rot symptoms in Beijing, Shandong and Hebei areas all belonged to *M. fructicola* (Fan *et al*. 2007).

The survival of *M. fructicola* in China was investigated in peach and nectarine orchards in Beijing. Viable conidia of *M. fructicola* were detected on mummified fruits from mid-March to the end of April (the flowering period), and viable *M. fructicola* was consistently detected in peduncles and asymptomatic plant tissue of shoots collected in winter and spring (Zhong *et al*. 2007). Nevertheless, the sexual stage of *M. fructicola* has not been found in China (Zhong *et al*. 2005). Zhong *et al*. (2006) and Zhang *et al*. (2006) also studied the disease development pattern of brown rot in peach and nectarine orchards. No latent infections were detected on most varieties from early to mid growing season in orchards in the Beijing area, while various levels of latent infection were detected in late maturing varieties near harvest.

**Gummosis**, called 'Liujiaobing' in Chinese, is one of the most destructive diseases in China. It is more severe in the area along the Yangtze River and south of it. The incidence of gummosis lies between 30 and 40%, but may reach 90% in poorly managed or replanted orchards (Jin *et al*. 2000; Luo *et al*. 2005).

In general, two kinds of gummosis were reported. One was attributed to abiotic factors, such as insect damage, wounding, heavy pruning and heavy clay soil conditions (Chen *et al*. 1989; Jin *et al*. 2000; Cao 2003; Zhang *et al*. 2004; Wang 2005). The other with blister or wart symptoms at early stage was attributed to fungal infections of *Botryosphaeria dothidea* (Jin *et al*. 2000).

Fungal gummosis was first reported in China in early 1980's, and the causal fungus was reported to be *Macrophoma* sp. in a preliminary experiment (Chen 1982) and *Botryosphaeria ribis* (syn. *Botryosphaeria dothidea*) without any pathogenicity test data (Cao *et al*. 1982). The pathogen of gummosis in Chongqing was identified as *B. dothidea* (Luo *et al*. 2005). Wu *et al*. (1985) studied peach gummosis disease in Shanghai and identified the pathogen as *Physalospora persicae* (the imperfect stage was described as *Macrophoma* sp.) following the identification of the fungus done by Japanese. Chen (1985) and Luo *et al*. (2005) confirmed that *B. dothidea* was the cause of the gummosis following Koch's postulates. Other reported fungal pathogens for gummosis were *Leptosphaeria* sp. and *Cucurbitaria* sp. (Zhang *et al*. 1994). *B. dothidea* is generally accepted as the pathogen that causes gummosis (IPCAAS and CRICAAS 1994).

**Table 1** Fungal diseases of peach and nectarine in China.

| Plant disease | Pathogen | Location (Province/city) | References |
|---|---|---|---|
| Anthracnose | *Gloeosprorium laeticolor* *Gloeosprorium serotinum* | Zhejiang, Fujian, Liaoning, Hebei, Guizhou, Sichuan, Jiangsu | Xiang 1957; Dai *et al*. 1958; Wei *et al*. 2000; Wei *et al*. 2004 |
| | No report of pathogen | | Gu *et al*. 2006; Hua *et al*. 2007; Li 2007 |
| Black spot | *Alternaria alternata* | Hebei | Zhang *et al*. 1995 |
| Brown rot | *Monilinia laxa*; *Monilinia* spp.; *Monilia cinerea* | Beijing, Shandong, Hebei, Gansu, Xinjiang, Zhejiang, Sichuan, Yunnan, Jiangsu, Fujian | Xiang 1957; Dai *et al*. 1958; Chen *et al*. 2003; Lin *et al*. 2004; Chen *et al*. 2007 |
| | *Monilinia fructicola* | Beijing | Zhu *et al*. 2005 |
| | No report of pathogen | Liaoning, Guizhou | Luo 1995; Sun *et al*. 2006; Sun *et al*. 2006; Feng 2007; Mao *et al*. 2007 |
| Canker | *Phomopsis eres* | Jiangxi | Liu and Tang 1995 |
| Fruit rot | *Alternaria tenuis*; *Aspergillus luchuensis*; *Cephalothecium roseum* | Sichuan | Xiang 1957 |
| | *Phomopsis amygdalina Canonaco* | Sichuan, Anhui | Xiang 1957; Dai *et al*. 1958; Ye and Pu 2004 |
| Gray mold | *Botrytis cinerea* | Zhejiang, Shandong, Liaoning | Xiang 1957; Fei *et al*. 1998; Wang and Wang 2001; Zhao *et al.* 2007; Wang *et al*. 2007 |
| Gummosis | *Botryosphaeria dothidea* (*B. ribis*) | Fujian, Chongqing | Dai *et al*. 1958; Jin 2000; Luo *et al*. 2005 |
| | No report of pathogen | Shanxi, Zhejiang, Jiangsu, Shandong | Ma *et al*. 1996; Cao 2003; Zhang 2004; Wang 2005; Sun and Zhou 2006 |
| Leaf curl | *Taphrina deformans* | Liaoning, Shaanxi, Tibet, Sichuan, Yunnan, Guizhou, Shandong, Anhui, Jiangsu, Zhejiang, Fujian | Xiang 1957; Dai *et al*. 1958; He *et al*. 2003; Huang and Jiang 2005 |
| | No report of pathogen | Xinjiang, Jiangxi, Hebei, Hubei | Zhu 1985; Wu 1989; Liu and Ren 1991; Guo 1993; Cai 1995; Lu *et al*. 1996; Liu and Li 1997; Qiu and Yu 1997; Yang 1997; Zhao 1997; Jiang 1999; Zhang and Wang 1999; Xue *et al*. 2003; Wang *et al*. 2006; Ban *et al*. 2007 |
| Leaf spot | *Mycosphaerella pachyasca* | Shandong | Dai *et al*. 1958 |
| Leucostoma canker | *Leucostoma persoonii* (*Valsa leucostoma*) | Hebei, Xinjiang, Shandong | Dai *et al*. 1958 |
| Leucotelium white rust | *Leucotelium pruni-persicae* | Tibet, Sichuan, Yunnan, Guizhou, Hunan, Anhui, Jiangsu, Guangdong | Dai *et al*. 1958 |
| Postharvest fruit rot | *Trichothecium roseum* | Sichuan | Dai *et al*. 1958 |
| Powdery mildew | *Podosphaera leucotricha*; *Podosphaera tridactyla* | Beijing, Hebei, Yunnan, Guangdong | Xiang 1957; Dai *et al*. 1958 |
| Rhizopus rot | *Rhizopus nigricans* *Rhizopus artocarpi* | Liaoning, Sichuan | Dai *et al*. 1958 |
| Ring rot | *Macrophoma kawatsukai* (*Physalospora piricola*) | Sichuan | Xiang 1957 |
| Rust | *Tranzschelia pruni-spinosae* | Sichuan, Yunnan, Hunan, Jiangsu, Jiangsu, Jiangxi, Fujian, Guangdong, Guangxi | Dai *et al*. 1958 |
| Scab | *Cladosporium carpophilum* *Cladosporium padi* | Hebei, Tibet, Sichuan, Shandong, Jiangsu, Guangdong, Fujian | Xiang 1957; Dai *et al*. 1958 |
| | No report of pathogen | Anhui | Li *et al.* 2006; Sun 2007 |
| Shot hole | *Cercospora circumscissa* | Guangdong, Hebei, Sichuan, Yunnan, Jiangsu, Fujian, Guangxi | Xiang 1957 |
| | *Cylindrosporium padi* | Tibet, Fujian | Dai *et al*. 1958 |
| | *Wilsonomyces Clasterosporium carpophilum* | Tibet, Anhui | Dai *et al*. 1958 |
| | No report of pathogen | Shanxi | Cao 2003 |
| Sooty mould | *Fumago vegans* | Yunnan, Jiangsu, Guangdong, Guangxi | Dai *et al*. 1958 |
| Southern blight | *Athelia rolfsii* (syn. *Corticium centrifugum*) | Sichuan | Dai *et al*. 1958 |
| White mold | *Cercosporella persicae* | Liaoning, Tibet, Jiangsu, Guangdong | Dai *et al*. 1958 |
| Wood rot | *Fomes fulvus* | Hebei, Shandong, Jiangsu | Dai *et al*. 1958 |
| Plaster disease | *Septobasidium bogoriense* | Zhejiang, Sichuan | Xiang 1957; Dai *et al*. 1958 |
| Round spot disease | *Coniothyrium nakatae* | Shanxi, Shandong | Dai *et al*. 1958 |
| Other diseases | *Fusarium avenaceum* *Fusarium cerasi* *Fusarium lateritium* (*Gibberella baccata*) | | Dai *et al*. 1958 |
| | *Nothopatella chinensis* | Hebei | Dai *et al*. 1958 |
| | *Phyllosticta persicae* | Hebei, Beijing | Dai *et al*. 1958 |

The development pattern of gummosis in China was studied by Chen (1985). The conidia of *B. dothidea* were rubbed onto newly developed sprouts and the inoculation was performed periodically starting from late April with 7-10 days intervals. Results showed that 10-50% of sprouts inoculated between late April to late May developed symptoms of gummosis after 43-84 days, while 90-100% of sprouts inoculated between early June to early July developed symptoms after 14-82 days. Sprouts inoculated in late July did not develop gummosis symptoms by the end of the season. Chen (1985) then concluded that the pathogen can invade new sprouts from late April to early July. The fungal pathogen, *B. dothidea*, was found to invade the sprouts mainly through wounds and lenticels and the new sprouts were more susceptible to infection than old ones (Chen 1985; Yu *et al*. 2001). Chen (1985) also studied the spore dynamics in the field and found that the density of spores in the field was positively correlated to the amount of rain fall. The two time periods with high incidence of gummosis development in China were from late May to late June, and early August to early September (Chen 1985).

The resistance of peach varieties to gummosis has been investigated by several groups. Zhao *et al*. (1994) found that peach varieties with white flowers tend to be more resistant. The investigation of 273 varieties from the Nanjing Germplasm Collection showed that '*Tianjinshuimi*', '*Baisha*', '*Zhouyehuanglu*', and '*Dahonghua*' were highly resistant, but none of them were immune to gummosis (Zhao *et al*. 1996). Ma *et al*. (1996) studied the inheritance pattern of resistance by investigating the offspring resulting from crosses between varieties with different degrees of resistance. The levels of resistance of offspring ranged from susceptible to highly resistant. It was then concluded that resistance to gummosis was inheritable. Yu *et al*. (2001) tested the activity of phenylalanine ammonia-lyase (PAL), peroxidase, polyphenol oxidase, and the contents of chlorogenic acid and lignin in inoculated leaves of peach varieties with different levels of resistance. Result revealed that the resistance of peach to gummosis was closely related to the activity of these three enzymes, whose activity was, therefore, suggested to be regarded as a physiological and biochemical index for screening peach resistance to gummosis (Yu *et al*. 2001). The activities of polyphenol oxidase and peroxidase also increased in leaf tissues after the application of carbendazim or Liujiaoling (a chemical used to control gummosis) (Zheng *et al*. 2006).

**Anthracnose** caused by *Colletotrichum* spp. is serious on peaches in greenhouses (Gu *et al*. 2006). The levels of resistance among different peach varieties to anthracnose varied greatly (Wei *et al*. 2000, 2004; Hua *et al*. 2007; Li 2007). In general, the late maturing peach varieties were more resistant to anthracnose than the early maturing ones. The very early maturing varieties were the most susceptible ones followed by the early maturing varieties and the late varieties. In recent years, gibberellin (GAs) has been used to increase fruit setting and fruit size, and to shorten the growth stage. The dose of GA was increased from 67 to 133 mg/L, sometimes even to 200 mg/L (Gu *et al*. 2006). The misuse of GA lead to the over-flourishing of trees with distorted fruit, fruit with a soft core, large, yellow and thin leaves, and poor ventilation which favors the infection of pathogens (Gu *et al*. 2006).

## Diseases caused by bacteria

The two important bacterial diseases are bacterial spot and crown gall. Bacterial spot caused by *Xanthomonas campestris* pv. *pruni* was listed as a nation-wide/common pathogen in local pest management calendars (Zhao *et al*. 2007). The pathogen mainly attacks leaves, but also can infect fruit and small branches. Two kinds of spots usually developed on branches after infection. One is called spring canker and the other called summer canker. The spring canker could develop to 1-10 cm, and played an important role in disease dissemination (Cao 1997).

**Crown gall** caused by *Agrobacterium tumefaciens* (Smith & Townsend) Conn is an important root disease occurring in the peach production areas, such as Liaoning, Jilin, Inner-Mongolia, Beijing, Hebei, Shanxi, Shandong, Henan, Jiangsu, Zhejiang, Shaanxi, Anhui and Fujian provinces, Shanghai city and Guangxi Zhuang autonomous Regions (Cao 1997; Fei *et al*. 2002; Tu 2002; Gong 2003; Huang *et al*. 2004; Tao 2004; Xu *et al*. 2006). Because crown gall could only be found in some restricted orchards, it was regarded as an inter-province quarantine pest in some provinces. A survey reported that 30-40% of trees were infected in northern China (Chen *et al*. 2002) and approximately 3800 ha of orchards were affected in Beijing suburbs (Tao *et al*. 2004). In some cases, up to 80% of plants were infected leading to the death of a large amount of seedlings (Yang *et al*. 2004).

## Diseases caused by viruses or viroids

Although more than 40 viruses and virus-like agents infecting *Prunu*s spp. have been identified worldwide (Ogawa *et al*. 1995). So far, only four virus- and one viroid-causing diseases on peach and nectarine have been identified in China. They are *Tobacco mosaic virus* (TMV), *Prunus necrosis ring spot virus* (PNRSV), *Prune dwarf virus* (PDV), *Apple chlorotic leaf spot virus* (ACLSV) and *Peach latent mosaic viroid* (PLMVd). More diseases caused by viruses or viroids are likely be found when further investigations are carried out.

There are a few reports related to TMV and PEV on peach and nectarine. TMV was isolated and identified from peach trees with red leaf symptoms based on ELISA tests in 2000 (Liu *et al*. 2000). PDV was detected in 1.4% of peach samples from Shaanxi orchards in a survey done in 1995-1996 (Ruan *et al*. 1998).

PNRSV was found first in a stone fruit germplasm preservation plot of the Beijing Academy of Agriculture and Forestry Sciences. Later on, it was subsequently detected in Shaanxi, Hebei, Sichuan and Liaoning provinces, Beijing city, and Xinjiang Uigur Autonomous Region (**Table 2**) (Ruan *et al*. 1998; Ma 2003; Liu *et al*. 2004; Hou 2005; Dai 2006). Meanwhile, in order to obtain virus-free meristems and differential medium for cultivation of grafted scions, thermotherapy was established for commercial production (Li *et al*. 1996). The genetic variations among isolates of PNRSV from China were revealed by analysis of the coat protein (*cp*)-gene sequence. Results showed that Beijing isolates belonged to Group I, the severe pathotype, while Hebei isolates belonged to Group II, the mild pathotype (Ma 2003). Furthermore, PNRSV-specific antiserum was obtained and the titer was determined to be 1:1024 by ACP-ELISA which provided the basic conditions for serological detection of PNRSV (Chen *et al*. 2006).

PLMVd infection on peach was first described in 1996 (Wang *et al*. 1996). The disease was named peach latent mosaic disease or peach (yellow) mosaic disease. Subsequently, 1.0% of peach trees with similar symptoms were observed during a survey conducted in orchards in Shaanxi during 1995-1997 (Ruan *et al*. 1998). Peach samples from Liaoning, Hebei, Shandong and Shaanxi provinces were identified as PLMVd both by artificial inoculation of the woody indicator plant GF-305 and by dot-hybridization (Zhang *et al*. 2000). An infection rate of 22.9% of PLMVd was detected in Sichuan and Hubei provinces by tissue-printing and dot-hybridization (Liu *et al*. 2004). A year later, PLMVd was detected by RT-PCR and molecular hybridization techniques in peach samples from Wuhan, Hubei province. A reliable procedure of tissue-printing blot for PLMVd detection in batch samples was developed. Further studies on the PLMVd isolate P3 from peach variety '*Yuhualu*' were conducted. The RT-PCR products were collected and cloned into pMD18-T for sequencing. The full-length cDNA showed 90-96% homology with that of previously reported isolates (Xu *et al*. 2005). Furthermore, 8 cDNA clones were analyzed in the improved SSCP and

**Table 2** Incidence of PNRSV and PDV on peach and nectarine in past decade.

| Province or city | Author | Percentage incidence (%) | | Technique used | Year |
|---|---|---|---|---|---|
| | | PNRSV | PDV | | |
| Beijing | Ma YX | 30 | – | DAS-ELISA | 2003 |
| Beijing | Hou YL *et al.* | 100 | 100 | RT-PCR | 2005 |
| Hebei | Ma YX | 4.2 | – | DAS-ELISA | 2003 |
| Liaoning | Hou YL *et al.* | 100 | 100 | RT-PCR | 2005 |
| Shaanxi | Ruan XF *et al.* | 35.1 | 1.4 | DAS-ELISA | 1998 |
| Sichuan | Liu X *et al.* | 5.7 | 11.4 | DAS-ELISA | 2004 |
| Xinjiang | Dai ZX *et al.* | + | – | RT-PCR | 2006 |

PAGE to evaluate their potential in viriod characterization and genetic diversity study. The genetic diversity within PLMVd field isolates from peach showing different symptoms was further investigated to reveal the relation between sequence variation and symptoms incited (Xu *et al*. 2006, 2007).

ACLSV was first detected from 2 peach samples from northern China in 1998 (Ruan *et al*. 1998). An incidence as high as 60% in peach samples was subsequently detected in Sichuan province during a survey conducted in 2004 (Liu *et al*. 2004). The ACLSV isolates from China were studied by Zheng *et al*. (2007). The *mp* (mobile protein) and *cp* genes were analyzed and the 46 kDa fusion protein was expressed effectively and showed positive immonogenicity to polyclonal antibody.

### Diseases caused by nematodes

So far, only root-knot nematode (*Meloidogyne* sp.) was reported from peach and nectarine in China. Root-knot nematode was detected in peach orchards in Sichuan, Fujian province (Zhang 1996). Study of the resistance to root-knot nematodes suggested that the resistance was controlled by the species-specific major genes and that the phenomenon was stable for years, while resistance at the strain level was variable. Zuo *et al*. (1988) found that a peach line from Henan province in central China showed high resistance to root-knot nematodes, which was promising material for root stock breeding. Ye *et al*. (2006) found that Zhubo No. 4 and Zhubo No. 5, the rootstock materials from Japan, were immune to *Meloidogyne incognita* and no segregation was found among seedlings, but segregation in resistance was found among *Prunus tomentosa* seedlings, and both immune and resistant phenotypes were present. In this survey, similar situations were also found among seedlings of *P. persica*, not only resistant but also susceptible phenotypes were present. However, no further study has been published.

## DISEASE CONTROL AND RELATED RESEARCH

In general, fungicide application is still one of the most effective control measures in the production of peach and nectarine. Bordeaux mixture and lime sulfur were widely used for controlling peach leaf curl, brown rot, anthracnose, fungal gummosis, shot hole disease, etc. (Li and Mou 1996; Lu *et al*. 1996; Zhao 1997). As the preparation of these two fungicides are time-consuming and labor intensive, it is inconvenient for most small growers to use. Therefore, researchers put more effort in screening more effective and easy-to-use chemicals. The fungicides listed in **Table 3** are the primary ones that have shown effective control of diseases on peach and nectarine. Among them, mancozeb, carbendazim, and thiophanate-methyl are the popular ones currently used by growers.

Due to an increase in living standards, consumer demands for quality and safety of fruit have increased. This leads to changes in disease management towards production of safer fruit with less toxic and environment friendly chemicals. Consequently, the production of organic fruit was boosted, and integrated pest management was stressed more than before, and more effort was put into searching for alternative methods, such as using physical barriers, effective biocontrol agents and herbal extracts. As a result, fruit bagging has been widely applied to the high value late maturing varieties by growers (Lin *et al*. 2004; Hua *et al*. 2007). The extracts from some Chinese herbs and other plants, such as wintergreen (*Pyrola rotundifolia*) giant knotweed (*Rhizoma polygoni*), *Magnolia officinalis*, usnea (*Usnea montis-fuji*), *Conyza bonariensi*, *Conyza Canadensis*, etc. were shown to restrict the development of brown rot (Li *et al*. 2004; Ai *et al*. 2006; Wu *et al*. 2006, 2007; Yu *et al*. 2007; Liu and Xu 2008). The inhibitory effect of chitosan on *Monilinia fructicola* and *Rhizopus* sp. was also studied *in vitro* (Li *et al.* 1997; Li and Li 2002).

Researches on biological control of crown gall were

**Table 3** Fungicides used to control diseases of peach and nectarine.

| Disease | Bordeaux mixture | Lime sulfur | Mancozeb | Carbendazim | Thiophanate-methyl | Difenoconazole | Chlorothalonil | Thiram, urbacide, ziram | Copper abietate | Other fungicides used in control | Reference |
|---|---|---|---|---|---|---|---|---|---|---|---|
| anthracnose | + | + | + | + | + | + | | + | | Bromothalonil, myclobutanil, prochloraz-manganese chloride complex | Sun *et al*. 2006; Hua *et al*. 2007 |
| brown rot | + | + | + | | | + | | | | Tebuconazole, propineb, flusilazole, fenbuconazole, triflumizole, pyrimethanil, iprodione, benomyl, streptomycin | Sun 2006; Sun *et al*. 2006; Chen *et al*. 2007 |
| gummosis | + | + | | + | | | | + | | Quicklime, HA-Cu | Cao 2003; Zheng *et al*. 2006 |
| leaf curl | + | + | + | + | + | | + | + | | Jinggangmycin; copper sulphate; barium sulphide; Dowicide G; triadimefon | Li and Mou 1996; Lu *et al*. 1996; Qiu and Yu 1997 Zhao 1997 |
| peach black scab | | + | + | + | + | | | | + | Flusilazole, zhongshengmycin | Yi *et al*. 2000; Sun and Gong 2007 |
| bacterial shot hole | + | + | | | | | + | | + | Ningnanmycin, oxine-copper, streptomycin, zhongshengmycin | Yi *et al*. 2000; Feng *et al*. 2003; Liu *et al*. 2006 |

carried out by scientists in China Agricultural University, Nanjing Agricultural University and the Institute of Micro-organisms, Chinese Academy of Science. The efficacy of biological agent E26, a nonpathogenic strain of *A. vitis* isolated from the crown gall of grapevine, was compared with K84 (Ma and Wang 1995; Liang *et al*. 2001). Experiments done in the greenhouse showed that E26 had a broader inhibition spectrum and could inhibit 85.7% of the tested strain of *A. tumefaciens*. Result of agrocin assay indicated that agrocin production was a stable property of E26 (Wang *et al*. 2003). A protocol was developed for the isolation and purification of agrocin of E26. The purified agrocin was very stable and strongly inhibitory to the tested pathogens including 17 crown gall isolates from diverse hosts and the pathogens in the genus of *Pseudomonas*, *Xanthomonas* and *Erwinia* (Li *et al*. 2004). The efficacy of some antibiotics and chemicals was also tested for the control of crown gall disease in lab and in the field. Sodium dichloroisocyanruate, sodium hypochlorite, ethylicin, tobramycin, ciprofloxacin, gentamycin and their mixtures had significant control effects (Luo *et al*. 2004).

Eight bacterial strains antagonist to *M. fructicola* were isolated from soils in Pinggu, Beijing (Yang *et al*. 2006). The antagonist bacteria were found to disrupt the super-micro-structure of *M. fructicola* (Li 2000; Yang *et al*. 2006). The effect of *Bacillus subtilis* (B-912) on the control of post harvest brown rot of peach and nectarine was also studied (Fan *et al*. 2000).

## SUMMARY

A literature survey on diseases of peach and nectarine in the past 30 years in China revealed that there was an uneven distribution of research work in this field. For example, among the 110 references, 62% of them were on disease control, and 18% were related to disease diagnostics, 4% to host resistance and 3% to disease development pattern. More-over, most of the research work on disease control was aimed at screening effective fungicides, biocontrol agents or herbal extracts. This indicated that there is a strong demand for information on effective control of diseases. There is a great shortage of basic studies related to disease survey and disease development patterns due to the shortage of funding, especially from the central government, on studies related to fruit pest protection. The limited funding from local government can barely meet the demand of solving problems directly related to the fruit production, therefore, the number of scientists working on fruit disease have greatly declined in the past 10 years. Information on infection dynamics, pathogen survival in orchards and disease epidemics are essential for effective control of the disease, because such information can guide growers to apply control measures wisely and efficiently. Although the development patterns of most diseases have been investigated in other countries and the information are available as references, the development of each disease may differ geographically due to the differences in weather conditions and cultural practices.

More funding should be set up to encourage collaboration between different research groups. Under the current system, in many cases, publications from different research groups frequently contained similar research work. Sometimes the reported results were greatly different, but there were no follow-up studies to resolve the differences. Co-operation among different research groups working on a nation-wide disease can provide a better picture of a disease. We can expected that more research papers on fruit diseases will be published in the near future since, as of last year several big projects relating to fruit protection were set up by the Ministry of Agriculture and more are expected in the next four years.

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