PITAYA DISEASES IN TAIWAN

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ABSTRACT

Pitaya (or dragon fruit) including white-fleshed and red-fleshed species have become a common commodity of fruit in Taiwan; in 2015, the total cultivated area was more than 2,000 hectares. The crop protection of pitaya was initiated at the end of last century. A pitaya viral disease caused by Cactus virus X had been first reported in Taiwan in 2001. Another two viruses: Zygocactus virus X and Pitaya virus X involved in the viral diseases were found in the later studies. A fungal disease caused by Bipolaris cactivora leading to fruit decay was reported in 2005, but B. cactivora has not ever been prevalent in Taiwan. Anthracnose caused by Colletotrichum gloeosporioides, C. truncatum, and/or C. boninense often affected postharvest pitaya fruits. Some fungi such as Alternaria sp., Diaporthe/Phomopsis complex, Penicillium sp., and Rhizopus stolonifer were occasionally isolated from rotten fruits. The infections of Lasiodiplodia theobromae and/or Fusarium oxysporum were reported to give rise to fruit rot. Stem canker and fruit spot caused by Neoscytalidium dimidiatum and wet rot caused by Gilbertella persicara also lead to postharvest fruit rot. Sooty mold induced by Cladosporium cladosporioides and/or Phaeosaccardinula javanica were usually relevant to Hemiptera insects. In addition, cactus cyst nematode (Cactodera cacti) was found infectious to pitaya, but its host range was restricted in few species of Cactaceae. N. dimidiatum causing stem canker has damaged severely to pitaya production and the disease has world-wide spread as a limit factor of dragon fruit growing. The general strategies for disease management include the use of pathogen-free seedlings, field sanitation, avoiding spray watering, and chemical application. Some control agents for organic farming, Bordeaux mixture for example were used and the further tests are in progress.

INTRODUCTION

Pitaya or dragon fruit including species of Hylocereus undatus Britton & Rose with white flesh, H. polyrhizus (Weber) Britton & Rose with red flesh, and H. costaricensis (Weber) Britton & Rose with purple flesh have become a common commodity of fruit in Taiwan. Total cultivated areas were around 1,676 hectares in 2014 and 2,032 hectares in 2015. The annual production in 2015 was about 38,965 tons valuing US$85 million, in which 170 tons were exported. The domestic pitaya industry is facing various challenges including the over expanding of cultivated area and yield in Taiwan, the commodity price competition with Vietnam and Malaysia, the quarantine requirements for Japanese market, and the boosting of pitaya plantation in China (Yu 2015).

To ensure the production with quality and safety, pitaya cultivation should be integrated with pest management. The pitaya protection projects concerning with identification of disease causal agents were initiated in Taiwan at the end of last century. Some recent advances in researches conducted in Taiwan will present in this report.

Viral Diseases

In 1999, plants of H. undatus showing systemic mottle on the stem were found and a flexuous rod-shaped virus was isolated from diseased samples. The virus had been identified as a strain of Cactus virus X (CVX) by host range and serological analysis (Liou et al., 2001). CVX that originally infected plants of Cactaceae is a potexvirus reported in Europe and USA in the 1960s (Bercks 1971; Brandes and Wetter 1959; Casper and Brandes 1969). In nature, CVX is transmitted by sap or grafting. The virus experimentally inoculated to Celosia argentea causing chlorotic spots, and to Gomphrena globosa, Chenopodium amaranticolor, C. quinoa, C. murale causing necrotic lesions. Filamentous virus particles with 490-510 × 13 nm were observed in diseased tissues (Liao et al. 2003). Antisera against CVX isolates were prepared (Liao et al. 2003; Liou et al. 2004b), by which ELISA techniques for virus detection was developed, especially for those applied to virus survey and indexing of pitaya seedlings. Molecular identification with complete nucleotide sequence of CVX was
determined (Liou et al. 2004a). By use of indirect ELISA to detect the CVX in different tissues of pitaya, Liao et al. in 2003 indicated that virus contents were higher in young shoots or parts with initial symptoms of chlorotic spots and/or mottling than those in pulp or peel with necrosis or yellows. The result of a survey in 2003 revealed that the incidence of CVX was ranged 50-90% in Taiwan. The virus distributed widely even reached Kinmen, Taiwan’s outer island near China.

CVX had existed in Taiwan before the first report of CVX on *H. undatus* was published by Liou, et al. in 2001 (Chen and Wang 1982; Chen and Tzeng 1996). The earliest record of CVX on pitaya was issued by Shinkai and Natsukai in 1997. However, the potexvirus isolated from *H. undatus* had been characterized early (Fudi-Allah et al. 1983). Up to date, occurrence of CVX on *Hylocereus* spp. are recorded as follows: Brazil (Duarte et al. 2008), Indonesia (Wibowo et al. 2011), Korea (Chung et al. 2012), and China (Peng et al. 2016). Although it is not yet to be reported, CVX may already exist in pitaya plantations in Mexico (Valencia-Botín et al. 2013). In addition to CVX, other cactus-infecting potexviruses might also exist in most of pitaya growing areas in the world.

The genus *Potexvirus* reported to infect pitaya (*H. undatus*) includes 4 species: *Cactus virus X* (CVX) (Liou et al. 2001; Liao et al. 2003; Liou et al. 2004a, 2004b), *Zygocactus virus X* (ZyVX) (Mao et al. 2007), *Pitaya virus X* (PiVX) (Li et al. 2010) and *Schlumbergera virus X* (SchVX) (Duarte et al. 2008). ZyVX infecting pitaya is the first report in Taiwan (Mao et al. 2007). PiVX was recognized as a new potexvirus infecting pitaya and the name was designated on the basis of complete nucleotide sequence (Mao 2008; Li et al. 2010). Accordingly, the multiplex RT-PCR for simultaneously detecting CVX, ZyVX and PiVX was developed by Chang et al. (2015). To reduce the cost and time for virus detection, the modified multiplex RT-PCR was applied, in which a rapid extraction solution was adopted to simplify the procedure of RNA extraction.

**Stem canker**

Pitaya stem canker caused by *Neoscytalidium dimidiatum* (Penz.) Crous & Slippers was first found in September 2009 and it was spread widely in Taiwan (Chuang et al. 2012). Diseased plants showed small, circular, sunken, orange spots on the stems and that subsequently develop into cankers. From the surface of the cankers, pycnidia of *N. dimidiatum* were erumpent and the stems became rotten. Colonies grew and produced abundant dark gray to black aerial mycelia by plating infected tissues on acidified potato dextrose agar and incubated at room temperature for 1 week. Hyphae are branched, septate, and brown, from which 0- or 1-septate arthrospores were born.

Stem canker is a recently emerging disease that has spread rapidly to all planting areas in the world and limits the production most. Since the first report was publicized by Chuang et al. (2012) in Taiwan, *N. dimidiatum* causing stem or fruit canker of pitaya has been recorded in China (Lan et al. 2012; Yi et al. 2013; Yi et al. 2015), Malaysia (Mohd et al. 2013; Mohd et al. 2015), Israel (Ezra et al. 2013), Thailand (Athipunyakom et al. 2015), Vietnam (Hieu and Hoa 2015), Indonesia (Muas and Jumunidang 2015) and USA (Sanahuja et al. 2016). The control strategies include the use of disease-free seedlings, field sanitation, avoiding spray watering, and fungicide applications. Mycelia growth was effectively inhibited by cyprodinil + fludioxonil, azoxystrobin + difenoconazole and tebuconazole. Spore germination was inhibited by 80% metiram, 50% trifloxystrobin, pyraclostrobin, azoxystrobin, azoxytrobin + difenoconazole and iminoctadine. These fungicides have been recommended for the control of anthracnose of pitaya, and could also be used to control stem canker of pitaya in the field (Ni et al. 2013; Ni et al. 2015).

**Wet rot**

Flower and fruit wet rot of pitaya caused by *Gilbertella persicaria* (Eddy) Hesseltine was first found in August 2009 as a new record in Taiwan (Lin et al. 2014a). It is one of the major diseases that led to great loss on pitaya production in Taiwan (Lin et al. 2015). The disease occurred mainly during rainy season, and the pathogen could affect flowering, fruiting and storage of fruits. Necrotic and rotten symptoms appeared on infected flower buds and petals. Young fruits with necrosis or internal black rot were observed and that were failed to develop and dropped prematurely. The mature fruits were water-soaked and soft rot during the postharvest period. Under humid conditions, white to black sporangia could be observed on the surface of infected tissues.

The occurrence of *Gilbertella persicaria* on pitaya was also reported in Japan (Taba et al. 2011) and China (Guo et al. 2012). The similar symptoms of dragon fruit rot were observed in Taiwan but the pathogen was previously identified as a *Rhizopus stolonifer* (Tsai et al. 2010). Not only in Taiwan, *R. stolonifer* causing fruit rot also reported in Japan (Taba et al. 2005) and Thailand (Oeurn et al. 2015). However, after the reexamination, Tsai’s specimen was verified to be identical to *Gilbertella persicaria* based on morphological and molecular
characteristics (Lin et al. 2014a). Isolates causing pitaya wet rot were named as *G. persicaria* var. *pitaya*, which could be discriminated from holotype of *G. persicaria* by their split sporangial walls, internal transcribed spacer (ITS) sequences and virulence to fruits of pitaya (Lin et al. 2015).

To control the disease, using chemicals such as cyprodinil + fludioxonil and tebuconazole before and after raining is essential. Immediately remove the infected tissues from the orchards can efficiently reduce the pathogen inocula. Harvesting in the raining day should be avoided. Storing the fruits below 12 °C can reduce the disease incidence and assure a good quality.

**Postharvest diseases**

1. **Anthracnose caused by Colletotrichum spp.**

Postharvest fruits of pitaya are also affected by some diseases, which will reduce the market value by showing spots and/or necrosis on the fruit surface or shorten the shelf life due to the fruit water-soaking and rotting. Based on the survey of pitaya orchards during 2009-2013, anthracnose caused by *Colletotrichum* spp. is one of the major diseases of postharvest pitaya in Taiwan (Lin et al. 2014b; 2014c). Symptoms of diseased fruits appeared as brown colored sunken spots, with or without water-soaked necrosis on the peels (Fig. 1). At least 3 groups of *Colletotrichum* species were involved in causal agents of anthracnose, i.e. *C. gloeosporioides* species complex, *C. truncatum*, and *C. boninense* species complex. The isolation frequency were 73.4% (*C. gloeosporioides*), 21.8% (*C. truncatum*) and 4.8% (*C. boninense*), respectively.

![Fig. 1. Pitaya fruit anthracnose caused by *Colletotrichum gloeosporioides* (A), *C. truncatum* (B), and *C. boninense* (C).](image)

Anthracnose caused by *C. gloeosporioides* (Penz.) Penz. & Sacc. on pitaya had been reported in Japan (Taba et al. 2006), USA (Palmateer et al. 2007), Brazil (Takahashi et al. 2008), Malaysia (Masyahit et al. 2009), China (Ma et al. 2014), Indonesia (Muas and Jumjunidang 2015), Thailand (Athipunyakom et al. 2015) and Vietnam (Hieu and Hoa 2015). Occurrence of *C. truncatum* (Schwein.) Andrus & W.D. Moore had been reported in China (Guo et al. 2014), Thailand (Athipunyakom et al. 2015; Meetum et al. 2015) and Malaysia (Vijaya et al. 2015; Mohd et al. 2015). Some other species of *Colletotrichum* were also reported to infect pitaya in Thailand (Meetum et al. 2015).

**Fruit rot**

Depending on cultivation and storage conditions, some other postharvest diseases are also important to the marketability of pitaya, including fruit rot caused by *Bipolaris, Phomopsis*, or *Fusarium*, black rot caused by *Lasiodiplodia*, brown spot caused by *Neosygalidium*, and green mold caused by *Penicillium*. Symptoms of *Phomopsis* fruit rot caused by *Diaporthe/Phomopsis* complex were appeared with brown colored and water-soaking spots on the fruits (Fig. 2A). Symptoms of Fusarium fruit rot caused by *Fusarium* sp. were appeared colored brown and sunken spots on the surface like the initial symptoms of anthracnose but they were covered with white mycelium later (Fig. 2B). Black rot of fruit was caused by *Lasiodiplodia theobromae* (Pat.) Griffon & Maubl or *Neosygalidium dimidiatum*, their symptoms were also appeared with brown colored and needle-like spots on the surface of the fruits like those caused by *Phomopsis* but with less water-soaked spots (Fig. 2C). The symptoms of *N. dimidiatum* infected fruits would turn to black, dried, and mummy-like in the late stage of pathogenesis (Fig. 2D). Brown spot on pitaya fruit was caused by *Alternaria* sp., at room temperature the symptoms developed to brown, sunken spots and followed by covering with dark green mycelium mat (Fig. 2E). Green mold of pitaya fruit was caused by *Penicillium* sp. mainly, the white and sunken spots were appeared
when the infected fruits stored under low temperature (Fig. 2F).

![Image](image1.jpg)

**Fig. 2.** Postharvest disease of pitaya fruit caused by *Diaporthe/Phomopsis* sp. (A), *Fusarium* sp. (B), *Lasiodiplodia theobromae* (C), *Neosyntalidium dimidiatum* (D), *Alternaria* sp. (E), and *Penicillium* sp. (F).

Methods for protection of pitaya fruits from postharvest diseases are suggested as follows: 1) Bagging on young fruits after flower fading by use of clean and water-proof sack; 2) Applying fungicides during fruiting; and 3) Storing the fruits under 0-4°C. With these treatments, most of disease progress could be terminated and the severity would be lessened except brown spot caused by *Alternaria* sp. and green mold caused by *Penicillium* sp.

**Others**

1. **Fruit decay**

Fruit decay caused by *Bipolaris cactivora* (Petr.) Alcorn was the earliest record of pitaya fungal disease in Taiwan (Wang and Lin, 2005), but it has not ever prevalent in Taiwan (Lin et al. 2014c). Symptoms of infected fruits showing brown lesions and covered with brown to black conidia on the surface of fruits were observed (Fig. 3) (Lin et al. 2014c). Due to the discovery of *B. cactivora* causing fruit rot of dragon fruit imported from Vietnam, the vigilant quarantine measures are suggested to be adopted by Chinese authorities (He et al. 2012). The occurrence of *B. cactivora* on pitaya are also recorded in Japan (Miyahira et al. 2006; Taba et al. 2007), Israel (Ben-Ze’ev et al. 2011; Mizrahi 2015), USA (Tarnowski et al. 2011), Thailand (Athipunyakom et al. 2015; Oeurn et al. 2015), and Vietnam (Hieu and Hoa 2015).
2. Sooty mold

Sooty molds are flower buds or fruits covered with layers of dark green to black mycelia of fungi (Fig. 4A), and occasionally coloration of the fruits (Fig. 4B). Mycelia mass, induced by honeydew that secreted by insect or plant itself, appears to be a layer of black ash to cover the tissues. The causal fungi of the sooty mold are Cladosporium cladosporioides (Fresen.) G. A. deVries (unpublicized data), and/or Phaeosaccardinula javanica (Zimm.) W. Yamam (Yeh et al. 2016). They are saprophytic fungi that do not invade the host directly, but they take the honeydew secreted by Hemiptera insects as nutrients. Pitaya fruits contaminated by sooty mold would be seriously affected to their marketability. Rationalized fertilization, sufficiently watering, and controls of mealy-bugs and aphids in the field can reduce the incidence of sooty mold (Yeh et al. 2016).

CONCLUSIONS
The major diseases occurred on pitaya in Taiwan are listed in Table 1, containing the viral diseases caused by 3 species of viruses, fungal fruit rot caused by Bipolaris, Alternaria, Fusarium, Phomopsis, and Penicillium, anthracnose caused by Colletotrichum spp., wet rot caused by Gibberella persicara, and stem canker caused by Neoscytalidium dimidiatum. Nevertheless, Phaeosaccardinula javanica causing sooty mold and cactus cyst nematode (Cactodera cae) are minors.

Most of these pathogens are in favor of humid environment and they invade from the wound, so the general strategies for disease managements include the use of pathogen-free seedlings, field sanitation, avoiding spray watering, and chemical application.

For controlling anthracnose, stem canker, and wet rot simultaneously, strains of Bacillus amyloliquefaciens with antibiotic effects to C. gloeosporioides, N. dimidiatum and G. persicara were isolated and developed as microbial biocontrol agents (Kuo 2016). Some other control agents for organic farming, Bordeaux mixture for example, were tested.

Anthracnose is the most important postharvest disease worldwide that is attributed to infection of species or species complexes of Colletotrichum. In the future, accurate identification based on morphology and phylogenetic analyses are needed (Phoulivong et al. 2012). To discriminate the species or subspecies within C. gloeosporioides, C. truncatum, and C. boninense species complex, multi-loci phylogenetic analyses are in progress.

Pitaya is commercially propagated by cutting and grafting, by which viruses are easily transmitted. CVX is already carried by most of the pitaya plants in Taiwan, so the virus-free cuttings and seedlings are hardly to be found. Therefore, setup of virus indexing program and virus-free propagation system are strongly recommended for controlling these viral diseases (Li et al. 2015). An immunostrip with the simplest procedure and the optimal condition for CVX detection in pitaya tissue was developed. The efficiency of immunostrip for CVX detection is equal to that used in ELISA or to that in simplified multiplex RT-PCR (Fig. 5). For CVX indexing in healthy seedling propagation, the immunostrip is available and is ready to be commercialized (Fig. 6). In addition to CVX, other cactus-infecting viruses might also carried by pitaya in the world. Further identification of virus is needed to meet the requirements of quarantine decision, plant breeding, and plant disease management.

Fig. 5. Comparative results of CVX detection by using of immunostrip, multiplex RT-PCR, and ELISA.
Fig. 6. Indexing of CVX by immunostrip; negative result in healthy stem (left) and positive result in CVX-infected stem (right).

Table 1. Occurrence of pitaya diseases reported in Taiwan

<table>
<thead>
<tr>
<th>Causal Agents</th>
<th>Disease</th>
<th>Year</th>
<th>Authors</th>
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<tbody>
<tr>
<td><strong>Viruses</strong></td>
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<tr>
<td>Cactus virus X</td>
<td>Mottle</td>
<td>2001</td>
<td>Liou et al.</td>
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<tr>
<td>Zygocactus virus X</td>
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<td>2007</td>
<td>Mao et al.</td>
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<tr>
<td>Pitaya virus X</td>
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<td>2010</td>
<td>Li et al.</td>
</tr>
<tr>
<td><strong>Fungi</strong></td>
<td></td>
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<tr>
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<td>Fruit decay</td>
<td>2005</td>
<td>Wang and Lin</td>
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<td>Fruit rot</td>
<td>2010</td>
<td>Tsai et al.</td>
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<tr>
<td>Diaporthe spp.</td>
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<td>2010</td>
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<tr>
<td>Phomopsis spp.</td>
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<td>2010</td>
<td>Tsai et al.</td>
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<td>Penicillium citrinum</td>
<td>Green mold</td>
<td>2010</td>
<td>Tsai et al.</td>
</tr>
<tr>
<td>Rhizopus stolonifer</td>
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<td>2010</td>
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</tr>
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<td>2014</td>
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<td>Yeh et al.</td>
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<td>Cyst nematode</td>
<td>2012</td>
<td>Chen et al.</td>
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