Overview of Occurrence, Prevention and Control of *Panonychus citri* in China

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Abstract In order to further promote the prevention and control research of *Panonychus citri* and improve its control effect, this paper summarizes the main influencing factors of the outbreak, main control technology and drug resistance of *P. citri*, and puts forward the research focus and control strategy.

Key words *Panonychus citri*; Drug resistance; Prevention and control

1 Introduction

Panonychus citri, belonging to *Panonychus*, Tetranychidae, Acariformes, is one of the most important insect pests in citrus production[1]. *P. citri* is widely distributed in various citrus producing areas in China, including Guangxi, Guangdong, Jiangxi, Sichuan, Chongqing, Zhejiang, Jiangsu, Hunan, Hubei and other provinces (cities and districts)[2]. It can harm 112 species of plants, especially those in Rutaceae, Rosaceae, and can also damage *Osmanthus fragrans*, *Clausena lansium*, *Ficus carica* and other cash crops[3]. In addition to the egg stage, *P. citri* can infest citrus leaves and fruits at all other growth stages, especially young leaves and tender buds, easily leading to defoliation and abscission of fruits[4]. After being damaged by *P. citri*, there will be gray white holes on the surface of citrus leaves and fruits, and mottled leaves and striped fruits will form in severe cases[5]. *P. citri* generally adopts amphigenesis, but can also perform parthenogenesis. Its annual generation is closely related to the temperature of the year. When the annual average temperature is around 20 ℃, it can occur about 20 generations a year, and one generation can be completed with an average of 16 d. Due to short growth and development cycle, serious overlap of generations and special reproductive mode, it is very difficult to control *P. citri*[6].

2 Factors influencing the outbreak of *P. citri*

There are many factors affecting the occurrence of *P. citri*, mainly including environmental and climatic factor, citrus cultivation and management factor, natural enemy factor and chemical control factor[7].

2.1 Environmental and climatic factor *P. citri* prefers the environment with high temperature and low relative humidity, and reaches the peak of occurrence when the temperature is 20 – 30 ℃ and the relative humidity is around 70%. High temperature in summer is not conducive to the growth and development of *P. citri*. When the temperature exceeds 30 ℃, its mortality rate increases and the number drops sharply[8]. In addition, summer is often accompanied by strong convection weather such as heavy rain, and the erosion of heavy rain will also reduce the population density. Studies have shown that when the temperature is appropriate and the rainfall ranges from 18.6 mm to 29.9 mm, the population density is reduced by 45% – 74% after the rainfall[9]. When the temperature drops in winter, the activity frequency of *P. citri* reduces significantly. *P. citri* survives the winter as adult mites and eggs near the petiole, or in branches furrows and branch cracks, and then propagate and damage in large numbers when the temperature is appropriate in spring of the next year.

2.2 Cultivation and management factor Scientific orchard management can effectively delay the outbreak of *P. citri*. Field investigation demonstrated that to pursue yield and economic benefits, some orchards blindly increases planting density, which not only affects the usual water and fertilizer management and chemical control, but also facilitates the spread of *P. citri*. As a result, when a single tree is damaged by *P. citri*, the entire orchard will soon be damaged[10]. Timely clearing orchard in winter can reduce the amount of overwintering insects, and avoid excessive population of overwintering insects, thus effectively reducing the difficulty of prevention and control in the following year[11].

2.3 Natural enemy factor There are many natural enemies of *P. citri*. At present, the common natural enemies that can prey on *P. citri* in China include predatory mite, *Stethorus* sp. and flower bug[12]. In recent years, the frequent use of organophosphorus, pyrethroids and other pesticides not only kill harmful mites, but also sharply decrease the population of their natural enemies, and it becomes more dependent on chemical control. After the ecological balance of an orchards is destroyed, the damage of *P. citri*, which lost the control of natural enemies, becomes more rampant, trapping in a vicious cycle[13].

2.4 Chemical control factor At present, chemical control is still the major measure against *P. citri*, but because of its small

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size, rapid reproduction, short generation cycle and unique reproductive mode, it brings many difficulties to chemical control. The adult, nymph and egg of *P. citri* are not visible to the naked eye, so it is easy to miss the best time for prevention and control. In actual production, the control of *P. citri* is usually started when the population has developed to a certain scale. In addition, *P. citri* has developed resistance to a variety of acaricides due to long-term use of chemical agents[14]. In addition to drug resistance, resurgence (refers to the phenomenon that the use of some pesticides leads to larger quantity and serious harms of pests than that before the use) is also related to chemical control, and the fundamental reason is that chemical agents break the original ecological balance, and have uneven effectiveness to various harmful organisms in the original ecosystem.

3 Prevention and control of *P. citri*

At present, the integrated control measures including chemical, biological, agricultural and physical methods are mainly adopted to control *P. citri*[15]. It is necessary to grasp the key control time of *P. citri* to get twice the result with half the effort. In addition to effectively reducing the initial quantity of mite population through winter orchard clearing, the early peak period of spring and autumn is the key period for chemical control in the growth season[16].

3.1 Chemical control Chemical control has the advantages of high efficiency, convenience and low relative cost[16]. At present, acaricides registered for the prevention and control of *P. citri* in China can be divided into organotins, carbamates, formamidines, pyridines, thiazoles, pyrazoles, *etc.* from the structure point of view, and can be divided into natural products and synthetic products according to the source[17-18]. The modes and mechanisms of action of various acaricides registered for the prevention and control of *P. citri* are shown in Table 1.

Table 1 Mechanism of action of various acaricides

Type	Acaricide	Mode of action	Mechanism of action
Organotins	Fenbutatin oxide	Contact toxicity, stomach toxicity, systemic action	Inhibiting the nerve tissue of harmful mites
Organotins	Azocyclotin	Contact toxicity, stomach toxicity	Inhibiting the oxidative phosphorylation process of nerve cells
Carbamates	Bifenazate	Contact toxicity, stomach toxicity	Inhibiting γ-aminobutyric acid (GABA) receptors and mitochondrial respiration
Formamidines	Semiamitraz	Contact toxicity, stomach toxicity, fumigation	Inhibiting monoamine oxidase activating octopamine receptor, and blocking nerve conduction
Formamidines	Amitraz	Contact toxicity, stomach toxicity, fumigation	Inhibiting the activity of monoamine oxidase, activating adenylate cyclase, and causing strong nerve excitation
Other heterocycles	Cyetpyrafen	Contact toxicity, stomach toxicity	Overinhibiting complex II activity of oxidative respiratory chain (electron transport chain)
Other heterocycles	Etoxazole	Contact toxicity, stomach toxicity	Inhibiting the embryonic formation of mite eggs and the molting process of nymphs
Other heterocycles	Spirodiclofen	Contact toxicity, stomach toxicity	Inhibiting the fat synthesis of harmful mites and blocking their energy supply
Other heterocycles	Pyridaben	Contact toxicity	Overinhibiting respiration
Other heterocycles	Hexythiazox	Contact toxicity, stomach toxicity	Inhibiting chitine synthesis and interfering with metabolism in insects
Other heterocycles	Fenpyroximate	Contact toxicity, stomach toxicity	Overinhibiting oxidative respiratory chain complex I, that is, NADH dehydrogenase complex
Other heterocycles	Cyenopyrafen	Contact toxicity	Overinhibiting complex II activity of oxidative respiratory chain (electron transport chain)
Other non-heterocycles	Fenpropathrin	Contact toxicity, stomach toxicity, fumigation	Blocking the closure of Na^+ channel
Other non-heterocycles	Propargite	Contact toxicity, stomach toxicity, fumigation	Inhibiting the activity of Na^+/K^+-ATPase and Mg^{2+}-ATPase
Other non-heterocycles	Cyflumetofen	Contact toxicity, stomach toxicity	Interfering with inhibition of mitochondrial protein complex II
Other natural products	Abamectin	Contact toxicity, stomach toxicity	Stimulating the production of GABA, blocking the transmission of efferent nerve transformation, and interfering with their neural activity
Other natural products	Matrine	Contact toxicity, stomach toxicity	Paralyzing nerve center and leading to protein coagulation and pore blockage of insect body

Chemical agents had been mainly used to control harmful mites from sulfur in the inorganic acaricide period to the large-scale promotion and use of organic synthetic acaricides in the mid-20th century, and to the emergence of organotin acaricides in the 1970s, which mainly inhibited respiratory metabolism, as well as mite growth inhibitors in the 1980s[19]. At present, chemical control is still the major method against *P. citri*, and needs a unique mechanism of action due to the requirements of high efficiency, low toxicity and green environmental protection. Cyetpyrafen is a novel acrylonitrile acaricide developed by Shenyang Sinochem Pesticide Chemical Research and Development Co., Ltd.[20], which has high activity against adults, nymphs and eggs of *P. citri*, and has excellent field control effect[21]. Field tests carried out by Liu Shaowu *et al.*[22] showed that the control effect of 30% cyetpyrafen SC 100 mg/L on *P. citri* reached 100% at 3 and 10 d post treatment in Nanning, Guangxi, and that at 15 and 20 d post treatment exceeded 99%. Spiromesifen, a spirocyclic tetronic acid acaricide developed by Bayer, can play a good role in the prevention and control of *P. citri* nymphs, and also promote the closure of the ovarian tube of female adult mites, thus reducing their egg-laying ability[23].

New acaricides have no cross-resistance to common acaricides, and are biosafe and suitable for integrated pest control, with excellent residual effect, good plant compatibility, and no environmental pollution. In addition, the use of additives can better exert the activity of chemical agents and make up for the shortage of pharmaceutical dosage forms. It can not only increase the adhesion and ductility of medicine liquid and increase the anti-erosion ability, but also enhance the penetration of its target, so that medicine liquid can contact the target quickly and smoothly, thus achieving good control effect[24]. Yang Tingmi *et al.*[25] showed that by adding 2 972.97 and 4 950 mg/L of mineral oil to 48 mg/L spirodiclofen, the control effect on *P. citri* at 1 d post administration could be increased by 31.25% and 34.68%, and that at 3 d post administration could be increased by 25.84% and 26.84%, respectively. Reasonable selection of acaricides, accurate application dose and accurate application period as well as mixed and rotated use of different acaricides are important matters to ensure the ideal chemical control effect.

3.2 Biological control Since the "3R" problem (resistance, resurgence, residue) brought by chemical control is becoming increasingly prominent, it is urgent to develop green biological prevention and control. The biological prevention and control against *P. citri* is mainly achieved through predators, parasitoids and biocontrol bacteria. Katayama *et al.*[26] found that *Neoseiulus californicus* inhibited the population density of *P. citri*. Fadamiro *et al.*[27] showed that predatory mites had certain control effect on *P. citri*. The biological control of *P. citri* has also been studied thoroughly in China. For example, Zhang Guanghua *et al.*[28] controlled *P. citri* by releasing *Amblyseius cucumeris*, which could reduce the application frequency of chemical agents and reduce the economic cost. Peng Jianbo *et al.*[29] found that the use of predatory mites to control *P. citri* had excellent control effect, and the fruit quantity and quality in the orchards controlled by predatory mites were significantly better than those controlled by chemical agents. Ling Peng *et al.*[30] found that releasing *A. barkeri* could effectively control *P. citri*, and the predatory ability of *A. barkeri* to *P. citri* was proportional to temperature within a certain range. Huang Jiasheng[31] suggested that the control effect of *A. cucumeris* on *P. citri* could reach 85% – 95%. In recent years, the use of microorganisms to control *P. citri* has been further studied. Biological control is conducive to protecting the ecological balance of orchards, restoring the number of natural enemies of mites, and realizing natural control of natural enemies of *P. citri*[32].

3.3 Agricultural control Agricultural control is mainly adopted to control the occurrence of *P. citri* by strengthening the cultivation management of citrus. (i) Water and fertilizer management can be strengthened to enhance tree potential and improve the resistance of citrus trees to *P. citri*, which can reduce the occurrence of *P. citri* to a certain extent. (ii) The ecological environment of the orchard is protected to create an environment conducive to the survival of natural enemies of *P. citri*, maintain the normal operation of the biological chain, and exert the natural control effect of natural enemies. (iii) Clearing the orchard in winter and pruning diseased branches can minimize the initial quantity of overwintering insects as much as possible, thus laying a good foundation for the prevention and control of *P. citri* in the following year.

4 Drug resistance of *P. citri*

Since the 1980s, there have been reports of resistance of *P. citri* to insecticides. In 1996, Zhang Gebi *et al.*[33] monitored that the population of *P. citri* in Guilin had developed a moderate level of resistance to amitraz. In 2001, Liu Chunrong *et al.*[34] found that *P. citri* in a citrus orchard in Quzhou area developed a low level of resistance to propargite, with a resistance ratio of 1.9 – 4.2 times. In 2001, Gao Chaoyue[35] tested the efficacy of different chemicals against *P. citri* and found that *P. citri* in Sanming area of Fujian Province had developed resistance to isocarbophos. Meng Hesheng *et al.*[36] found that after indoor subculture for 12 generations, the resistance of *P. citri* to pyridaben increased to 35 times. Liu Yonghua[37] monitored the resistance of *P. citri* population in Beibei District of Chongqing for consecutive 2 years from 2008 to 2009, and found that the relative resistance ratios of *P. citri* population to fenpropathrin and pyridaben increased by 5.1 and 2.2 times, respectively. The resistance of *P. citri* to acaricides has also been reported abroad. In 1990, Teramoto *et al.*[38] reported that *P. citri* showed resistance to propargite and chlorfenethol in the citrus orchard of Kyushu University, Japan. In 1995, Yamamoto *et al.*[39] reported that *P. citri* developed low level resistance to hexythiazox in a citrus orchard in Hamawara, Shizuoka Prefecture, Japan. Dker *et al.*[40] found that the resistances of 9 populations of *P. citri* to abamectin, etoxazole, spirodiclofen, spirotetramat and pyridaben in Turkey were 2.81 – 34.82 times, 1.22 – 18.35 times, 1.23 – 40.43 times, 1.76 – 27.50 times and 2.24 – 75.06 times, respectively. Due to the unscientific and irrational drug use, *P. citri* has developed different levels of resistance to various insecticides under the main mode of chemical control. Therefore, while searching for new targets and developing new agents, it is also necessary to scientifically and rationally use existing acaricides (that is, reducing the frequency of application, alternating the use of various acaricides and screening excellent compound formulations), and conduct comprehensive control in combination with other control measures.

5 Suggestions

5.1 Strengthening resistance monitoring For a long time, the application of chemical pesticides has been the most efficient and direct measure to control *P. citri*. However, it is precisely because of the long-term and high frequency use of acaricides that *P. citri* has developed different levels of resistance to common acaricides such as abamectin, bifenazate, spirodiclofen, pyridaben, *etc.*, which leads to certain difficulties in the selection of agents for the prevention and control of *P. citri*. Timely monitoring the resistance level of *P. citri* to common acaricides in main citrus growing areas can provide reference for the prevention and control and drug resistance control of *P. citri* in main citrus producing areas. Because of the increasing difficulty in developing new agents, more attention should be paid to the scientific and rational use of existing acaricides to extend their service life. In areas with high resistance levels, the application frequency of insecticides and acaricides should be reduced, or the use of such insecticides and acaricides should be suspended, and the development of drug resistance should be closely monitored. Existing agents can be compounded to screen for compounds with synergistic effects to delay the development of drug resistance[6].

5.2 Strengthening biological control research Under the background of environmental protection and agricultural "double reduction", it is helpful to the greening prevention and control of *P. citri* by strengthening the research of biological control. Pesticides are selectively used, which should be non-toxic or low toxic to natural enemies such as predatory mites in the field, to ensure the population of their natural enemies, and a mature chemical-biological control system must be established. For example, predator mites + biological pesticides can be used to control *P. citri* in orchards. The impact of the number of natural enemies released, drug selection and dosage on *P. citri* population should be explored.

5.3 Strengthening the development of comprehensive prevention and control system A mature chemical-biological-agricultural control system can be established by strengthening the monitoring and early warning of *P. citri* in orchards, ensuring the number of natural enemies of *P. citri*, strengthening the research and development of highly effective and low toxic agents, and scientifically and rationally using agents and agricultural operations, so as to ensure the high efficiency and sustainability of the prevention and control of *P. citri*.

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(iii) Under the wheat/green manure/maize zonal rotation system in Bijie, the sowing width of wheat should be guaranteed to be 0.5 m under the 1.65 m zonal cropping system, and the sowing rate of wheat should be arranged according to the basic seedling of 1.2 million plants/hm^2. It is recommended to apply fertilizer precisely, and 180 kg/hm^2 potassium sulfate compound fertilizer ($N/P_2O_5/K_2O$ = 15/15/15) can be selected as the standard to apply the base fertilizer when sowing wheat. In the early stage of wheat stripe rust, 15% triadimefon WP can be sprayed evenly at the dose of 1 050 g/hm^2 by a high-power sprayer in a sunny day.

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