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Revisão/Review

Citrus insect pests and their non chemical control in China

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SUMMARY

Citrus insect pests are important factors affecting production of citrus in China, and cause serious damage to citrus yield and fruit quality. Due to the high fruit quality standards demanded in recent years, citrus pest management has to provide fruit not only with almost no pest damages, but also with minimal pesticide residues. In this report, we review current status of citrus insect pests and their non-chemical control (green control) in China, including agricultural control such as cultural measures, sanitation of winter orchards, trunk paint, pruning, citrus orchards ground cover and so on; biological control, for instance, conservation of natural enemies via orchard management, artificial mass rearing and release of natural enemies, microbial and mineral pesticides. Additionally, application of sex pheromone, food baits, physical and mechanical control techniques such as light traps, yellow sticky trap and fruit bagging have been summarized.

Index terms: citrus insects, biological control, agricultural control, physical and mechanical control.

Insetos pragas de citros e seu controle não químico na China

RESUMO

Os insetos pragas são fatores importantes que afetam a produção de citros na China e causam sérios danos ao rendimento e à qualidade da fruta cítrica. Devido aos altos padrões de qualidade dos frutos exigidos nos últimos anos, o manejo de pragas de citros deve fornecer frutos não apenas com quase nenhum dano de pragas, mas também com resíduos mínimos de pesticidas. Neste relatório, revisamos o estado atual dos insetos pragas de insetos de citros e seu controle não químico (controle biológico) na China, incluindo controle agrícola, como medidas culturais, sanitização de inverno dos pomares, pintura de tronco, podas, plantas de cobertura do solo dos pomares e assim por diante; controle biológico, por exemplo, conservação de inimigos naturais através do manejo do pomar, criação massal artificial e liberação de inimigos naturais, pesticidas microbianos e minerais. Além disso, a aplicação de feromônio sexual, iscas de alimentos, técnicas de controle físico e mecânico, como armadilhas de luz, armadilha pegajosa amarela e ensacamento de frutas.

Termos de indexação: insetos de citros, controle biológico, controle agrícola, controle físico e mecânico.

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INTRODUCTION

Citrus is grown in more than 52 countries around the globe that depicts its significance among the fruit crops. China and Brazil are the leading producers of citrus generating 45 million tons (MT) of citrus together, followed by USA, India, and Mexico with an annual production of 10.7, 8.6 and 7.2 MT, respectively (CGA, 2012). According to Shan (2008), total area under citrus cultivation is estimated about 1.7 million hectares in China. On the other hand, it has been estimated that during 2014/15 China produced 35.7 thousand tons of world fresh citrus with top ranking worldwide (CGA, 2016). In China, citrus insect pests include more than 74 species, though, only a few (50~60 species) occur consistently and widely distributed with substantial economic importance (Yang, 2004).

In the previous 40 years economically important insect pests (Table 1) have been recorded as a major threat to citrus production in China (Zhang & Li, 2012). Citrus fruit quality (appearance, sugar content, and per fruit weight) and quantity is badly affected because of failure in timely pest management implementations (Wang et al., 1999). Chemical and non-chemical control are considered as two main methods of suppressing insect pests of citrus. Often, these methods are supposed as alternatives in insect pest control. Chemical controls involve only prompt and temporary demolition of localized insect pest populations. Therefore, citrus growers preferred to use only chemical control because of less awareness or it seems easy to follow and generate visible results

Table 1. Citrus insect pests in China

Sucking insect and mite pests	Fruit and bud pests	Chewing pests of leaves	Trunk borers
Citrus red mite (Panonychus citri)	The Chinese citrus fruit fly (Bactrocera citri)	Citrus butterfly (Papilio demoleus)	Citrus flat headed borer (Agrilus auriventris)
Citrus rust mite (Phyllocoptruta oleivora)	The oriental fruit fly (Bactrocera dorsalis)	Leaf beetles (Podagricomela nigricollis, Clitea metallica)	Citrus brown longicorn beetle (Nadezhdiella cantori)
Citrus bud mite (Eriophyes sheldoni)	Castor pod borer (Dichocrocis punctiferalis)	Citrus leaf miner (Phyllocnistis citrella)	Citrus long-horned beetle (Anoplophora chinensis)
The arrowhead scale (Unaspis yanonensis)	Fruit-piercing moths (Eudocima phalonia)		
Black Parlatoria scale (Parlatoria zizyphus)	Citrus blossom midge (Contarinia citri)		
Cotton cushiony scale (Icerya purchasi)			
Pink wax scale (Ceroplastes rubens)			
Whitefly (Dialeurodes citri)			
Orange spiny whitefly (Aleurocanthus spiniferus)			
Citrus psyllid (Diaphorina citri)			
Aphid (Aphis gossypii)			
Citrus aphid Toxoptera citricidus Kirkaldy			

Source: Zhang & Li (2012).

with quick decrease of all arthropod including beneficial insects (Xiao et al., 2010). In response, continued use of chemicals led to dramatic resurgences of insect pest populations (Wu & Nan, 1989). Undesirable effects of insecticides on non-target arthropods and rise of insecticide resistance resulted in the resurgences (Zhao, 2000). For instance, broad spectrum insecticides used against citrus caterpillar or thrips resulted in the outbreak of various citrus mites and scale pests (McCoy, 1977; Abrol & Singh, 2003; Dreistadt, 2012). Resurgence of mite infestation was observed after different pyrethroid insecticidal treatments, with significantly higher population than the pretreatment counts (Abrol & Singh, 2003). Similarly, overuse of insect growth regulators (IGRs) in replacements with organophosphate insecticide allowed secondary pests e.g. scale species to become as primary pest (Grafton-Cardwell et al., 2006).

Previously, insecticides such as organochlorine pesticides (OCPs) were mostly used for citrus insect pest controls. Chinese Ministry of Agriculture has banned or restricted the use of organochlorine pesticides. Currently, none of these insectcides are used in citrus orchards. (MOA, 2017). Meanwhile, due to high toxicity, bioaccumulation and environmental persistence, use of such chemicals is considered to be a massive threat for higher trophic organisms (Jones &Voogt, 1999; Nakata et al., 2002). China began to exclude agricultural use of many pesticides including aldrin, dieldrin, DDT, HCH, HCB, heptachlor and chlordane since the beginning of 1980s (Editorial Committee on China Environmental Yearbooks, 1990).

However, China has a very protracted background of non-chemical control to diminish citrus insect pests. For instance, hundreds years ago, Chinese citrus growers placed predatory ants nests Oecophylla smaragdina Fabricius (Hymenoptera: Formicidae) under trees to control pests feeding on leaves (Doutt, 1964; Yang, 2002). During last three decades, especially in citrus orchards, substantial efforts has been made for non-chemical control, numerous published scientific achievements in biological control techniques and some additional executions are the testimonial of these efforts (Li et al., 2005; Wei et al., 2007; Yang & Wang, 2008).

In a nutshell, with gradual increase of insecticide resistance, environmental pollution and emerging concerns of insecticide residues, it has become mandatory to look for alternatives citrus insect pests control methods to minimize the further use of insecticides. Hence, diversified approaches are essential as a part of integrated pest management (IPM) for better environmental protection. Consequently, non-chemical control strategies are thought to be promising replacement including, agricultural, physical traps, attractants and baits, biological, mineral oil applications and some new technologies such as sterile insect technique (SIT) based on RNAi and transgenic techniques (CRISPR Cas9) (Luo et al., 2008; Yang & Wang, 2008; Li et al., 2010; Zheng et al., 2015).

The objective of this review is to summarize the available information on the development, research and field application of non-chemical control techniques used for citrus insect pests in China; and highlighting the benefits of those non-chemical control techniques for economic and environmental concerns. In addition, this review also signifies the glimpse of advanced techniques for the control of citrus insect pests in future.

OVERVIEW OF AGRICULTURAL AND CULTURAL PRACTICES

Cultural control services are employed to create the less attractive environment for pests survival, growth, reproduction, dispersal, and to enhance the pest's natural control. The purpose is to achieve pest numbers reduction, either below EIL (economic injury levels), or sufficiently enough to allow biological controls to take effect. Here is the portfolio of under practice cultural control methods in China.

Sanitation of orchards during summer and winter

During winter, clean up orchards by digging out trees infested with huanglongbing disease and remove deadwood, fruit drop and dry branches in order to diminish the overwintering insects e.g. whitefly, leaf miner, fruit fly, and leaf beetles etc. Moreover, winter ploughing destroys the habitats of soil overwintering insects such as leaf beetle, fruit fly pupa and citrus blossom midge. While, summer shoots and buds also played an adverse role for citrus production. Huang et al., (2014) discussed scientific fertilization before flowering phase to balance the tree nutrition while emphasizing to avoid fertilizing nitrogen during summer shoots growth period.

Moreover, removing 1~3 cm long summer shoots, once each 7-10 days tends to suppress aphids, psyllid, white fly and leaf miner populations (Ye et al., 2007).

Pruning

Pruning is also being experienced in citrus orchards of China to minimize the pest population. Rational pruning of infested leaves and branches increased the ventilation of citrus orchards ensured to decrease aphids and whitefly populations (Marti & González, 2010; Mao et al., 2014).

Cover crops improves population density of natural enemies

In past, integrated management of citrus pests in China, especially mites, was based on utilization and protection of predatory mites (Huang et al., 1978, 1981; Zou, 1988). Ground cover plants presence is closely correlated with the population densities of predatory mites (Liang & Huang, 1994). The weed, Ageratum conyzoides L. (Asterales: Asteraceae) was observed as supplementary source of increasing predatory mites population densities against the citrus red mite Panonychus citri McGregor (Trombidiformes: Tetranychidae) (Liang & Huang, 1994).

Several leguminous cover crops (such as bell bean, Austrian winter pea and white clover) results in the increase of predatory mite Euseius tularensis Congdon (Mesostigmata: Phytoseiidae) populations in China. Researchers found that adequate pollen is provided as a food source to E. tularensis by these leguminous cover crops, which helps to produce enough predatory pressure to suppress the citrus thrips populations (Grafton-Cardwell et al., 1999).

In addition, cover plants increase population density and provide an alternate source of food, shelter and habitat for natural enemies of citrus pests (Zhang et al., 2013). Zhao et al. (2014) investigated biological control of P. citri and found that in citrus orchards especially from September to December ground cover crop A. conyzoides L. offer a rich source of food for predatory mites with highest population densities.

White color paint of trunks

Trunks painted with white color can be helpful to avoid from sunshine burning and can prevent infestation of insect pests like Longhorn borer Anoplophora chinensis Forster (Coleoptera: Cerambycidae) egg laying. Furthermore, Longhorn borer killer is used to kill the longhorn larvae (Li & Wu, 1993).

Fruit bagging

Fruit bagging method can inhibit fruit fly egg laying and fruit piercing moth damage after some preliminary measures, first and foremost, bagging time in sunny day supposed to be from 9:00-11:00 and 15:00-18:00. Afterward, fruits need to clean from insects and diseases with pesticides spray before bagging and finally keeping the mouth of bag downward (Ju, 1998; Chen et al., 2012). In China, fruits are bagged with breathable materials such as old newspapers, phone book paper, grey colored paper bags, transparent micro-perforated cloth material or mosquito netting. Moreover, insect pollinated fruits should be bagged at a stage of fruit development or after fruit set, in order to prevent insect pests, especially fruit flies, from finding and laying eggs in the fruits.

MINERAL OILS

No doubt, mineral oils have protruding potential to control a wide range of citrus insect pests, including psyllid, scale, leaf miners, aphids and mites (Beattie & Hardy, 2005; Leong et al., 2012). For instance, Rae et al. (1997) found that psyllid 1st and 2nd instars were most susceptible after spraying petroleum oil, while eggs being the most tolerant to oil. While, field application of mineral oil in combination with predatory mite against citrus red mite provided satisfactory control compared with chemical control (Fang et al., 2012). Lu (2015) reported that significantly reduced population of red wax scale invites to emphasize on the potential of mineral oil to control citrus insect pests (Table 2).

PHYSICAL TRAPS

Physical traps with attractive effects are mainly used in different ways: to efficiently trap insect pests to kill them or for sampling methods to estimate population of relevant insect in a given landmass (David & Pat, 1990).

Frequency trembler grid lamps

Accordingly, frequency trembler grid lamps based on phototaxis mechanism being a useful low cost source in China, generally to control lepidopteran (Noctuidae) pests of citrus (Lu, 2009). This method has proved its success

Table 2. Efficacy of mineral oils against wax scale

Treatment	Initial population	7 days post treatment		
		No. of living insects	decreased rate	Correcting effect (%)
Mineral oil 100×	366	35	90.44	87.48
Spirotetramat(240g/L)4000×	351	41	80.32	84.70
Methidathion(40%)1000×	476	72	84.87	80.19
Nicotine and matrine(1.2%)1000×	381	51	86.61	82.47
Control	495	378	23.64	

Source: Lu (2015).

through reduced input expenses, environmental protection and maintenance of ecological balance (Lu, 2009).

Black-light lamps

Likewise, black light lamps have long been used in China with simple, practical and low cost method showing rapid effects particularly against citrus pests of Lepidoptera and Coleoptera. Although, its attractive effect is not as good as of frequency trembler grid lamps but it is helpful for providing reliable data for pest forecasting (Wang et al., 2008).

Colored sticky cards

Colored sticky cards have been used worldwide for monitoring of whiteflies, thrips, leaf miners, aphids and other insects in the field and greenhouses of various crops (Berlinger, 1980; Byrne et al., 1986; Megeed et al., 1994; Qiu & Ren, 2006). Colored sticky traps are extensively used for the control of several citrus insect pests in China. For instance, blue and yellow sticky cards revealed strong attractive effects against thrips, aphids and white flies, respectively (Heinz et al., 1992; Yao & Zheng, 2008; Rodriguez-Saona et al., 2010).

In addition, food attractive lures for the control of Bactrocera minax Enderlein (Diptera: Tephritidae) (Zhou et al., 2012), hydrolyzed protein trap against fruit fly (Lasa & Tadeo, 2015), botanical attractant baits (Ju et al., 2012) and sex pheromone traps (Hwang & Chu, 1987) against several insects have been practiced in China. We have identified sex pheromones of the B. minax and developing effective traps at State Key Laboratory of Agricultural Microbiology, Institute of Urban and Horticultural Entomology, College of Plant Science and Technology, Huazhong Agricultural University, Wuhan, China. In addition to this, we are also developing traps in different color fruit shapes in order to control oriental fruit fly (unpublished data).

BIOLOGICAL CONTROL

Moderately speaking, research development in biological control has developed quickly in China. Between 1981 and 1984, 53 insect pest species and 100 natural enemies have been identified in a survey of citrus insects and their natural enemies (Lo & Chiu, 1986; Niu et al., 2014).

Parasitoid

The 41 parasitoids in one order, Hymenoptera, represented by 23 genera and 5 families (Table 3) have been found against citrus insect pests in China (Niu et al., 2014). Probably the oriental fruit fly Bactrocera dorsalis Hendel (Diptera: Tephritidae) is the most notorious pest of citrus. Various parasitoid species can be used as effective control strategy against oriental fruit fly. Eight species within four families of Hymenopterous parasitoids were recorded in Guangdong province citrus orchards inventory (Yao et al., 2008). Presence of parasitoids in Chinese citrus orchards clearly indicates the significance of commercial biological control methods (Table 3). The parasitoid, Tamarixia radiata Waterston (Hymenoptera: Eulophidae) which was discovered in the area of northwestern India (Punjab) (Waterston, 1922), showed high parasitism efficiency against Asian citrus psyllid Diaphorina citri Kuwayama (Hemiptera: Liviidae) (Mann & Stelinski, 2010). Currently the parasitoid is found in Brazil, China, Guadaloupe, Indonesia, Mauritius Mexico, Pakistan, Philippines, Nepal, Taiwan, Vietnam, Puerto Rico and the United States (Waterston, 1922; Chien et al., 1991;

Table 3. Predators, Parasitoids and Pathogens of economically important insect pests in China

Insect pest (scientific name)	Pest family (order)	Predators*	Parasitoids**	Pathogens***	References
Citrus psyllid (Diaphorina citri Kuwayama)	Psyllidae (Hemiptera)	Coelophora biplagiata Swartz, Adalia bipunctata L., Agistemus exsertusGonzalez, Rodolia cardinalis Mulsant,Cheilomenes sexmaculata Fabricius,C. quadriplagiata Swartz, C. pallens Rambur,R. limbata Motschulsky,Scolothrips longicornis Priesner, Sospitachinensis Mulsant, C. septempunctata Wesmael, C. rufilabris Burmeister, Coccinella septempunctata L., Harmoni axyridisPallas,Lemnia circumsta Mulsant, Megalocaria dilatata Fabricius, Olla vnigrum Mulsant, Propylaea japonicaThunberg.	Psyllaephagus diaphorinae Lin & Tao, Tamarixia radiata Waterston, Diaphorencyrtus aligarhensis Shafee, Alam and Argarwal, D. diaphorinae Lin & Tao, Tetrastichus sp.	Beauveria bassiana Balsamo	*(Chen, 1992; Yu, 2001; Ren, 2008; Nin & Qin, 2009; Zhang et al., 2009) **(Ren, 2008; Nin & Qin, 2009; Mao et al., 2010) ***(Nin & Qin, 2009)
Citrus red mite (Panonychus citri McGregor)	Tetranychidae (Trombidiformes)	Stethorus iphonulus Kapur, Erigonidium graminicolum Sundevall, Amblyseius barkeri Hughes, A. cucumeris Oudemans, A. orientalis Ehara, Oligota sp.			*(Wei et al., 1997, 2007; Gan et al., 2001; Zhang et al., 2002; Xiao et al., 2005; Gao & Pan, 2007; Ling et al., 2008; Ou-Yang et al., 2007)

*References of predators, **References of parasitoids, ***References of pathogens.

Table 3. Continued...

Insect pest (scientific name)	Pest family (order)	Predators*	Parasitoids**	Pathogens***	References
Orange spiny whitefly Aleurocanthus spiniferus Quaintance	Aleyrodidae (Hemiptera)	Chilocorus gressitti Miyatake, C. kuwanae Silvestri, C. rubidus Hope, Adalia bipunctata L., Ankylopteryx octopunctata Fabricius, Anystis baccarum L., Chrysopa septempunctata Wesmael, C. sinica Tjedea, Harmonia axyridis Pallas, Telsimia emarginata Chapin, Mallada desjardinsi Navas, Propylaea japonica Thunberg, P. quatuordecimpunctata L., Erigonidium graminicolum Sundevall, Serangium japonicum Chapin	Aphytis chrysomphali Mercet, Comperiella unifasciata Ishii, Psyttalia lounsburyi Silvestri, Amitus hesperidum Silvestri, A. longicornis Förster, Encarsia albiscutellum Girault, E. aseta Hayat & olaszek, E. azimi Hayat, E. collecta Chou & Su, E. Formosa Gahan, E. ishii Silvestri, E. japonica Viggiani, E.lahorensis Howard, E. nipponica Silvestri, E. obtusiclava Hayat, E. smithi Silvestri	Paecilomyces aleurocanthus Petch, Isaria fumosoroseus Wize, Aschersonia aleyrodis Webber, Verticillium lecanii Zimmerman, Pleurodesmospora coccorum Li & Huang	*(Zhang et al., 2004; Guo et al., 2007; Li, 2009; Ren, 2008) **(Zhu & Chen, 1994; Ye et al., 1996; Huang et al., 2000; Guo et al., 2006b; Yang & Wang, 2008; Nin & Qin, 2009) ***(Han & Cui, 2004; Zhang et al., 2004; Guo et al., 2006b)
Aphid Aphis gossypii Glover	Aphididae (Hemiptera)	Chrysopa septempunctata Wesmael, C. saucia Tjedea, C. orbiculus Gyllenhal, H. axyridis Pallas, Hylyphantes graminicola Sundevall, L. Coelophora biplagiata Swartz, Lycosa grahami Fox, Tetragnatha sp., M. sexmaculates Fabricius, P. japonica Thunberg, S. ctomaculata Fabricius		Entomophthora aphidis Hoffm, Cladosporium sp.	*(Ren, 2008; Xiong, 2004) ***(Feng, 1986; Li et al., 1997)

*References of predators, **References of parasitoids, ***References of pathogens.

Table 3. Continued...

Insect pest (scientific name)	Pest family (order)	Predators*	Parasitoids**	Pathogens***	References
Oriental fruit fly Bactrocera dorsalis Hendel	Tephritidae (Diptera)		Aganaspis sp., Diachasmimorpha longicaudata Ashmead, Aceratoneuromyia indica Silvestri, Fopius arisanus Sonan, F. vandenboschi Fullaway, Pterolophia fletcheri Silvestri, P. incise Silvestri, Spalangia longepetiolata Boucek, Dirhinus giffardii Silvestri	B. bassiana Balsamo	** (Lin et al., 2006; Guo et al., 2006a; Zheng et al., 2006; Liang et al., 2007; Lu et al., 2007; Shao et al., 2009; Yao et al., 2008; Zhang et al., 2008b) ***(Pan et al., 2006, 2008; Yuan et al., 2010; Zhu, 2010)
Citrus leaf miner Phyllocnistis citrella Stainton	Gracillariidae (Lepidoptera)	Chrysopa boninensis Okamoto		Bacillus thuringiensis Berliner	*(Zhen & Yang, 2009) ***(Zhang, 2001)
Leaf beetle Clitea metallica Chen	Chrysomelidae (Coleoptera)	Labidura riparia Pallas			*(Nin & Qin, 2009)
Citrus aphid Toxoptera citricidus Kirkaldy	Aphididae (Hemiptera	Ischiodon scutellaris Fabricius, Alesia discolor Fabricius, Chrysopa septempunctata Wesmael, C. saucia Mulsant, C. orbiculus Gyllenhal, Harmonia axyridis Pallas, H. yedoensis Takizawa, Lemnia biplagiata Swartz, Menochilus Sexmaculates Fabricius, Synharmonia octomaculata Fabricius, P. japonica Thunberg		Fusarium lateritium Nees, E. aphidis Hoffm	*(Ren, 2008; Xiong, 2004) ***(Feng, 1986; Song, 2001)

*References of predators, **References of parasitoids, ***References of pathogens.

Table 3. Continued...

Insect pest (scientific name)	Pest family (order)	Predators*	Parasitoids**	Pathogens***	References
Thrips Frankliniella occidentalis Pergande	Thripidae (Thysanoptera)	Orius sauteri Poppius, A. barkeri Hughes, A. cucumeris Oudemans		B. bassiana Balsamo, Pandora neoaphidis Remaudière &.Hennebert, Pandora nouryi Humber, Zoophthora anhuiensis Li	*(Xiong, 2004; Zhi & Ren, 2006; Li et al., 2007; Liu et al., 2007; Ren, 2008; Zhang et al.,2007) ***(Feng, 1986; Li et al., 2003; Gui et al., 2005; Bao & Feng, 2006; Zhang et al., 2008b)

*References of predators, **References of parasitoids, ***References of pathogens.

Hoy et al., 2001; Étienne et al., 2001; Halbert & Manjunath, 2004; Pluke et al., 2008; León & Sétamou, 2010).

Predators

Arguably, predatory insects are the largest group of natural enemies used to control citrus insect pests. Among the 53 species recorded, Coccinellidae documented as dominated family including 30 predatory species in China (Table 3) (Niu et al., 2014). In China, many predatory mites have been described to control mite pests, especially Amblyseius cucumeris Oudemans (Mesostigmata: Phytoseiidae), A. barkeri Hughes (Mesostigmata: Phytoseiidae) and A. orientalis Ehara (Mesostigmata: Phytoseiidae), widely used in citrus orchards. In 1997, A. cucumeris was first imported to China, targeting P. citri and Phyllocoptruta oleivora Ashmead (Prostigmata: Eriophyidae), and successfully mass-reared on artificial diet in couple of years. Now, it has been broadly used among 20 crops in more than 20 provinces of China (Zhang et al., 2002).

The Asian citrus psyllid is also a vector of phloem limited bacterial disease of huanglongbing in China (Yang et al., 2006). Predators of this major pest D. citri includes green lacewings (Neuroptera: Chrysopidae), ants (Hymenoptera: Formicidae), ladybird beetles (Coleoptera: Coccinellidae), praying mantids (Mantodea: Mantidae), whirligig mites Anystis baccarum Linnaeus (Prostigmata: Anystidae) and spiders have been recorded in China (Wu, 1994; Wei et al., 1995). Gan (2006) demonstrated the successful application of biological control (A. cucumeris) compared with chemical control area and control area in Jinchengjiang district, Guangxi, China. Predator A. cucumeris resulted in highly significant decline (94%) in average population of P. citri, Eotetranychus kankitus Ehara (Prostigmata: Tetranychidae) and P. oleivora, during 24-92 days (Table 4).

Pathogens

Biological pesticides include the use of viruses, bacteria or entomopathogenic fungi to control insect pests of various crops. Almost, two decades ago, Starnes et al. (1993) demonstrated that microbial pesticides contributed <1% of the total of insecticide market worldwide. But, microbial control has been gaining importance since 1984, because of the increased resistance to chemical insecticides, environmental concerns in addition to improved performance of microbial control.

Entomopathogenic fungi have substantial prospective to become major component of sustainable IPM, either alone or in combination with predators or parasitoid (Table 3). Occasionally, with some crop damage being acceptable, entomopathogenic fungi are best used to control insect pest population below economic threshold level (Shah & Pell, 2003). Four entomopathogens Acrostalagmus aphidum Oudem (Hypocreales: Hypocreaceae), Paecilomyces javanicus Friederichs & Bally (Hypocreales: Cordycipitaceae), Verticillium lecanii Zimm. (Deuteromycetes: Moniliaceae) and Beauveria bassiana Balsamo (Hypocreales: Clavicipitaceae) have been recorded in association with citrus psyllid in China (Xie et al., 1988; Ye et al., 1994). Another important entomopathogenic fungus, Isaria fumosorosea (Hypocreales: Cordycipitaceae), can be used to cope with the Asian citrus psyllid (Avery et al., 2011, 2013) and brown citrus aphid populations (Pick et al., 2012), with a negligible influence on beneficial arthropods.

Similarly, B. bassiana CQBb111 isolates has strong pathogenicity and adaptability being evaluated to control citrus psyllid in China (Pu, 1985; Yu & Sun, 2003). In the same way, combination of B. bassiana with A. cucumeris against D. citri reduce the average hatching rate and increase average mortality of young nymphs under laboratory conditions (Zhang et al., 2011). Wang et al. (2013) described four virulent isolates of Aschersonia placenta Berk (Hypocreales: Clavicipitaceae) against D. citri with

Table 4. Population decline of citrus mites

Treatment	Population base	Population decline rate after the release of predatory mites (%)							
		11d	24d	37d	47d	58d	72d	82d	92d
Biological control	216	85.65	95.83	98.61	99.07	98.67	99.07	94.44	98.61
Chemical control	221	71.04	61.90	73.30	94.57	44.34	62.44	61.54	71.04
Control	239	-2.51	-7.11	22.59	61.09	70.71	72.38	41.00	23.43

Source: Gan (2006).

highest mortality rates 72.7%. D. citri mortality raised up to 78% after application of highly virulent islolates of I. fumosorosea (Liu, 2016). However research in this era started in China in the 1960s (Feng, 1986). But according to Niu et al. (2014) only 15 pathogens were recorded in China against various economically important insects.

DEVELOPING SIT BASED ON RNAI AND TRANSGENIC TECHNIQUE CRISPR CAS9

Previously, irradiation has been described to have deleterious effects on competitiveness and quality of SIT based mass-reared flies e.g., Ceratitis capitate Wiedemann (Diptera: Tephritidae) (Lux et al., 2002; Barry et al., 2003), Anastrepha obliqua Macquart (Diptera: Tephritidae) (Toledo et al., 2004), Anastrepha ludens Loew (Diptera: Tephritidae) (Rull et al., 2007). As part of ongoing research projects in our laboratory, we are aiming to develop SIT based on RNAi and CRISPR Cas9, especially against B. dorsalis in order to provide evidence required to improve the use of different tactics for IPM.

Using CRISPR-Cas9 based gene driving system and RNAi by silencing sex determination genes (Zheng et al., 2015), we are trying to develop SIT without irradiation. Similarly, our results demonstrated that by feeding dsRNA and bacteria expressing dsRNA, it is possible to silence genes through RNAi (Zheng et al., 2015). Furthermore, our results could facilitate studies of the reproductive organ specific roles of miRNAs (Peng et al., 2016) and theoretical approaches for applying RNAi worldwide against various insect pests of citrus.

CONCLUSION

In conclusion, for the reasons of pest resurgence, increased resistance and health hazards, pesticides use will arguably decline over the next few decades. Growers become aware of the economic and environmental benefits, for this motive, demands for non-chemical control methods are also rising. Moreover, with continuous research perspectives, in terms of improvement for non-chemical control techniques, China has started to make dynamism towards modernization but still there is a long way to go in all salient aspects related with citrus insect pest management.

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