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Research Progress on Green Control Technology of Fruit and Vegetable Fruit Fly Pests

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Abstract

The larvae of fruit and vegetable fruit fly pests feed on the inner pulp of the fruit, causing the fruit to turn yellow before it is ripe and fall off prematurely. In severe cases, the fruit will fall off completely, which has a serious impact on the fruit yield and quality. Fruit and vegetable fruit fly pests have become an important type of pest in China's fruit and vegetable producing areas, which will have a serious impact on the healthy development of the fruit and vegetable industry. This paper summarizes the current research status of fruit and vegetable fruit fly pest monitoring technology and agricultural control, biological control, physical and chemical control and other comprehensive control technologies at home and abroad, and looks forward to the development direction of comprehensive control technology, in order to provide a reference for the control of fruit and vegetable fruit fly pests.

Subject Areas

Plant Science

Keywords

Fruit Flies, Green Control Technology, Sex Attractant Technology

1. Background

Female adults of fruit and vegetable fruit flies pierce the fruit skin and lay eggs in unripe fruits, so they are also called "needle flies". Their larvae feed on the fruit pulp, causing the fruit to turn yellow before it is ripe and fall off prematurely. In severe cases, the fruit will fall off completely, which has a serious impact on fruit yield and quality [1]. Fruits and vegetables infested by fruit flies are difficult to identify in the early stages of the infestation, and their eggs can spread rapidly along with the infested fruits and vegetables through cross-regional transportation.

Therefore, fruit and vegetable fruit flies have become an important pest in China's fruit and vegetable producing areas, seriously affecting the healthy development of the fruit and vegetable industry [2] [3]. At present, the main fruit and vegetable fruit fly species in Zhejiang Province are *Bactrocera dorsalis* Hendel, *Bactrocera* (*Zeugodacus) scutellata* Hendel and Zeugodacus *depressus* Shiraki [4] [5]. The oriental fruit fly, also known as the citrus fruit fly or the oriental fruit fly, belongs to the order Diptera, family Tephritidae, and is a major pest of fruit and is listed as a worldwide quarantine pest [1]. The adult oriental fruit fly lays eggs in the fruit during the color change period, and its larvae feed inside the fruit. It harms a wide range of crops, including more than 250 kinds of fruits such as citrus, mango, and guava. The striped fruit fly mainly harms economic fruits and vegetables such as pumpkin and mango. In recent years, it has become one of the main fruit fly pests of fruits and vegetables in some areas. The striped fruit fly lays eggs on fresh fruits and vegetables, and its larvae feed inside the fruits, causing them to fall. In addition, the striped fruit fly also lays eggs on the flowers of crops. Wang Xingjian [6]'s research shows that the adult striped fruit fly can lay eggs on the flower buds of Japanese snake gourd. After the flower buds fall to the ground, the larvae burrow into the soil to pupate. The pumpkin fruit fly belongs to the order Diptera, family Tephritidae, genus Tephritidae. The adults mainly harm a variety of fruits and vegetables, such as pumpkins and watermelons, and horticultural crops. Different species of fruit flies harm fruits and vegetables in similar ways, mainly by feeding on the inside of the fruit, causing the fruit to fall and rot. The main differences in their morphological characteristics are the different black stripes between the abdominal segments and the differences in the wing veins and patches on the wings. The differences between different fruit flies are mainly in host plants and distribution areas. Jinhua area has suffered serious damage from the citrus fruit fly. In 2018, an outbreak of the citrus fruit fly in Yuandong Township caused economic losses of more than 10 million yuan to peach farmers in the township [7]. In addition to economic losses, due to improper selection of pesticides, unreasonable prevention and control measures, and excessive reliance on chemical pesticides in the process of fruit fly pest control, the "3R" problem of chemical pesticides (*i.e.*, pesticide residue, resurgence of pests, and resistance) is particularly prominent [8], which seriously affects the quality and safety of China's agricultural products. At the same time, chemical pesticides also kill a large number of beneficial organisms in orchards and farmland systems, destroying the biodiversity of farmland systems, leading to ecological imbalance in orchards and farmland systems and losing the function of regulating pests. Qin Yuchao [9] *et al.*'s research shows that the main climatic factor affecting the occurrence and growth of fruit flies in the local area is temperature, and it is also affected by other factors such as rainfall. Luo Wei [10] *et al.*'s research shows that under the future climate scenario, the area of the high-suitable habitat of the citrus fruit fly south of the Yangtze River will increase by as much as 16.2% - 37.5%. Therefore, in the context of the transformation of fruit fly control from single chemical control to comprehensive control combining agricultural control, physical control, biological control and chemical control, it is crucial to develop a set of comprehensive fruit and vegetable fruit fly control plans suitable for the local area by integrating various technical means.

2. Monitoring and Early Warning of Fruit and Vegetable Fruit Flies

The monitoring and early warning of fruit and vegetable fruit flies is divided into two parts, namely dynamic monitoring of the pest occurrence area and checkpoint quarantine. Due to the characteristics of fruit flies such as being relatively hidden in the early stage, having a long occurrence period, and being difficult to control, it is very difficult to achieve accurate control. Pest monitoring provides information such as pest population size and distribution for early pest control, thus improving the accuracy of pest control [10]. After years of development, agricultural pest monitoring and early warning technology have evolved from traditional sex attractant monitoring technology based on lures and traps to smart agricultural pest identification monitoring and early warning technology combined with the Internet of Things. Checkpoint quarantine technology has also evolved from traditional heat treatment, cold treatment, and radiation treatment technologies to the current fumigation technology [11].

2.1. Pest Dynamic Monitoring

Traditional dynamic monitoring of fruit flies involves collecting insects through physical and chemical trapping and manual identification. This method is time-consuming and labor-intensive, has gradually become out of touch with the times, and is gradually being eliminated. The latest smart agricultural pest identification monitoring and early warning technology uses computers and a variety of sensors to replace human senses. The sensor uploads data to the client in real time, and the user can view the relevant data, improving the timeliness of pest detection (**Figure 1**). The system can also view historical data and historical reports, pest disaster early warning, and remote control through the client [12]. The Internet of Things system combines photovoltaic power generation technology, using solar panels, batteries and other devices to form a photovoltaic power generation system to power the entire Internet of Things system [13]. However, the current conversion efficiency of solar panels is not high, and the photovoltaic system is easily affected by weather and has an unstable power supply. The Internet of Things system can also be combined with intelligent insect identification technology, which combines the Internet of Things system with a database, obtains relevant information about insects through the Internet of Things system and compares it with the data in the database to obtain the insect species (**Figure 2**). But in general, the cost of setting up the Internet of Things is relatively high, and its applicability and popularity in small and medium-sized orchards and farmlands need to be improved.

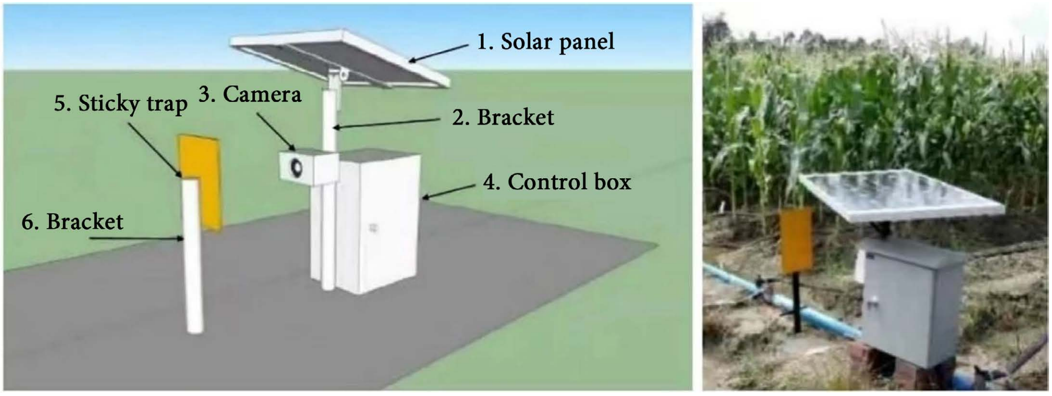

Figure 1. Intelligent pest monitoring and early warning system (cited from Guo etc. [11]).

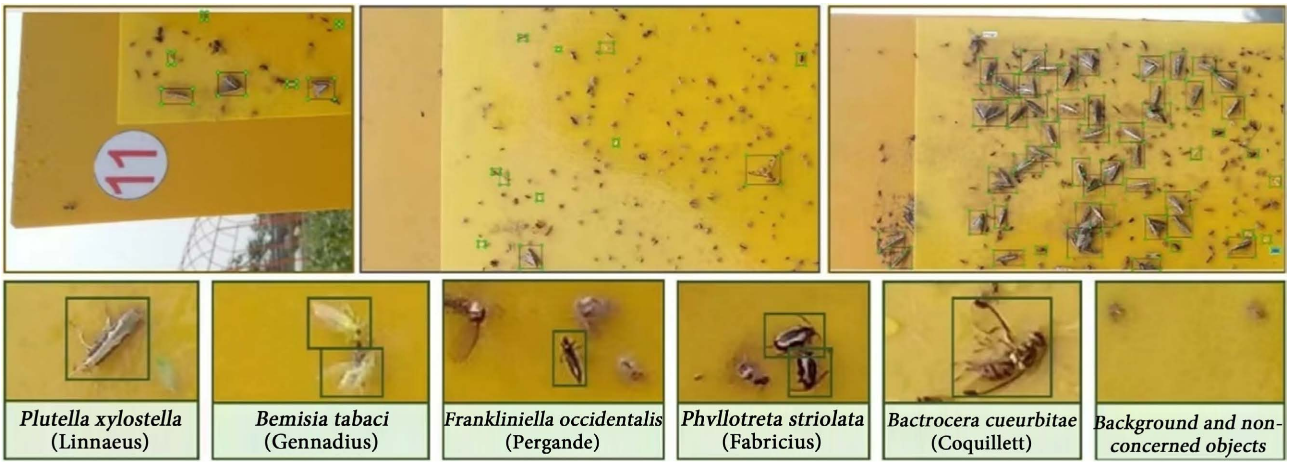

Figure 2. Automatic pest identification system (Quoted from Guo etc. [11]).

2.2. Border Quarantine

Border quarantine is an important means to prevent the spread of fruit flies. Traditional quarantine techniques are mostly inefficient and their use rate is gradually decreasing. For example, heat treatment requires the fruit core temperature to rise to above 46˚C, which will greatly reduce the quality and shelf life of the fruit; cold treatment has a low pest killing rate; and people have certain concerns about the safety of radiation treatment [14]. The current mainstream phosphine low-temperature fumigation treatment technology can make up for the shortcomings of most traditional quarantine technologies. Phosphine has become one of the most widely used fumigants due to its low boiling point, high toxicity, low residue, broad spectrum of insecticides, and low price. However, due to improper use of technical methods by users in the past, many pests have developed resistance to phosphine. Wang Di *et al.* [15] found that when 2.28 mg/L phosphine was used to fumigate fruits with orange flies of different ages for 96 hours and 144 hours, the mortality rate of the pests reached 100%, and there was no obvious effect on the quality of the fruit. As more and more flies such as the striped fly invade China, finding more targeted fumigants can more effectively control the damage caused by flies.

3. Comprehensive Control Technology for Fruit and Vegetable Fruit Flies

3.1. Agricultural Prevention

3.1.1. Fruit Bagging

Sharma *et al.* [16] found that fruit bagging can reduce the damage to fruits caused by various pests and diseases, including fruit flies, and can also reduce damage caused by sunburn, fruit cracking, bird pecking, etc. However, Zhang *et al.* [17] found that bagging can also affect the quality of fruits. Bagging will increase the temperature inside the bag, and the poor humidity and light intensity inside the bag will lead to poor appearance quality of the fruit. It will also affect the internal qualities of the fruit, such as taste and sugar content. Therefore, when choosing fruit bags, choose fruit bags with good light transmittance and air permeability to ensure the quality of the fruit. Ali *et al.* [18] found that if the fruit bags of apples and pears were opened 10 days before harvest, the color of the fruit could be roughly restored to the state without bagging. Therefore, opening the fruit bags sometime before harvest is also a way to ensure the quality of the fruit

3.1.2. Cleaning the Orchard and Deep Ploughing in Winter

The main purpose of cleaning an orchard is to collect and uniformly treat fallen and worm-infested fruits in the orchard. In the study by Li Yan *et al.* [19], it was mentioned that picking up worm-infested fruits and burying them deeply can reduce the source of insects. From before the fruits mature to the end of picking, pick up and destroy fallen and worm-infested fruits every week. If there are many fallen fruits, they need to be treated every day. The worm-infested fruits picked from the trees are placed in worm-infested fruit treatment bags and sealed for centralized treatment. By cleaning the orchard, fruit fly larvae and pupae at different stages can be killed, the base number of fruit fly populations can be reduced, and the development and reproduction of larvae and pupae can be avoided to achieve a control effect. In the study by Jiang Risheng [20], it was mentioned that deep plowing of the orchard in winter can kill the overwintering pupae of fruit flies and prevent fruit flies from harming fruit trees in the next year.

3.2. Physical and Chemical Control Technology

3.2.1. Sexual Attractant Luring Technology

Sex attractants have the advantages of being highly specific, non-toxic, and environmentally friendly. They are a new pest control technology developed in recent years [21].

The orange fruit fly mainly uses methyl eugenol (ME), a substance that is the precursor of sexual maturity of the male adult orange fruit fly, in combination with a trap to kill male flies and interfere with mating between male and female flies, thereby reducing the number of fertilized eggs and achieving the purpose of regulating the fruit fly population [22]. The sex attractant for the striped fruit fly is Cue-lure, which has an effective trapping range of less than 0.8 km^2. Lin Huafeng *et al.* have shown through trapping practice that Cue-lure has the best trapping effect on the striped fruit fly among various physical and chemical control technologies [23]. Steiner *et al.* [5] first used liquid sex attractants to control the orange fruit fly in 1955 and gradually promoted it in areas where the orange fruit fly occurs. Subsequently, Ohinata *et al.* [5] continued to explore ways to improve the trapping effect of sex attractants by changing the composition of sex attractants, and used Thixcin E as an extender of toxic male bait to control fruit flies. However, most of the sex attractants at home and abroad are only targeted at males, and are easily affected by the composition and concentration of the sex attractants, ambient temperature, etc., and the trapping effect is not ideal.

3.2.2. Food Attractant Trapping Technology

Food attractants are adult behavior regulators developed based on the pests' preferred food sources or plant volatiles. They can attract both male and female adults. Steiner *et al.* [24] began using hydrolyzed protein to control Hawaiian fruit fly pests in the 1950s. China is also developing low-cost hydrolyzed protein attractants. Wang Bo *et al.* [25] used enzymatic hydrolysis to extract hydrolyzed protein from waste beer yeast and processed it. The attraction rate for the citrus fruit fly reached 60.00%. It has excellent effects and low cost. It can fully utilize the waste yeast in beer and is environmentally friendly. Sweet and sour wine has the best attraction effect for pumpkin fruit flies. It also has strong attraction activity for the citrus fruit fly and the striped fruit fly.

At present, as a green control technology, the application of food attractants is still limited. For example, the effective period of food attractants is short. Most domestic products only last for 20 - 30 days, and the attractants need to be replaced midway. Therefore, the development of food attractants that can attract fruit flies for a long time and are easy to operate is the focus of future research on food attractant-killing technology. (See **Figure 3**)

Figure 3. Sex trap.

3.2.3. Plant-Derived Attractants

Plant-derived attractants mainly use host-specific plant volatile substances, crude extracts, etc. for trapping and killing. Wu Yingxiang *et al.* [26] adjusted the proportion of essential oil components to prepare a compound essential oil microcapsule suspension, which attracted 82% of male insects and 25% of female insects. It is highly efficient, environmentally friendly, and low-toxic., less likely to develop resistance and other advantages. Asarum *sieboldii* Miq extract can significantly reduce the population of *Bactrophora dorsalis* in carambola orchards, with a control effect of more than 90% [27]. However, the current extraction method has a low yield of essential oils (about 1%). To achieve commercial production, it is necessary to further improve the process level and reduce costs.

3.2.4. Insect Trapping

Insect traps are an efficient way to trap fruit flies, but during their application, it was found that many factors affect the trapping effect of insect traps. The first is the effect of the hanging position on the trapping effect of insect traps. Kuang Shizi's [28] study found that the trapping effect of insect traps hanging in the middle and upper parts of fruit trees is better than that of other parts. This may be because the number of fruits hanging in the middle and upper parts of fruit trees is greater than that in other parts, resulting in a larger number of fruit flies active and distributed. The second is the effect of the color of the insect trap on the trapping effect. Chen Haiyan's [29] study found that yellow insect traps are more effective in trapping orange fruit flies. This may be related to the orange fruit fly's tendency to yellow. Different colors will have a greater impact on the trapping effect of fruit flies. Jasrotia *et al.* [30] found in their study that climate factors will affect the trapping effect of rectangular yellow insect traps (area 3622 cm^2). For example, appropriate rainfall and sunlight can promote the trapping effect of rectangular yellow insect traps. (See **Figure 4**)

Figure 4. Insect trap.

3.2.5. Combination of Multiple Attractant and Control Technologies

Lu Huixiang *et al.* [31], sex attractants were combined with yellow boards to trap diamondback moths. The study found that the combined control method increased the trapping rate by 50% - 70% compared with the general control method, and the control effect was significantly improved. In a study by Wei Jianhua *et al.* [32], it was found that the use of a combination of physical and chemical trapping technology combined with multiple trapping methods can better protect natural enemies, play a role in biological regulation, and further protect the ecological security of agriculture. The use of a combination of multiple trapping methods can increase the trapping effect and be more conducive to protecting the ecological environment in the process of controlling fruit and vegetable fruit flies.

3.3. Biological Control

3.3.1. Release of Sterile Male Insects

This method aims to gradually reduce the number of fruit flies by continuously releasing a large number of sterile male insects in areas where fruit flies are severely infested so that they can mate with wild female insects and cannot produce offspring. The earliest conventional sterile insect technique (SIT) was proposed by Knipling in 1955. Later, through research, it was found that sterile male insects can be released when applying SIT [33]. After the advent of SIT, it has been widely used internationally and successfully controlled a variety of fruit flies. For example, Okinawa, Japan, successfully controlled melon fruit flies using SIT; and Western Australia successfully controlled Queensland fruit flies using SIT [34]. China started using this technology relatively late, and the main targets of control were the orange fruit fly and the orange fruit fly. From 1975 to 1981, Taiwan Province released sterile orange fruit fly male insects to control an orchard area of 39,300 hm^2. The fruit damage rate dropped from 6.7% before the control to 0.018%, with an effect of 99.73 % [35]. Hu Jianfeng *et al.* [36] found that the longest survival time of sterile males in the field was 15 days, and the sterility rate of eggs laid after mating with wild females was as high as 91%, and the release control effect was good. The application of sterile technology to control fruit flies is a relatively environmentally friendly and advanced practice. It has good control effects, little impact on the environment, and strong specificity. However, this method is currently expensive to implement and takes a long time to implement, and is not suitable for large-scale promotion and use.

3.3.2. Release of Natural Enemies of Fruit Flies

Fruit flies have a variety of natural enemies, which can be mainly divided into predatory natural enemies, parasitic natural enemies, pathogenic microorganisms, etc. Among them, parasitic wasps have the most significant control effect. Four species of *B. dorsalis* parasitoids, including *Fopius arisanus* and *Diachasmimorpha longicaudata*, have been successfully promoted and used in Hawaii, with an average parasitism rate of up to 70% [37]. When Huang Juchang *et* *al.* [38] conducted experiments on releasing Alishan leafminers in citrus orchards to control *Bactrocereus dorsalis*, they found that the diffusion distance was affected by factors such as the topography of the garden, wind direction, the size of the canopy of the host crop, and the degree of airtightness of the orchard. Therefore, when releasing parasitoids and sterile fruit flies, the distance to the release point and the quantity released need to be considered to achieve better release effects.

Predatory natural enemies can be roughly divided into three categories: mites and spiders, natural enemy insects, birds and amphibians. The release of *Zosterops japonicus*, chickens, ducks and other creatures can feed on fruit fly larvae on the ground. Lingshan County has cultivated and released Zosterops japonicus to control the fruit fly, with a control rate of 83.01% [39].

Pathogenic microorganisms play a certain role in the sustainable control of fruit flies, mainly fungi, pathogenic nematodes, and symbiotic bacteria. Pan Zhiping *et al.* [40] used *Beauveria bassiana* to test the pathogenicity of *Bactrocera dorsalis* and found that it had the lowest toxicity to mature larvae and the highest toxicity to adults, indicating that the use of fungi to control *Bactrocera dorsalis* has certain research prospects. Some symbiotic bacteria such as *Wolbachia* have also been isolated from *Bactrocera fasciatus* which show obvious attraction to female flies [41]. Further research on symbiotic bacteria in fruit flies may open up new ways to control fruit flies.

3.4. Chemical Control

The use of chemical agents is a relatively simple and effective method, which can be divided into two methods: Poison bait and spraying chemical agents [42]. Currently, the fruit fly pesticides registered in China include thiamethoxam, imidacloprid, avermectin, avermectin + polymyxin, avermectin + chlorpyrifos, chlorpyrifos + chlorpyrifos, and avermectin benzoate.

Li Jianying *et al.* [43] determined the indoor toxicity of six different insecticides to the fruit fly and found that 70% emamectin benzoate and 97% chlorpyrifos had good effects when using the quantitative drip method to kill eggs, the continuous immersion method to kill larvae, and the film method to kill adults. However, the same pesticide had different effects on the control of the fruit fly at different stages. Lan Yiquan *et al.* [44] found that 12.5% deltamethrin EC, 1% avermectin benzoate EC, 2.8% avermectin EC, and 5% highly effective chlorfenapyr microemulsion could effectively kill the larvae of the fruit fly. Yuan Jiusheng [45] used a mixture of 90 % crystalline trichlorfon 800 - 1000 times and 3 % brown sugar to lure and kill the citrus fruit fly, achieving a certain control effect. Studies have shown that the residual time of cypermethrin in water is very short, it is easily decomposed in the environment and absorbed by solid matter; avermectin is biogenic, easily degradable, and non-toxic, and more than 80% of it is degraded 28 days after application [46]. Scientifically selecting high-efficiency, low-toxic, low-residue, and environmentally friendly pesticides, reasonably adding spray adjuvants, and using advanced spraying technologies such as low-volume spraying and electrostatic spraying to reduce the dosage can greatly reduce the impact of chemical agents on the environment [47].

Chemical control of fruit flies has been carried out for more than 20 years. Due to the irrational use of pesticides, the resistance of fruit flies to some pesticides has increased rapidly and serious pesticide residues have polluted the environment. Scientific use of pesticides is an emergency measure during an outbreak of the citrus fruit fly. The best prevention and control period is determined according to the law of its occurrence, and scientifically selected high-efficiency, low-toxicity, low-residue, environmentally friendly pesticides are used to improve pesticide utilization and control effects.

4. Conclusion

In summary, there are currently a variety of control methods for fruit flies, and many have achieved good control effects. However, when implementing specific control methods, farmers lack information on pest population size and distribution due to the lack or insufficiency of fruit fly population dynamics surveys, resulting in low control efficiency. There are many types of insect traps on the market, and the trapping effects vary. It is necessary to screen insect traps with good trapping effects through experiments. Sex attractants and food attractants are easily affected by the environment, evaporate quickly, and protein attractants lack unified standards. The insect trapping effect is not very stable. The research on plant-based attractants is limited to the laboratory level, the cost of use is high, and it is difficult to promote and utilize. With the promotion of light trapping technology, the problem of low accuracy of insect traps for non-target pests has gradually become prominent. Therefore, in the future, it is still necessary to further study the effects of factors such as light intensity and wavelength on the accuracy of light traps to provide a scientific basis for the innovation of control technology. Therefore, in order to prevent and control fruit flies, a pest with strong transmission and reproduction capabilities, we should fully master efficient detection methods and comprehensively use physical and chemical control, agricultural control and other control methods to build a green, economical and reliable prevention and control system.

5. Outlook

The existing fruit fly monitoring method has changed from trap-based to a smart agricultural pest identification monitoring and early warning system combined with the Internet of Things. However, this method is relatively expensive and can be developed in the direction of reducing the deployment cost and increasing the popularity of monitoring devices. Fumigation quarantine has a great impact on the storage time of fruits at low temperatures. In the future, fumigants with less impact on fruits can be explored. Although the use of sex attractants can trap fruit flies economically and efficiently, they lose their effectiveness quickly, and the exploration of effective ingredients for sex attractants that can evaporate stably should be accelerated. Although food attractants represented by protein hydrolysates have an attractive effect on both male and female fruit flies, they have defects such as being unable to kill fruit flies themselves and unstable effects. Overcoming these shortcomings is the next development direction. At the same time, research on the biological mechanism of fruit flies' tendency to natural plant volatiles will have a good development prospect. For biological control, it is recommended to conduct a resource survey of local fruit fly natural enemies, conduct research on the control mechanism of natural enemies, screen natural dominant natural enemies, and introduce dominant natural enemy species through quarantine tests and other procedures to control fruit fly populations. The method of releasing sterile male insects is effective and environmentally friendly, but the cost is relatively high at present, so new ways to reduce the cost can be explored. As a conventional prevention and control method, agricultural control measures can be developed in the direction of reducing labor costs while ensuring good prevention and control effects.

Conflicts of Interest

The authors declare no conflicts of interest.

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