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Study on the Occurrence Regularity of Invasive Whitefly Bemisia Tabaci Population

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Abstract: The B biotype whitefly Bemisia tabaci (Gennadius) (Hemiptera: Aleyrodidae) is an invasive species in China, witch severely damage the production of numerous crops through direct feeding and transmission of plant viruses. In order to clarify the major biological characteristics of a whitefly as an alien invasive species, reveal the seasonal growth and decline of its population quantity, the law of fluctuation from year to year and it's influencing factors and improves the monitoring, prevention and control level. Our study investigates the main biological characteristics and the population quantity's fluctuation of the whitefly Bemisia tabaci in Linhai, Zhejiang province, China. Adult whiteflies were investigated in the greenhouse and field from 2006 to 2011 with using yellow sticky boards. The results show that the whiteflies can produce 11 generations each year with an evident generation overlapping. The number of whiteflies in the greenhouse started to increase from June, with a significant increase after July and then reached its peak during August and September. With the temperature drop, the whitefly population started to decrease after mid-October. The observation of the insects indicated that whiteflies are capable of surviving within the whole year under the greenhouse condition. On the other hand, the overwintering frequency for the whitefly in the open field was approximately 20%. Moreover, the main factors that affect the population dynamics of whiteflies in the field include the initial population number, climate condition, farming system and flood inundation, among which, the temperature condition is the most important.

Keywords: Bemisia tabaci, biological characteristic, fluctuation law, influencing factors, population dynamics, whitefly

INTRODUCTION

The whitefly *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) is a famous species complex pest with a worldwide distribution. Some of the whitefly complex members severely damage the production of numerous crops, such as kidney bean, cotton, tomato and tobacco, through direct feeding and transmission of plant viruses (Brown *et al*., 1995; Chu *et al*., 2004; Lin *et al*., 2004). In China, numerous important economic crops in Guangxi, Yunnan, Guangdong, Hainan, Zhejiang and Shanghai have suffered significant damages since the invasion of the B biotype whitefly from the mid- to the late-1990s, resulting in huge production loss (Luo and Zhang, 2002; Wan *et al*., 2009). This situation has worsened in many regions in China with the continuous spread and virus transmission of the invasive whitefly (Zhang *et al*., 2005; Alemandri *et al*., 2012). The whitefly has invaded Taizhou by transporting nursery-grown plants, which, in turn, spread and cause damages to other plants, such as melons, solanaceous vegetable, beans, cruciferae and many other vegetables, resulting in a serious loss in field production. Many efforts have been conducted on the taxonomy, biology, ecology and control of the whitefly. Others successively described the basic biological characteristics of the whitefly. It investigated the invasion mechanism of the whitefly, focusing on the competition between the invasive and indigenous whiteflies (Boukin *et al*., 2007; Dinsdale *et al*., 2010). However, many issues have not been deeply and systematically studied, particularly the population ecology and movement rules of the whitefly. Many efforts have been conducted on the taxonomy, biology, ecology and control of the whitefly. Luo and Zhang (2002) successively described the basic biological characteristics of the whitefly. Wan *et al*. (2009) investigated the invasion mechanism of the whitefly, focusing on the competition between the invasive and indigenous whiteflies. However, many issues have not been deeply and systematically studied, particularly the population ecology and movement rules of the whitefly. In the current study, greenhouse rearing and yellow-board trapping systems were applied to

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investigate the population infestation regularity and the influencing factors of the invasive whitefly *Bemisia tabaci* from 2006 to 2011. This study aims to clarify the main biological characteristics and reveal the rule of the seasonal growth and decline of population quantity and influencing factors of the invasive whitefly.

MATERIALS AND METHODS

The sexual attraction on dynamics of the adult whitefly in an open field was observed during winter and spring to analyze the relationship between the whitefly surviving rate and climate changes. The biological characteristics of the whitefly in a greenhouse were observed from 2006 to 2007. Poinsettia and kale cultivated in pots with a nylon cover were used as host plants. The whiteflies used in the experiment were collected from a local region (Taizhou, China).

The adult whiteflies were attracted with a yellow sticky board for the investigation. The monitored information included the following:

- **Location:** A suburban vegetable production base in Linhai
- **Time:** The whole period from 2007 to 2011
- **Crops:** Vegetables in a greenhouse and in the open field were used in the experiment. The greenhouse was covered with shelter covers from late December to late April of the following year and was then removed. Combinations of tomato/pakchoi/cucumber/ tomato were planted in the green house for the whole year. For the open field system, combinations of pakchoi/cucumber/cowpea/ free of plants/pakchoi were planted for the whole year
- **Method:** Homemade plastic yellow sticky board (30 cm×45 cm) painted with engine oil was used in the experiment. The sticky board was repainted after every investigation on the trapped adult whiteflies. Four yellow sticky boards were suspended on the crops in the greenhouse and open field during the whole process, having a separation distance of 15 m to 20 m and height of 80 cm to 100 cm. The quantity of the trapped insects was recorded every five days

The current study aims to determine the main factors that affect the population dynamics of the whitefly by analyzing the survival dynamics and movement characteristics of the whitefly population, together with the results of the field investigation and meteorological data.

RESULTS AND DISCUSSION

Overwintering of the whitefly: Results of the systematic monitoring on the adult whitefly in the suburban vegetable production base in Linhai from 2006 to 2011 are listed in Table 1. The results indicate that the winter temperature is the key factor of the overwintering of the adult whitefly. Based on the meteorological data analysis together with our investigation, from mid-December to mid-February of the following year, adult whiteflies cannot overwinter in the open fields at an average temperature below 8°C. On the other hand, the adult whiteflies can safely overwinter in the open field at an average temperature above 8°C.

Generation characteristics of the whitefly: The whiteflies were observed on poinsettia in a greenhouse. Eleven generations of the whitefly were observed in Linhai during the experiment and overwinter with the pupa stage. An evident generation overlapping was observed from the second generation and the eclosion peaks for each of the whitefly generation occurred during the following periods: late February to mid-March for the overwintering generation; late April to early May for the first generation; late May to of June for the second generation; mid-June to early July for the third generation; mid-to late July for the fourth generation; early August for the fifth generation; late August to early September for the sixth generation; mid-to late September for the seventh generation; late September to early October for the eighth generation; mid- to late October for the ninth generation; early to mid-November for the tenth generation; after which, the wintering period occurred with the pupa formation. In May 2007, the first whitefly generation (26 pots) reared in the poinsettia plants after overwintering was transferred to a glass house to observe the population dynamics. The results indicate that the whitefly population increased slowly in the early period. Moreover, the population increased gradually from June, rapidly after July and then significantly in August and September. The whitefly population started to decrease with the decrease in temperature

Table 1: Relationship between numbers of trapped whitefly adults and temperature of winter in the open field

		Numbers of trapped whitefly adults (numbers with each sticky)							
Year (month)	Temperature (Avg)/°C	Mid of Dec.	Later of Dec.	Early of Jan.	Mid of Jan.	Later of Jan.	Early of Feb.	Mid of Feb.	Later of Feb.
2006 (mid of Dec.)–2007 (mid of Feb.)	7.82	_	_	_	_	_	0	0	0
2007 (mid of Dec.)–2008 (mid of Feb.)	8.54	28	4	2	2	2	6	5	7
2008 (mid of Dec.)–2009 (mid of Feb.)	7.77	3	4	0	0	0	0	1	1
2009 (mid of Dec.)–2010 (mid of Feb.)	8.70	20	18	0	0	0	0	0	0
2010 (mid of Dec.)–2011 (mid of Feb.)	7.81	1	0	0	0	0	0	0	0

after mid- to late October. Therefore, the whitefly populations of the fourth, fifth, sixth, seventh and eighth generations were much higher and can cause more losses to crop productions compared with the other generations.

Biological features of the whitefly: The developmental stages of the whitefly include the egg, nymph, pupa and adult stages. The adult whiteflies prefer to feed and lay eggs on young leaf of host plants. The whitefly eggs are elliptical in shape and gather on young leaves on the upper part of the plants. The eggs are typically laid on the back of the leaf blade with only a few on the surface. The eggs are laid in random and usually in heaps. The roots of the eggs have an egg pedicle that inserts into the plant tissue. Freshly produced eggs are light white covered with wax, making them hard to identify with a naked eye. With the help of the magnascope, the egg pedicle that is fixed vertically onto the blade tissue can be seen clearly. The egg pedicle gradually becomes brown-black during the development. Approximately 80 to 120 eggs were observed for each of the female whitefly. The whitefly nymph is divided into four stages. Newly emerged nymphs move within 1 cm to 2 cm on the leaf around the egg shell and then choose the proper position to settle down, usually on the part around the leaf vein. Nymphs will not move from its position on the leaf thereafter during ecdysis. In the fourth stage, the nymph secretes amount of wax and the body wall becomes thick and hard with a smooth surface. During this period, the nymph becomes subnymph and turns yellow.

The greenhouse observation and open field investigation indicated that the adult whiteflies gradually move to the top leaves of the plants with the growth of the host plant, forming the vertical distribution pattern of the different whitefly stages from the top to the bottom of the host plants. The adult whitefly and newly produced eggs are found on the top leaves, the brown-black eggs and nymphs in the first to third stages are mostly found in the middle part of plants, while the subnymph and puparium mainly gather on the lowest part of the leaves. Two red eyes can easily be identified in the late pupa stage before eclosion. During eclosion, the back of the puparium breaks into an inverted “T”-shaped crack where adults exuviate gradually, starting from the chest to the head. The newly emerged adults usually stay beside the larva puparium with two wings quilled on the back of the body. The two wings spread after approximately 15 min. Whiteflies are typically arranged in pairs of female and male and a large number of whiteflies sometimes gather together. Adult whiteflies tend to hide between overlapped leaves. The adult whiteflies become active and capable of short-distance flying at temperatures ranging from 25°C to 30°C. And adult whiteflies tend to fly around immediately with the disturbances. The adults will become slow and stay quietly on a leaf when the temperature declines to under 15°C. Furthermore, the adult whiteflies start to die gradually when the temperature decreases further to 7°C. However, some adult whiteflies retain their ability to fly and newly emerged adult whiteflies were observed even when the temperature decreases to as low as 12°C.

Population seasonal dynamics regularity: Figure 1 and 2 shows the results of the monitoring on the population dynamics of the whitefly in the suburban vegetable base greenhouse and open field systems from 2007 to 2011 in Linhai. The whitefly population seasonal dynamics presents a bimodal curve, in which the peak is high and abundant during the summer and is low and less in the autumn during the various years. The emergence of the adult whiteflies indicated differences between the greenhouse and open field systems. In the open field system, the start of the adults was observed on April 30, January 5, February 20, March 10 and March 25 from 2007 to 2011, which were delayed by 74, 0, 46, 5 and 79 days compared

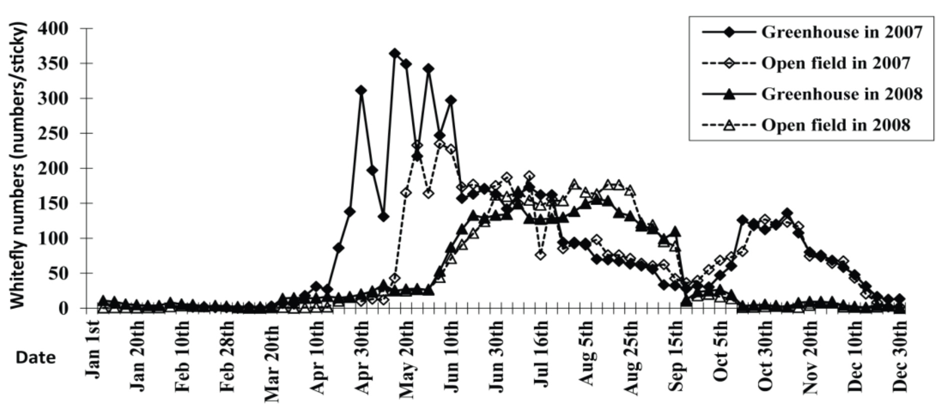

Fig. 1: Population dynamics of whitefly in Linhai (2007-2008)

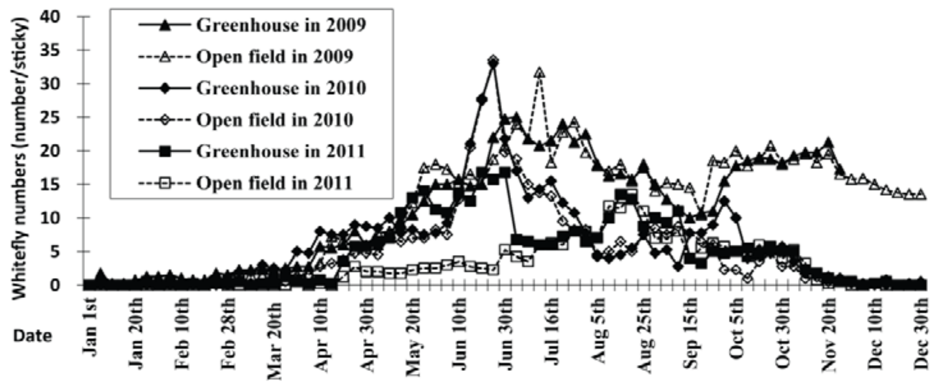

Fig. 2: Population dynamics of whitefly in Linhai (2009-2011)

with the greenhouse system, respectively, with an average of 41 days. These differences can be attributed to the fluctuation caused by the high and low temperatures of winter and spring in the different years. The population peak of the adult whitefly in the open field was similar to that in the greenhouse system. From 2007 to 2011, the summer peak of the whitefly population emerged from late April to late July, from mid-June to mid-September, from late May to mid-September, from mid-May to late July and from mid-May to early September. Accordingly, in the open field system, the number of whiteflies during the summer peak amounted to 2556, 2873, 459, 245 and 147, accounting for 54.5, 86.1, 52.9, 65.9 and 68.4% of the total number of whiteflies for that year, respectively. In the greenhouse system, the number of whiteflies during the summer peak amounted to 4048, 2610, 435, 258 and 265, accounting for 64.4, 79.3, 58.5, 57.8 and 75.1% of the total number of whiteflies for that year, respectively. Furthermore, a relatively low number of the whitefly population was recorded after the summer peak period and generally lasted for 20 days to 45 days. The whitefly population during the autumn peak appeared from late October to mid-November, from mid-to late November, from early October to late November, from mid-September to early October and from mid-to late October. In the open field system, the number of adult whiteflies during the autumn peak amounted to 689, 25, 204, 14 and 20, accounting for only 14.7, 0.7, 23.5, 3.8 and 9.3% of the total whiteflies for that year, respectively. In the greenhouse system, the numbers of whiteflies during the autumn peak amounted to 719, 35, 190, 51 and 26, accounting for only 11.4, 1.1, 25.5, 11.4 and 7.4% of the total whiteflies for that year, respectively. The whitefly population decreased drastically during mid- to late December, which is when the insect populations in both systems were relatively low and whiteflies transfer to warm overwintering areas.

Annual movement regularity: Based on the whitefly population dynamics from 2007 to 2011, the years 2007 and 2008 are clearly the outbreak years, whereas 2009 to 2011 are the years with a relatively less whitefly population. Using M as the number of trapped whiteflies for the whole year (number/sticky) and N as the quantized year (2002 was treated as the first invasion year; thus, the values of N = 6, 7, 8, 9, 10 during 2007 to 2011), the whitefly movement locus equation was obtained after the statistical analysis. The movement locus for the open field system can be expressed as follows:

$$M_{open\ field} = 312.21N^2\text{-}6187.1N\text{+}30787\ (n = 5,\ r = 0.9834^{**})$$

The movement locus for the greenhouse system can be expressed as follows:

$$M_{\ greenhouse} = 564.7\ N^2\text{-}10506N\text{+}49013\ (n = 5,\ r = 0.9967^{**})$$

The results of our study indicate that the movement cycle of the whitefly population takes approximately around 9 to 10 years and the population tends to decrease with a low ebb movement recent years, but is expected to return to an ascending movement eventually.

Base number of the whitefly population: Base number is the pacing factor for the production and development of a population. According to the whitefly monitoring results of the greenhouse and open field systems from 2007 to 2011, together with statistical analysis, the whitefly number of April is the most important base number for the existence and development of the whitefly population for the whole year. The whitefly population density in April is positively correlated with the trapping quantity for the whole year as follows:

$$Y = 8.3879M_4\text{+}1286.9\ (n = 10,\ r = 0.7082^{*})$$

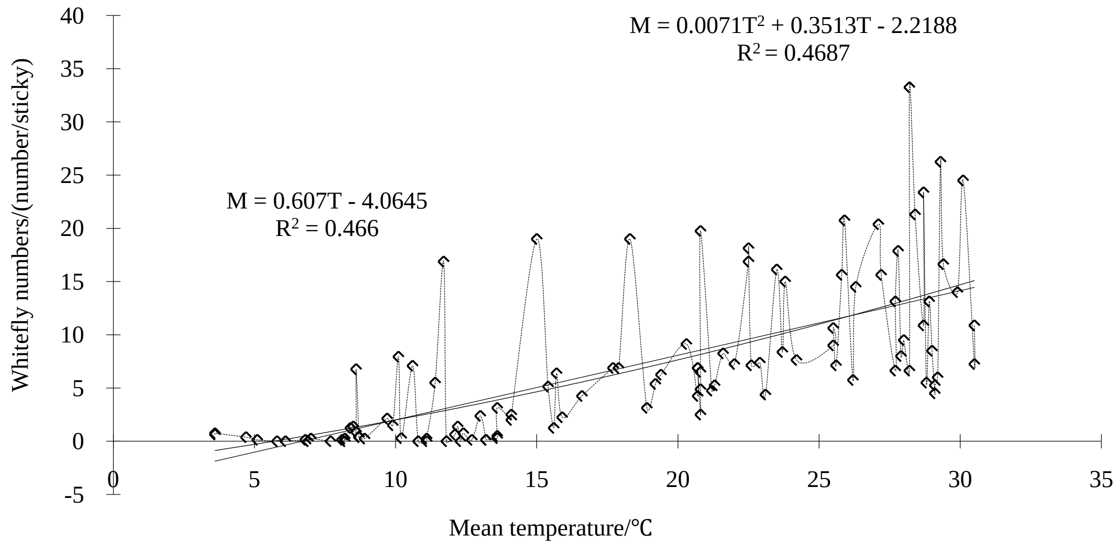

Fig. 3: Population dynamics of whitefly and temperature relationship (2009-2011)

Meteorological condition: Analyzing the relationships between the meteorological elements and the adult whitefly population, temperature was proven to be the most significantly related with the whitefly population dynamics. Figure 3 shows the statistical analysis of the conducted experiment from 2008 to 2010 (including 36 periods of 10 days each). This analysis indicates that the population density (M) varies with temperature. The linear model of M with respect to temperature is given by M = 0.607T-4.0645, (n = 36; r = 0.6826**) and the curvilinear model is given by M = 0.0071T2+0.3513T-2.2188, (n = 36; r = 0.6846**). The results show that the whitefly experiences difficulty in surviving when the average temperature in the period of 10 days is below 5°C to 8°C and that a temperature range of 8°C to 10°C is the state for the whitefly to survive criticality. When the average temperature during the 10 days is in the range of 10°C to 20°C, the whitefly population is in the state of low density and when the temperature is above 20°C, the population increases rapidly and continues to increase with increasing temperature. When the average temperature is above 30°C, the whitefly population is significantly affected by the rising temperature, leading to the valley period of the population dynamics. Then, with the suitable meteorological condition during summer and autumn, the population peak of autumn reappears, leading to autumn damage.

Tillage conditions: The whitefly population base number and temperature variation are the two main factors that affect the whitefly population dynamics movement. However, for the habitat and reproduction environment of the whitefly, the tillage conditions become the key factor instead. Results of the monitoring on the two systems (greenhouse and open field) show that the whitefly can basically live and reproduce during the whole year, except in the open field from January to March during winter (non-warm winter). Therefore, the average density of the whitefly population in the greenhouse was higher than that in the open field during winter and spring (2.74 times from January to March and 1.67 times from April to May). No whitefly population difference was observed between the two systems during June and the synchronous changes in population occurred from July to December. However, during warm winter, the trapped number of whiteflies in the greenhouse was significantly higher (one to three times) than that in the open field (Table 2). These results may be attributed to the whitefly overwintering in the greenhouse.

Flood inundation caused by typhoon: This study shows that typhoon and flood inundation have great effects on the whitefly population. As can be seen in Table 3, the suburban vegetable base in Linhai was intruded by typhoon on September 9, 2008, causing the inundation damage of over 30 ha of vegetables. Accordingly, the whitefly population decreased sharply, with an 84.16% decrease in the open field and 81.11% in the greenhouse. In addition, the vegetable base was damaged again by another typhoon on October 11 of the same year. Considering that the intensity of this typhoon was relatively weaker than the previous one, the vegetables in the greenhouse was only submerged for a short period of time. Consequently, the whitefly population decreased by 90% in the open field system, whereas only a 14.08% decrease was observed in the greenhouse and the low population density lasted until

Table 2: Sticky trapped numbers of whiteflies monthly from 2007 to 2011 in greenhouse and open field (numbers/sticky)

					May.	
Years open field	Jan.2007	Feb.0.00	Mar.0.00	Apr.0.00	10.00	630.00
	2008	4.75	17.00	3.75	50.50	151.50
	2009	0.00	3.25	12.25	30.75	72.75
	2010	0.00	0.00	4.75	20.75	40.75
	2011	0.33	0.67	0.75	6.25	12.75
	Avg	1.02	4.18	4.30	23.65	181.55
Greenhouse	2007	0.00	5.50	18.25	611.00	1600.00
	2008	39.00	28.50	37.50	96.75	164.25
	2009	5.50	7.25	14.00	34.00	60.00
	2010	0.00	1.00	16.75	45.50	49.75
	2011	0.75	1.00	2.75	16.25	62.50
	Avg	9.05	8.65	17.85	160.70	387.30
Years	Jan.	Feb.	Mar.	Apr.	May.	Jun.
Open field	2007	0.00	0.00	0.00	10.00	630.00
	2008	4.75	17.00	3.75	50.50	151.50

Table 3: Investigation of the effect to whitefly population caused by typhoon and inundation in vegetable base (2008, Linhai)

				Before typhoon		After typhoon		Decresed percentage
Investigation	Location	Hosts	Effect of typhoon	Period	Numbers/sticky	Period	Numbers/sticky	(%)
Investigation on whitefly population on typhoon of Sep. 19th	Suburb vegetable base of Linhai	Vegetable of open field	Inundation over 30 hectare	9/1-9/15	303	9/20-9/30	48	84.16
		Vegetable of greenhouse	Inundation over 30 hectare	9/1-9/15	323	9/20-9/30	61	81.11
whitefly population on typhoon of Oct. 11th	Suburb vegetable base of Linhai	Vegetable of open field	Inundation over 20 hectare	9/30-10/10	50	10/20-10/30	5	90.00
		Vegetable of greenhouse	Inundation over 10 hectare	9/30-10/10	71	10/20-10/30	61	14.08

the end of the year. Furthermore, the *Cucumis* melon in the sci-tech demonstration district greenhouse was not affected by the flood; and the whitefly population remained over 0.5 cm^{-2} (equal to 300 to 500 whiteflies per sticky board) on average from September to November. Therefore, a large scale inundation has a continuous and remarkable effect on the control of the whitefly population.

CONCLUSION

In this study, 11 whitefly generations for a whole year were obtained in Linhai, Zhejiang province according to laboratorial rearing and observation. These results provide important information for the monitoring and precaution of whitefly outbreaks.

Through the continuous monitoring of the whitefly in the two systems- greenhouse and open field of the suburban vegetable base, the whitefly population was found to develop annually in the greenhouse of Linhai, Zhejiang province. The whitefly population can also overwinter in the open field with only 20% of the overwintering frequency. The key factor for the whitefly survival in winter is the average temperature from mid-December to mid-February of the following year. The critical temperature for the survival of whiteflies ranged from 8°C to 8.5°C, indicating that whiteflies cannot overwinter with an average temperature below 8°C, but they can overwinter above 8.5°C. The whitefly population dynamics presents bimodal seasonal change patterns and the early presence of adult whiteflies varies per year. Adult whiteflies emerge in January in the open field system for some early years and in late April for some later years. The emergence of the whitefly has an average of 41 days (0 to 79 days) and is delayed in the greenhouse compared with the open field. The peak periods of the whitefly population in the open field and greenhouse systems are generally similar, in which the summer peak occurs from late April to late July for some early years and from mid-June to mid-September for some later years. The summer peak generally occurs from mid-May to early September. The adult whitefly population in the summer peak of the open field system accounted for 65.56% (52.9 to 86.1%) of the total population in a year, whereas in the greenhouse system, the summer peak accounted for 67.02% (57.8 to 79.3%) of the total population in a year. The autumn peak period generally appears from mid-October to late November, with an occurrence frequency of 60 to 80%. The adult whitefly population in the autumn peak of the open field system accounts for 15.83% (9.3 to 23.5%) of the total population in a year and in the greenhouse system, accounts for 13.93% (7.4 to 25.5%) of the total in a year. The whitefly population drops significantly in mid- to late December and the populations in both the open field and the greenhouse systems were maintained with a low density because of the transferring of the whitefly to the warm overwintering sites in the open field and greenhouse. The results of this study are consistent with the data obtained from the laboratory, which provide valuable information for timely control of these serous pests in practice.

The experimental and statistical results indicate that several factors affect the whitefly population dynamics. These factors include the base number of the population, meteorological condition, tillage conditions and typhoons. Among the analyzed factors, temperature was found to be the most important factor. Studies conducted on the various temperature effects on the Bbiotype whitefly development indicated that the temperature in the range of 20°C to 32°C is the appropriate temperature range for the population growth and reproduction of the whitefly (Liu *et al*., 2012; Parrella *et al*., 2012). In addition, the most suitable temperature is 26°C and the highest intrinsic rate of increase is at 29°C. Statistical analysis of the constant field monitoring and meteorological data from 2008 to 2010 indicated that the whitefly population density (M) changes with the average temperature (T, °C) within a specific period of 10 days in a month. The linear model of this relationship is given by M = 0.607T-4.0645, n = 36; r = 0.6826** and the curvilinear model is given by M = 0.0071T2+0.3513T-2.2188, n = 36; r = 0.6846**. The results of this study show that the whitefly experiences difficulty in surviving when the average temperature for the 10 days is below 5°C to 8°C and that the population is in the state of surviving criticality at temperatures ranging from 8°C to 10°C. The whitefly population was in the low density state at an average temperature ranging from 10°C to 20°C. And the whitefly population increased rapidly with increasing temperature above 20°C. Finally, the whitefly population decreased at an average temperature above 30°C. Thereafter, the whitefly population returned to its peak, causing a serious damage to the vegetables during autumn.

Based on a constant monitoring of the whitefly population for five years in the fields from 2007 to 2011, this study revealed that the whitefly population gradually decreases in the suburban vegetable base in Linhai. The whitefly population movement locus of whitefly for the open field system is given by Mopenfield = 312.21N2-6187.1N+30787 (n = 5, r = 0.9834**) and that for the greenhouse system is given by Mgreenhouse = 564.7N2-10506N+49013 (n = 5, r = 0.9967**). Further investigation is necessary to test if the variation rules revealed in this study are caused by the intrinsic factor of the long-term movement of the whitefly population or by external environmental forces, such as farming, climate, natural enemy, or pest management and control.

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