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Risk Evaluation of Main Pests and Integrated Management in Chinese Wolfberry, *Lycium barbarum* L.

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Abstract.- Chinese wolfberry *Lycium barbarum* L. (Solanales: Solanaceae), is an ancient herbal medicine and has been used for years in China. However, insect pests associated with this plant had not yet been well studied. The present study characterized the main pests associated with this plant. The method of risk assessment indices and the method of experience formulae were used to analyze the risk of pests under different management systems. The result demonstrates most frequent, incidental, and general insect pest in abandoned, organic and conventional fields. Analyses using CANCORR showed that the dynamics of pest populations were similar in all fields under different management system. Moreover, the matrices of correlation coefficients showed that dynamics of pests were significantly correlated. The correlation coefficients in dichotomous pattern *viz*. the abandoned field and the conventional field, the abandoned field and the organic field, the conventional field and the organic field were 0.8504, 0.8447, and 0.8564, respectively. Dynamics of the populations showed that the frequent disaster pests had two population establishment stages and one exponential growth stage in a year. The optimal controlling stages were from late part of the infancy period to early part of outbreak I period, middle of outbreak I period and from late part of dormancy period to early of outbreak II period. These were the key periods to control pest outbreak. The implications of these results are discussed.

Keywords: Chinese wolfberry field; control strategies; disaster pests; optimal separations; risk assessment**.**

INTRODUCTION

Lycium barbarum L. (Solanales: Solanacae) is a famous Chinese herbal medicine and a healthy food. In 2007, Ningxia cultivation area of *L. barbarum* was 12,006 mha (million hectares), Inner Mongolia 29,681 mha, Xinjiang 9,671 mha. *L. barbarum* accounts for about 30% of cultivated area in China, 50% of the country's output and 62% of the export volume. *L. barbarum* industry has become the main industry of Ningxia. *L. barbarum* products have become important brand names in China. With the continuous development of *L. barbarum* industry, the pests also become increasingly serious. The outbreak of insect pests seriously reduces the yield and quality of Chinese wolfberry, bringing huge economic losses to farmers. The risk assessment of harmful organisms was developed in the late 1970s. More studies were concentrated on the risk and the structure of community characteristics (Li *et al*., 1998; Solomon and Sibley, 2000; Liang *et al*., 2006), seasonal variations of zooplankton species (Yağcı, 2014) but most researches were on a single invasive species (Wang *et al*., 2003; Du *et al*., 2005; Chen *et al*., 2007; Yang *et al*., 2007) or ecosystem risk (Bai *et al*., 2002; Inamura *et al*., 2003; Lu *et al*., 2003; Ren *et al*., 2008). FAO/ISPM has stipulated the pest risk analysis (PRA) standard procedure in 2001.

There were a number of studies about prevention and control strategies, especially in the structure of community characteristic and control of the natural enemies (Ge *et al*., 2002); but studies from sub-community aspect have been conducted in scanty. Based on 5 risk aspects of these pests including their distribution area, degrees of harm, the number and species of natural enemies, the biological characteristics of pests, and ecological characteristics, for the first time, this paper analyses the comprehensive degree of harm from all kinds of sub-community pests in Chinese wolfberry fields. We examined the characteristics of different pests, proposed control measures, revealed the mechanism of the pest, and from this theory-based approach

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provided evidence for pest control and risk analysis.

MATERIALS AND METHODS

Sampling sites

Conventional field

Gardens of Yinchuan are located in 38°34´-36´N,106°8´-10´E the soil is alkaline mountain sierozem, 10 year old tree, better management, better tree potential, use pesticides 12 times a year , mainly abamectin, imidacloprid, chemical pesticide chlorpyrifos, etc.

Organic field

Ningxia Forestry Academy of Sciences organic Chinese wolfberry base (Organic Food Development and Certification Center-OFDC certification 38°34´-36´N,106°11´-13´E, the soil is alkaline mountain sierozem, 7 years old, better management, better tree potential, use pesticides 8 times a year, mainly azadirachtin, Li reed alkali, rotenone and sulfur rubber suspension agent.

Abandoned field

Ningxia Forestry Academy of Sciences Chinese wolfberry experiments center 38°27´-28´N,106°12´-13´E, the soil is ash brown, 6 years old, poor management, the trees grew well, pesticides. All trees species are *L. barbarum*, variety (Ningqi 1st), spacing 1m x 3m from 2007, making a system census for different artificial interference conditions Chinese wolfberry fields every 10 days from April to November.

Survey methods

A board type 5 random sampling method (Gao and Pang, 2006) was used, according to the characteristics of Chinese wolfberry trees. Each tree was divided into 5 areas: east, south, west, north and center. In each area one representative branch was chosen, giving priority to branches that were longer than 40 cm. We used visual estimation and sweeping net to investigate insect species and individuals. The type and number of insects in the range were noted visually. The common types were recorded; the rare types add the labels. The collected larvae were kept in a bottle and fed until they developed into adults and identified. Insects were also collected using sweep nets (50 sweeps) under the trees. The collected insects were placed into the killing bottles and taken to the laboratory for proper identification. Moreover, the type and number of insects were also recorded. Gall mites were also collected. One representative branch in each direction was brought back to the laboratory and fruits were dissected for insect inspection, then after all the arthropods were weighed.

Data sources

All of the original data were checked by statistical yearbook, government departments and research institutions. Distribution of pests in Chinese wolfberry growing area (P1) and degree of attention (P24) (derived from the Ningxia Academy of Agricultural Sciences Institute of Chinese wolfberry). The potential economic damage (P21), spread diseases and caused serious reactions of crops (P23) and capacity of migration and proliferation (P42) derived from the Ningxia Academy of Agriculture and Forestry Research Institute of plant protection, it's nearly 50 years of Chinese wolfberry material and research achievements. Capacity of adaptability (P43) was collected from climate data of Ningxia Meteorological Bureau 1958-1990 statistical year book while hazard sites (P22), individuals of one host (P31), average weight (P32) and life (P33) of different pests, generation of one year (P34), species (P51) and individuals (P52) of natural enemies in one host were derived from experimental investigation and laboratory test.

Analysis of risk sources

Risk sources involved in the community pest evaluation might be caused by an effect of the attributes of the pests and environmental factors. Attributes of the pests are decided by distribution, biological characteristics, ecological characteristics and degree of damage. Environmental factors are concerned with the property of soil, vegetation situation and agricultural tillage conditions, pesticide selection pressure, competition between species, predation, parasitism and mutual benefits (Harvey and Clouston, 1999; Landis, 2003; Iiyama *et al.*, 2005).

Analysis of historical data

Historical data were analyzed using the following indexes (P1) pest distribution range. This is the index of evaluating pest distribution, representing the adaptability of pests; degree of harm (P2) is an index evaluating damage done by the pest; biological characteristics (P3); ecological characteristics (P4), P4 is the main index, which determine the damage degree of pest insects; predation and parasitic effects (P5), this is affected by the species of natural enemies present and the size of their populations and can have a strong influence on the degree of pest damage. It can be used as an index of evaluating pest risk. Soil characteristics and vegetation conditions have an indirect effect on pests. Human interference in a farmland ecosystem is large, and very unstable, so it is not considered. Use of pesticides is common and very hard to standardize, so this is not considered; Interactions between species competition and mutual benefit relationships is changeable and does not play a major role on the harm of pests in agricultural ecosystems.

Qualitative analysis and evaluation index

This includes analysis of the risk source of agricultural damage, determining judgment indicators of risk assessment and establishment of evaluation standards (Table I).

Quantitative indicators

Index method of pest risk

Using a large number of data analyses, a pest risk assessment of comprehensive indicators system was established (Landis, 2003; Su *et al*., 2005) (Fig.1), which was divided into two systems, five aspects and fourteen indices. The indices were then quantified and at the same time, these numbers were combined using the Analytical Hierarchical Process (AHP) method (Swanson, 1998; Sydelko *et al*., 2001) to obtain the weighted scores. The scores from left to right were 0.079, 0.103, 0.059, 0.062, 0.034, 0.104, 0.052, 0.088, 0.042, 0.091, 0.079, 0.057, 0.051 and 0.099.

$$R=\Sigma Pi\times P,$$

Where R is consistency ratio, P is index value and Pi is weight. Using the classification standard (Table II), the weighted “pest risk index” evaluated the relative size of different pest risks in the community, in order to calculate the degree of risk of community pests by sample surveys.

Empirical formula method

After the comprehensive system was used to assign values to each index, considering that pest risk is closely related to individual number In1, weight W, average life L, generations of a year G, migration ability M, transmitted disease D, distribution area S, harm location P, natural enemy species N and number “In2”, the empirical formula method was used to calculate risk value DP (Table III).

$$DP = In1\times W\times L\times G\times S\times M\times D\times P/ In2\times N$$

Pest sub-community analysis method

For optimal separation, the main pest individual number in each investigation was used as the original data matrix (Gao, 1998; Gao and Pang, 2006). The different values were calculated from the various separation methods separated by time, the smallest different value is the most similar segment within the community. Finally, the optimal separation number and separation points were determined by the total variation.

Canonical correlation analysis

Taking Chinese wolfberry field pests sub-community as variables in the different management systems, typical correlation analysis was done for abandoned field and conventional field, abandoned field and organic field, conventional field and organic field, taking the correlation coefficient of each first pair of canonical variables

All the data processing analysis and mapping were processed by Microsoft Office Excel 2003, Microsoft Office Word 2003 and SAS 8.2.

RESULTS

Risk analysis of main pests in different managements

Pest risk index method

In the abandoned field, *Aceria palida* Keifer, *Aphis* sp., *Paratrioza sinica* Yang & Li were the frequent disaster pests. *Lema decempunctata* Gebler, *Jaapiella* sp., *Nycteola asiatica* and *Phthorimaea* sp. were the incidental disaster pests. *Psilothrips indicus* Bhatti, *Lygus* sp., *L. pratensis*, *Epithrix* sp., *Aculops lycii* Kuang, *Scotogramma trifolli* (Rottemberg), *Psylliodes obscurofaciata* Chen and

Table I.- Judgment indicators and evaluation standard of pests sub-community's risk assessment.

Number	Judgment indicator	Evaluation standard
P1	Distribution of pests in Chinese wolfberry growing area	Distribution of pests accounted for the distribution of Chinese wolfberry growing area. Beyond 80%, P1=4; between 50%-80%, P1=3; between 20%-50%, P1=2; under 20%, P1=1
P21	The potential economic damage	Production losses caused by pests. Beyond 30%, P21=4; between 10%-30%, P21= 3; between 1%-10%, P21=2; under 1%, P21=1
P22	Hazard sites	Borers-fruit pests , P22=4; flower-feeding and fruit-feeding pests, P22=3 ; leaf-feeding pests, P22=2; piercing sucking pests, P22=1
P23	Spread diseases and caused serious reactions of crops	Spread disease and caused serious reactions of crops. Beyond 3, P23=4; between 2-3; P23=3; only 1,P23=2,not spread disease, P23=1
P24	Degree of attention	Area of treatment target in Chinese wolfberry growing area. Beyond 80%, P24=4; between 50%-80%, P24=3; between 20%-50%, P24=2;under 20%, P24=1
P31	Individuals of one host	Individuals of one host through 15 investigation. Beyond 10000, P31=4; between 1000-10000, P31=3; between 100-1000, P31=2; under 100, P31=1
P32	Average weight of different pests	Average weight of different pests. Beyond 0.5g, P32=4; between 0.5g-0.1g, P32=3; between 0.05g-0.1g, P32=2; under 0.05g, P32=1
P33	Average life of different pests	Average life of different pests. Beyond 60d, P33=4; between 40d-60d, P33=3; between 20d-40d, P33=2; under 20d, P33=1
P34	Generation of one year	Generation of one year. Beyond 10, P34=4, between 5-10, P34=3; between 2-5, P34=2; under 2, P34=1
P41	Time of hazard	Time of hazard. Beyond 140d, P41=4, between 100d-140d, P41=3; between 50d-100d, P41=2,under 50d, P41=1
P42	Capacity of migration and proliferation	Strong long-distance migration capacity or proliferation in air, P41=4; Middle-distance migration, P42=3; migration by attaching to flying insects or birds, P42= 2, migration by crawling, P42=1
P43	Capacity of adaptability	Region of appropriate growth and reproduction account for the distribution of Chinese wolfberry growing area. Beyond 80%, P43=4, between 50-80%, P43= 3; between 20%-50%, P43=2, under 20%, P43=1
P51	Species of natural enemies in one host	Species of natural enemies in one host. Under 5, P51=4, between 5-10, P51=3, between 10-15, P51=2, beyond 15, P51=1.
P52	Individuals of natural enemies in one host	Individuals of natural enemies in one host. Under 20, P52=4, between 50-100, P52=3, between 20-50, P52=2, beyond 100, P52= 1

Table II.- Classification standard of pest risk index.

Classification standard	Frequent disaster pests	Incidental disaster pests	General pests
Pest risk index	X1 ≥2	1.8 ≤ X2 ≤2	≤1.8
Experience formula index	X1 ≥1700	1000 ≤X2 ≤1700	X3≤1000

Phthorimaea sp. were general pests. In the conventional field, *A. palida*, *Aphis* sp., *P. sinica* and *P. indicus* were the frequent disaster pests, while *Jaapiella* sp. and *Phthorimaea* sp. were the incidental disaster pests and all were general pests. In the organic field, the frequent disaster pests were same as in the abandoned field, but *P. indicus*, *Jaapiella* sp. and *Phthorimaea* sp. were the incidental disaster pests, and others were general pests (Table III).

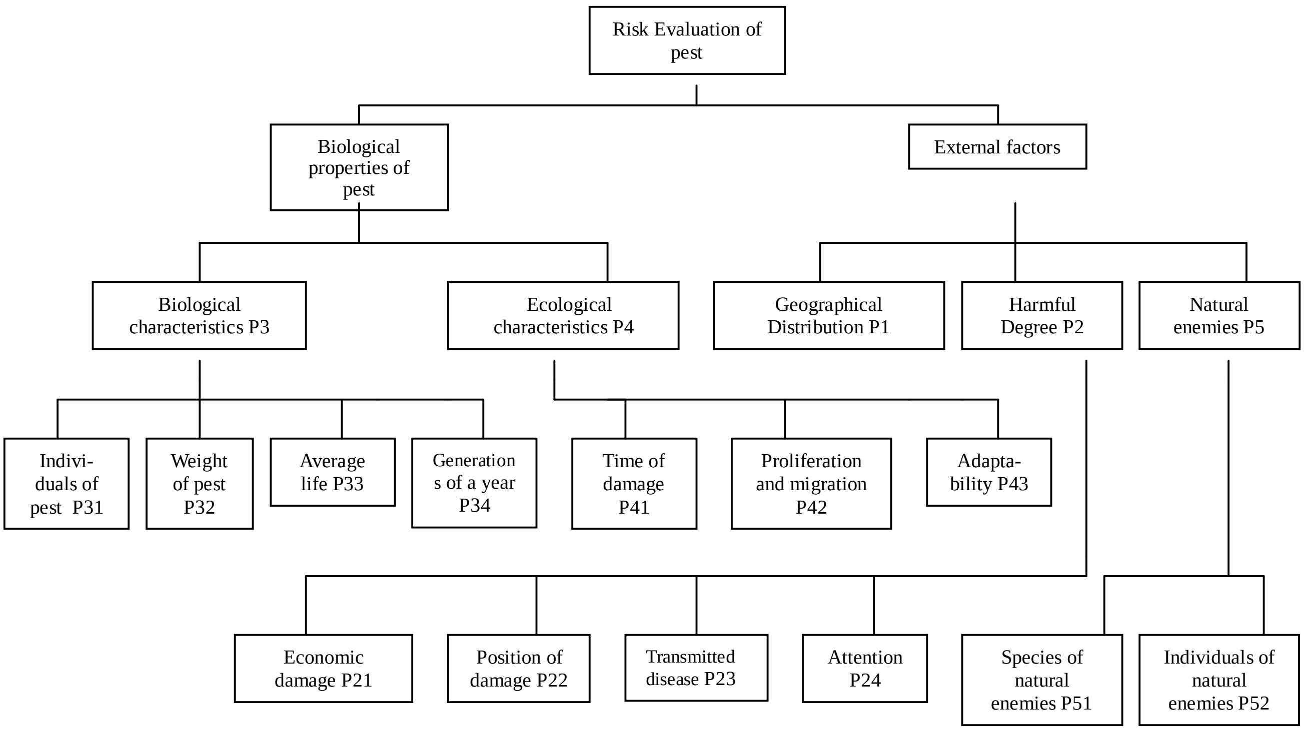

Fig. 1. Flow diagram of experiment.

Table III.- Risk assessment of pest - the method of risk assessment indices and experience formula.

Scientific name	Abandoned field		Conventional field		Organic field	
	formula	indices	formula	indices	formula	Indices
Aceria palida Keifer	1944	2.18	1536	2.29	3072	2.29
Aphis sp.	2048	2.18	2048	2.18	2048	2.05
Paratrioza sinica Yang & Li	1024	2.06	1024	2.06	1024	2.19
Lema decempunctata Gebler	1728	1.86	432	1.40	432	1.4
Jaapiella sp.	648	1.84	648	1.84	648	1.84
Phthorimaea sp.	96	1.80	288	1.86	288	1.86
Neoceratitis asiatica Becker	576	1.80	96	1.45	96	1.45
Psilothrips indicus Bhatti	324	1.73	1296	2.03	1296	1.88
Lygus sp.	576	1.57	288	1.47	288	1.47
Lygus pratensis L.	384	1.59	288	1.49	576	1.74
Epithrix sp.	216	1.56	72	1.21	72	1.21
Aculops lycii Kuang	48	1.43	24	1.18	24	1.13
Scotogramma trifolli Rottemberg	192	1.03	96	0.85	192	0.86
Psylliodes obscurofaciata Chen	144	0.93	48	0.93	48	0.68
Phthorimaea sp.	96	0.82	288	1.12	288	1.09

Empirical formula method

In the abandoned field, *Aphis* sp, *A. palida*, *L. decempunctata* were the frequent disaster pests while *Phthorimaea* sp. and *P. sinica*, *Jaapiella* sp. were the incidental disaster pests, and *N. asiatica*, *Lygus* spp., *Lygus pratensis* (L.), *P. indicus*, *Epithrix* sp. and *A. lycii* were the general pests. In the conventional field, *Aphis* sp., *A. palida*, *P. indicus* and *P. sinica* were the frequent disaster pests, *Jaapiella* sp. and *Phthorimaea* sp. were the incidental disaster of pests, the others were general pests. In the organic field *A. palida*, *Aphis* sp. and *P. indicus*, *P. sinica* were the frequent disaster pests, *Jaapiella* sp., *Phthorimaea* sp. and *P. indicus* were the incidental disaster of pests, the others were general pests (Table III).

Optimal separation of pest sub-community in different managements

The optimal separation method was used to deal with different management of Chinese wolfberry field pest sub-community separately, to obtain the total variation of each section in each community (Table IV), and to analyze the determination of pest sub-communities in species composition and quantitative changes. After the 5 paragraph separation, different management of Chinese wolfberry fields pest sub-community within the total variation gently declined, pest community total variation was more than 9.11 before 5 paragraph separation, after 5 paragraph separation pest community total variation was less than 4.9, different management of Chinese wolfberry fields pest sub-community change rules are basically the same, so we can conclude that the optimal separation number is 5. In the infancy stage (from March 28 to April 15) the weather gets warmer, the soil is thawing, Chinese wolfberry begins to sprout, psyllids (jumping plant lice) climbing a tree to reproduce is the most representative characteristic of this stage, other pests have not appeared. During the outbreak I period (from April 15 to July 18) the weather continues to warm, the abandoned field marked by *L. decempunctata* appearing massively and reproducing, organic field and conventional fields are marked by *A. palida* starting to climb the tree to feed. Following this, *L. pratensis*, *Jaapiella* sp., *N. asiatica*, etc. a large number of pests climb the tree to feed, this period is the key period of for Chinese wolfberry pest control. During the dormancy period (from July 18 to September 5) the weather is hot; it is rainy season, marked by the greatly reduced *Aphis* sp. population, the other pests population decrease in size. This period does not need pesticide control, except for *A. palida* that sometimes damage trees. The other pest population was too small to cause any harm. The outbreak II period (from September 5 to October 15) is marked by the *Aphis* sp. population size rises again, *L. pratensis* and *N. asiatica* also begin to increase, moving into the second prevention and cure key period.

Table IV.- Optimal separations of pests sub-communities in different management of Chinese wolfberry fields.

Stage numbers	Abandoned field	Conventional field	Organic field
2	73.58	50.49	59.89
3	60.35	41.41	49.12
4	51.34	35.22	41.79
5	42.35	27.74	34.28
6	37.25	22.24	30.13
7	33.35	19.57	27.96
8	28.25	16.24	24.13
9	26.35	14.57	21.96
10	23.62	11.01	18.92
11	20.35	9.76	15.26
12	17.51	7.13	13.13
13	14.96	6.69	11.24
14	12.36	5.54	9.51
15	9.32	4.78	7.21
16	6.35	3.04	5.98
17	3.62	2.08	2.94
18	1.62	1.11	1.31
19	0.85	0.77	0.92
20	0.35	0.24	0.28
21	0	0	0

The recession period (after October 15) is marked by decreasing the *Aphis* sp. population and vanishing of other kinds of pests. *Aphis* sp. produce eggs for surviving the winter, *A. palida* crawl enter the branches to overwinter, the arthropod community is in decline.

Control strategies and methods

Relevance of pest sub-community in different managements

Correlation matrices of pest sub-community in different management of Chinese wolfberry fields were analyzed. Abandoned field and conventional field, abandoned field and organic field, conventional field and organic field pest sub-community correlation coefficients were significant with 0.85, 0.84, and 0.86 respectively. This indicated that the pest population dynamics of the pest sub-community in different Chinese wolfberry gardens are consistent.

Determination of optimal control period

According to the study of main pests in different Chinese wolfberry garden and the result of optimal separation, *A. palida*, *Aphis* sp. and *P. sinica*, *P. indicus* are the most significant barriers to agricultural production. The *Jaapiella* sp. and *Phthorimaea* sp. may harm agricultural production of the Chinese wolfberry unexpectedly, the rest insect pests would not cause significant harm at present.

The disaster pest population dynamic curves under different management of Chinese wolfberry gardens are consistent. Around April 20 the pests started to damage trees, by the end of May to the early July the population expanded dramatically, the individual number was grown exponentially, this period lasted for a long time and caused the most harm. At the beginning of July population levels started to decline, and in middle of July to the beginning of September did not cause damage. At the beginning of September the population levels of *Aphis sp.* began to rise again, harming the autumn fruit harvest, and at the beginning of October various pest populations drop quickly. On April 20 the gardens would be closed for prevention and cure, and as Chinese wolfberry budding began, a variety of pests started to damage the trees in succession, which is the first building stage of Chinese wolfberry pests. After June 5 the temperature continued to rise, *Aphis sp.*, *P. indicus* and *A. palida* propagated massively, resulting in sharp increases in population size, which was the exponential growth period of Chinese wolfberry pests. Around September 15 Chinese wolfberry went through the dormancy period, *Aphis sp.* as the pest representative entered the Chinese wolfberry garden again, populations quantity rose again in succession, which was the second building group stage and population growth period of Chinese wolfberry pests.

As the weather conditions are different every year, climate changes vary greatly. Therefore, it is best to control and cure the pest, at the two period of time, both the pest grow exponentially early period and the first group build period, the first period is the later stage of infancy period of Chinese wolfberry to early stage of the first group build period of pest, the second period is the later stage of the dormancy period of Chinese wolfberry to early stage of the outbreak period of pest.

DISCUSSION

We created an insect comprehensive evaluation system for Chinese wolfberry and suggest the use of 2 sub-systems, 5 aspects and 14 indicators to reflect the integrated damage force of various pests. The key of risk assessment is the analysis of the risk source (Berlin *et al*., 2000; Sydelko *et al*., 2001; Inamura *et al*., 2003) and this paper analyses the influence of pest damage from the biological properties and environmental conditions in the two sub-systems, excluding the smaller effecting factors, based on the five aspects of pest distribution areas, the biological characteristics of pests, ecological characteristics, degree of harm, the number and kinds of natural enemies and 14 indicators for evaluation. The results are almost the same with actual observation results in Chinese wolfberry gardens, showing that the pest assessment system is applicable to Chinese wolfberry garden pest risk assessment, but whether it can be applied to other field pest sub-communities remains to be determined.

The results of the pest risk index method and empirical formula method were in substantial agreement. The two pest classification standard for Chinese wolfberry garden pest sub-community calculation results may be inconsistent with pests sub-community graduation standard for other plants, therefore, an independent graduation standard for each field pests sub-community should be established when establishing a risk assessment.

Since the farmland ecosystem is a highly people-centered production system, vegetation conditions are very simple, we opine that pest control should suppress the establishment of disastrous pest populations, and the key for effective control is to seize the most suitable control period. Pest's sub-community separated chronologically into 5 optimal separations: the infancy period, the outbreak I period, the dormancy period, the outbreak II period, and the recession period. As the weather conditions change every year, climate can change greatly in a year, therefore, identifying the two building groups, the early period and exponential growth early period, is the best prevention and cure periods. Since yearly climate temperature may change greatly, the timing of these periods may be advanced or delayed. So in reality, we should depend on local conditions, analyze and take timely effective measures.

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Conflict of interest declaration

The authors have declared that no conflicts of interest exist.

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