

梨小食心虫对阿维菌素的抗性 风险评估及其交互抗性

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摘要:【目的】明确阿维菌素致死中浓度(LC_{50})连续处理对梨小食心虫(*Grapholita molesta*)的抗性风险及其交互抗性。【方法】在室内条件下,采用浸果法测定阿维菌素对梨小食心虫田间种群(F)初孵幼虫的 LC_{50} 值;以F种群为基础,建立梨小食心虫对阿维菌素相对敏感品系(SS)、F种群连续6代接触 LC_{50} 浓度阿维菌素的田间抗性品系(FR)和6代未接触阿维菌素的田间对照品系(FS),测定阿维菌素对不同品系梨小食心虫初孵幼虫的毒力,计算其抗性水平;测定高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺对不同品系的毒力,分析不同品系与其交互抗性。【结果】田间种群对阿维菌素抗性倍数为4.608倍,敏感性降低;阿维菌素致死中浓度汰选2代后,梨小食心虫对阿维菌素抗性为低水平,汰选4代后升至中等水平,6代后升至20.304倍;未接触阿维菌素的梨小食心虫从第4代降为敏感,第6代时敏感性进一步恢复。抗性品系抗性现实遗传力 $h^2=0.186$,在致死率50%~90%选择压力下,梨小食心虫对阿维菌素抗性增加10倍,预计需汰选4~9代。汰选6代品系对高效氯氟氰菊酯抗性倍数为8.487倍,有交互抗性;对吡虫啉和氯虫苯甲酰胺无交互抗性。对照品系对高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺均无交互抗性。【结论】梨小食心虫对阿维菌素存在快速产生抗性的风险,中抗品系与高效氯氟氰菊酯有交互抗性,低敏感品系与3种药剂均无交互抗性。田间使用阿维菌素时可通过间隔用药或与无交互抗性药剂轮换使用来减缓抗性发展。

关键词:梨小食心虫;阿维菌素;初孵幼虫;抗性风险评估;交互抗性

中图分类号:S661.2; S436.612

文献标志码:A

文章编号:1009-9980(2024)03-0525-08

Resistance risk assessment and the cross-resistance of *Grapholita molesta* to avermectin

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Abstract:【Objective】*Grapholita molesta* is a major pest of many kinds of fruit crops in the world and China. Due to its characteristics of boring, hiding and generations overlapping, *G. molesta* is difficult to control. With the climate warming, and the change of cultivation mode and management technology in pear orchards, the damage of *G. molesta* has been increasing year by year in several major fruit species in China, including peaches, pears and apples. Currently, chemical pesticides are still one of the most effective measure to control *G. molesta*. Long-term frequent and non-standard use of pesticides has led to a gradual decline in the effectiveness of chemical control to *G. molesta*, and *G. molesta* has developed varying degrees of resistance to some pesticides in pear orchards. Avermectin, a high efficiency and low toxicity pesticide used in pear orchards frequently, was used for 5–7 times in a year to control many kinds of pests, such as *G. molesta*, *Aphis citricola* Van der Goot, *Tetranychus viennensis* Zacher, and so on. Over the past 20 years, the application concentration of avermectin has increased by 40 times in pear orchards due to its high dose and excessive usage times. Studies on avermectin mainly focus on

收稿日期:2023-12-22 接受日期:2024-01-23

基金项目:国家现代农业(梨)产业技术体系资助项目(CARS-28);山西农业大学博士基金(2021BQ56)

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its toxicity, control efficacy, management and efficiency in pear orchards. The change patterns of resistance and sensitiveness were studied with lethal concentration of 50% of avermectin to *G. molesta* in this paper. By studying the resistance and sensitivity changes, it is expected to obtain change patterns of resistance, development speed, resistance heritability of *G. molesta* to avermectin, and its interaction resistance with other pesticides that were also used in pear orchards, such as imidacloprid, chlorphenicol benzamide, lambda-cyhalothrin and so on. The objective of this experiment was to obtain theoretical basis for reasonable use avermectin to delay the development of its resistance in pear orchards. **【Methods】** In order to measure control efficiency of avermectin to *G. molesta* neonate larvae, the survival rate and damage rate of *G. molesta* neonate larvae were measured with fruitlets as the sample. The *G. molesta* neonate larvae and larvae were fed in an artificial intelligence incubator under the following conditions: (25±1) °C, 70%–80% relative humidity, 3000–4000 lx illumination and 15 h/9 h (L/D) photoperiod. The test agent was 92.00% avermectin, 96.0% Lambda-cyhalothrin, 96% imidacloprid and 96% chlorantraniliprole. Fruit dipping method was used to measure the resistance development of *G. molesta* to avermectin. These methods included: (1) the young fruits of apple with same variety, consistent size, and good appearance were wash with pure water, dried in air, and soaked in the pesticide solution for 10 seconds. (2) The young fruits were taken out from pesticide solution, excessive pesticide solution was absorbed with a filter paper, and they were placed on a plastic container with a wet filter paper and a lid at the bottom. (3) The paper containing 50 *G. molesta* ready-to-hatch eggs was placed on the young fruit gently, then the egg was managed to contact the fruit, and the relative humidity in the container was maintained above 90%. (4) Tween-80 aqueous solution with a mass fraction of 0.02% was taken as the control. Each process was repeated for three times. (5) The survival rate of *G. molesta* neonate larvae was surveyed in 78 h after laying eggs. Survey method was determined by observing carefully pest morphological characteristic and damage symptoms of *G. molesta* neonate larvae on apple and damage rate in 78 h. According to mortality of *G. molesta* neonate larvae, the toxicity equation and LC₅₀ were calculated with SPPS. Two strains of *G. molesta* neonate larvae were obtained from field populations, which were resistance-selection by LC₅₀ of avermectin. The field population was collected from pear orchards in Yanhu District, Yuncheng City, Shanxi province in 2022. Two strains were field resistant strain and field control strain. Field resistant strain was selected with LC₅₀ of avermectin, and the toxicity of earlier generation of *G. molesta* neonate larvae was measured for six times. Field control strain was fed with apples, which were not touched by any pesticides. The comparative strain *G. molesta* was susceptible strain that was reared 100 generations continuously in the lab. The toxicity of different strains of *G. molesta* was measured in 2 generations, 4 generations and 6 generations, respectively. The resistance ratio (RR) and sensitivity level of different strains *G. molesta* were calculated with resistance multiple formulas. In order to obtain cross-resistance of different strains of *G. molesta*, Lambda-cyhalothrin, imidacloprid and chlorflubenzamide that were used frequently in pear orchards were selected to assess the cross-resistance to field resistant strain and field control strain of *G. molesta*. Experimental data were analyzed with Duncan's new multiple range test ($p<0.05$). **【Results】** The LC₅₀ of avermectin of field population of *G. molesta* was $1.092 \text{ mg} \cdot \text{L}^{-1}$, and its resistance ratio was 4.608 times higher than the susceptible strain, with low sensitivity. The resistance level of field population selected with LC₅₀ avermectin at second generation was up to low resistance from low sensitivity. The LC₅₀ of field population increased continuously with the increase of selection generations when the resistance ratios were 11.966 and 20.304 times at fourth generation and sixth generation respectively, which increased to the medium resistance level. The sensitivity of the field population without exposure to avermectin in-

creased gradually. The resistance ratio of the field population decreased to 2.802 times at fourth generations, which was sensitivity. The toxicity of the field population of *G. molesta* without exposure to avermectin decreased from first generation to sixth generation and its sensitivity was further improved. The results also showed that the continuous use of avermectin in field populations of *G. molesta* caused a rapid increase in the level of resistance to avermectin. The sensitivity of strains of *G. molesta* without continued exposure to avermectin increased sensitivity to avermectin. The field population of *G. molesta* was selected with LC₅₀ avermectin for 6 generations, and its actual heritability of resistance was $h^2 = 0.186$. The actual heritability of F₀–F₂ and F₄–F₆ selection stage was 0.242 and 0.196, respectively. In the case of resistance heritability of 0.186, the resistance of *G. molesta* to avermectin increased by 10 times in about 4–9 generations. The resistance ratio of the 6th generation resistant strain of *G. molesta* to lambda-cyhalothrin was 8.487, which was a cross-resistance between them. The resistance ratio to chlorantraniliprole was 3.940, and its resistance ratio also increased. The resistance ratio to imidacloprid was 1.487 with no cross-resistance. The resistance ratios of the field population control strain to lambda-cyhalothrin, imidacloprid and chlorantraniliprole were 1.688, 0.962 and 1.243, respectively, and there was no cross-resistance among them. 【Conclusion】 *G. molesta* could develop resistance to avermectin rapidly. The low-sensitive field population of *G. molesta* could decrease sensitiveness with no exposure to avermectin. The medium-resistant strain had cross-resistance to lambda-cyhalothrin, and the low-sensitive strain had no cross-resistance to lambda-cyhalothrin, imidacloprid and chlorantraniliprole. The development of resistance of *G. molesta* to avermectin can be slowed down by interval medication or rotative application of avermectin and its non-cross-resistance pesticides in pear orchards. Therefore, avermectin should be used in pear orchards with an interval, and growers should reduce or limit the use frequency of lambda-cyhalothrin and chlorantraniliprole to avoid or delay the emergence and development of resistance, and ensure the control efficacy of avermectin and other pesticides, which were used in pear orchards frequently.

Key words: *Grapholita molesta*; Avermectin; Neonate larvae; Resistance risk assessment; Cross-resistance

梨小食心虫(*Grapholita molesta*)为世界和中国重大果树害虫,因其钻蛀性、隐蔽性、世代重叠严重等特点,其防治较为困难^[1-3]。目前梨小食心虫多采用化学药剂防控,药剂主要包括阿维菌素、氯虫苯甲酰胺、高效氯氟氰菊酯、毒死蜱等,化学药剂长期频繁不规范使用已导致害虫产生了不同程度的抗性^[4],其化学防治效果逐年下降^[5-6],阿维菌素为生物源类杀虫剂,生产上主要用于防治多种害虫^[7-9]。因其杀虫活性强、杀虫谱广,在梨园中常用于防治梨小食心虫、梨木虱、黄粉蚜和山楂叶螨等多种害虫^[10-12],年使用次数5~7次。因其用药不规范,20 a(年)间,阿维菌素在梨园中的施药浓度由0.5%制剂稀释4000倍增至5%制剂稀释1000倍,增加了40倍。笔者课题组测定了山西省不同区域的田间种群,部分种群已具中等抗性水平(待发表)。作为梨园主要防治药剂,阿维菌素在当前及今后较长时间内仍频繁

使用,因而,如何合理科学使用该药剂成为生产上迫切需要解决的问题。目前阿维菌素田间使用次数主要从农药残留和果品安全性等角度来确定,未从其抗性角度研究其使用技术;阿维菌素对梨小食心虫防控作用也多集中于研究其毒力和田间防效等,对其抗性发展规律、抗性现实遗传力及交互抗性等研究较少。笔者在本研究中以室内敏感种群为参照,以田间种群为基础,测定阿维菌素致死中浓度处理的梨小食心虫抗性发展和无药剂处理的敏感性变化趋势,获得其抗性变化趋势、发展速度、抗性遗传力及其与梨园常用药剂交互抗性,从抗性发展角度为该药剂合理使用、延缓抗性发展等提供理论依据。

1 材料和方法

1.1 供试虫源

供试梨小食心虫敏感种群(SS)为室内继代饲

养100代以上;田间种群(F)为山西省运城市盐湖区酥梨园采集的种群。饲养条件为:温度(25±1)℃、相对湿度70%~80%,光照度3000~4000 lx,光周期为L/D=15 h/9 h,下同。

1.2 供试药剂

阿维菌素(avermectin)原药,纯度92.0%,山东齐发药业有限公司;高效氯氟氰菊酯(lambda-cyhalothrin)原药,纯度96.0%,山东潍坊润丰化工股份有限公司;吡虫啉(imidacloprid)原药,纯度96.0%,辽宁宏峰科技有限公司;氯虫苯甲酰胺(chlorantraniliprole)原药,纯度96.0%,辽宁省沈阳丰收农药有限公司。

1.3 毒力测定

采用浸果法。具体参考庾琴等^[13-14]的方法,略有改动。挑选同一品种、大小一致、性状良好的苹果幼果,洗净晾干后,放入药液中浸泡10 s,取出后用滤纸吸掉多余药液,平稳放于底部铺有湿滤纸、具盖的塑料容器(直径为10 cm、高4 cm)中,将附有50粒待孵化卵的卵纸轻放于幼果上,有卵面接触果面,盖上盖,器皿中保持相对湿度90%以上;以0.02%的吐温-80水溶液为对照。每个处理设置3次重复。接卵后78 h调查蛀果数,依据蛀果孔洞处有无新鲜虫粪判定为幼虫是否死亡^[14],记录死亡虫数。

抗性倍数(resistance ratio, RR)=待测梨小食心虫种群LC₅₀/相对敏感种群LC₅₀。

参考黄彦娜^[15]抗性倍数划分标准:RR≤3为敏感、3<RR≤5为敏感性降低、5<RR≤10为低水平抗性、10<RR≤40为中等水平抗性、40<RR≤160为高水平抗性、RR>160为极高水平抗性。

1.4 梨小食心虫田间抗性品系汰选和敏感性恢复

在室内条件下,根据1.3获得的LC₅₀浓度阿维菌素对梨小食心虫田间种群(F)进行汰选,每代处理一次,处理时以药液完全湿润幼果且不流失为度。此后每代均使用上一代LC₅₀浓度进行汰选,连续施药6次后种群为田间抗性品系(FR);连续6代未施药种群为田间对照品系(FS),以实验室饲养的敏感品系(SS)为试验参考品系。

1.5 抗性风险评估

1.5.1 抗性现实遗传力估算 抗性现实遗传力(h^2)采用Tabashnik等^[16]的阈性状分析法计算,其中,R为选择反应,S为选择差异,i为选择强度, δ_p 为表性标准差。计算公式分别为:

$$h^2=R/S。$$

$R=[\log(\text{终 } LC_{50})-\log(\text{始 } LC_{50})]/n$,其中,n为选择代数,终LC₅₀为选择n代后的LC₅₀,始LC₅₀为选择前亲代的LC₅₀。

$$S=i\times\delta_p。$$

$i=1.583-0.019\ 333\ 6P+0.000\ 042\ 8P^2+3.651\ 941/P$ (10<P<80),P=100-平均校正死亡率,平均校正死亡率为抗性选育过程中各代死亡率用Abbott公式校正后的平均值。

$\delta_p=[1/2(\text{初斜率}+\text{终斜率})]^{-1}$,初斜率为选择前亲本毒力回归方程的斜率,终斜率为选择n代后的毒力回归方程斜率。

1.5.2 抗性发展速率预测 根据现实遗传力 h^2 ,可预测抗性上升x倍所需代数[$G_x=\lg x/(h^2 S)$],以及不同选择压力(50%~90%)下抗性上升10倍所需代数: $G=R^{-1}=(h^2 S)^{-1}$ ^[17]。

1.6 交互抗性测定

测定梨小食心虫3个品系对梨园中常用的3种药剂高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺的毒力,毒力测定方法同1.3。参照SS品系LC₅₀,计算3个品系抗性倍数,评估其是否存在交互抗性。

1.7 数据处理

利用Excel软件整理数据,利用SPSS 24.0进行单因素方差分析,求出斜率值、LC₅₀、卡方值、自由度和标准偏差等。

RR<1表示负交互抗性,1≤RR<5表示无交互抗性,RR>5表示有交互抗性^[18]。

2 结果与分析

2.1 阿维菌素对梨小食心虫不同品系毒力和抗性变化趋势

如表1所示,阿维菌素对梨小食心虫田间种群LC₅₀为1.092 mg·L⁻¹,抗性倍数4.608倍,为敏感性降低。该种群经LC₅₀阿维菌素汰选,随着汰选代数增加,其LC₅₀不断增加,汰选至第2代时由低敏感升至低抗性水平;汰选至第4代和6代时,其抗性倍数分别为11.966倍和20.304倍,增至中等抗性水平。未接触阿维菌素的田间种群敏感性逐渐上升,未施药4代后,田间种群抗性倍数降至2.802倍,为敏感;未接触农药6代时,梨小食心虫对阿维菌素的抗性为2.001倍,敏感性进一步提高。结果说明,已对阿维菌素敏感性降低的田间种群连续使用阿

表1 阿维菌素对梨小食心虫的初孵幼虫的毒力
Table 1 Toxicity of avermectin to the *G. molesta* neonate larvae

品系 Strains	斜率 Slopea	卡方值(自由度) $\chi^2(df)$	LC ₅₀ (95%置信区间) 95% confidence interval)/(mg·L ⁻¹)	RR
SS	0.918±0.105	9.539(13)	0.237(0.187~0.303)	1.000
F	1.276±0.073	18.613(16)	1.092(0.907~1.305)	4.608
FS(4)	0.939±0.065	17.952(16)	0.664(0.510~0.842)	2.802
FS(6)	0.813±0.058	10.576(16)	0.476(0.366~0.614)	2.001
FR(2)	1.027±0.070	13.333(22)	2.275(1.739~2.851)	9.599
FR(4)	1.126±0.061	14.241(22)	2.836(2.305~3.424)	11.966
FR(6)	1.110±0.072	9.778(19)	4.812(3.617~6.126)	20.304

注:SS. 敏感品;F. 田间种群;FS. F 种群连续 6 代未接触阿维菌素的田间对照品系;FR. F 种群连续 6 代接触 LC₅₀ 阿维菌素后的田间抗性品系;RR. 抗性倍数;表中数据为平均数±标准差。下同。

Note: SS. Sensitive strain; F. Field population; FS. Field control strain from F population without exposure to avermectin for six consecutive generations; FR. Field resistant strain from F population after exposure to LC₅₀ of avermectin for six consecutive generations; RR. Resistance ratio. Data in the table are mean±SD. The same below.

维菌素处理使其对阿维菌素抗性水平快速升高;而连续未接触阿维菌素的品系其敏感性逐渐提高。

2.2 梨小食心虫对阿维菌素抗性现实遗传力及抗性发展速率

结果(表2)表明,用阿维菌素汰选田间种群梨小食心虫 6 代,抗性现实遗传力 $h^2=0.186$,其中 $F_0 \sim F_2$ 汰选阶段的现实遗传力为 0.242, $F_4 \sim F_6$ 汰选阶段的现实遗传力为 0.196。结果说明,梨小食心虫对阿维菌素存在快速产生抗性的风险。

通过阿维菌素汰选田间抗性种群所得到的抗性现实遗传力 h^2 和选择差异 S ,分别计算在选择压力为 50%~90%的情况下,梨小食心虫田间种群对阿维菌素抗性增加 10 倍所需要的代数。结果(图1)表明,在抗性遗传力为 0.186 的情况下,阿维菌素对梨小食心虫抗性上升 10 倍需代数 4~9 代。结果说明,梨小食心虫抗性增加较快,较高浓度阿维菌素处理时,其产生中等抗性风险较大。

表2 梨小食心虫田间种群汰选品系的抗性现实遗传力
Table 2 Realized heritability of resistance strains of *G. molesta* in field population

筛选代数 Selected generations	初 log LC ₅₀ Initial log LC ₅₀	终 log LC ₅₀ Final log LC ₅₀	选择效应 R	存活率 P	选择强度 i	初斜率 Initial slope	终斜率 Final slope	标准差 δ_p	选择差异 S	现实遗传力 h^2
$F_0 \sim F_2$	0.038	0.357	0.159	52.396	0.757	1.276	1.027	0.868	0.658	0.242
$F_4 \sim F_6$	0.453	0.682	0.114	58.887	0.655	1.126	1.110	0.878	0.575	0.196
$F_0 \sim F_6$	0.038	0.682	0.107	56.723	0.688	1.276	1.110	0.824	0.567	0.186

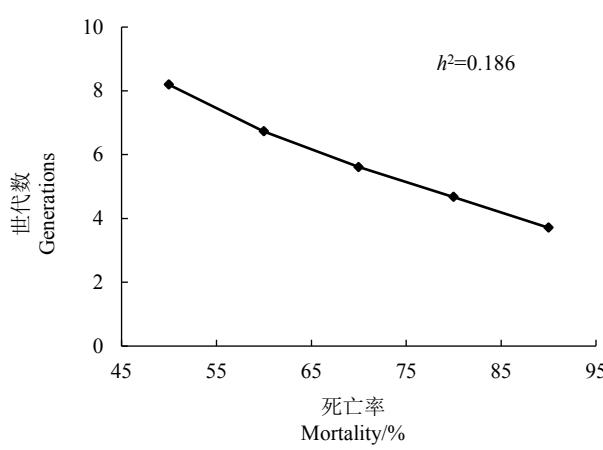


图1 不同选择压力下梨小食心虫对阿维菌素的抗性上升 10 倍所需世代数

Fig. 1 Generations required for a 10-fold increase in LC₅₀ of avermectin to *G. molesta* under different selection pressures

2.3 梨小食心虫不同品系对3种药剂的交互抗性

结果(表3)表明,田间种群阿维菌素汰选 6 代的 FR 品系对高效氯氟氰菊酯的抗性倍数为 8.487,存在交互抗性;对氯虫苯甲酰胺抗性倍数为 3.940,抗性倍数增加;对吡虫啉抗性倍数为 1.487,无交互抗性。田间种群连续 6 代未接触阿维菌素的 FS 品系对高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺的抗性倍数分别为 1.688、0.962 和 1.243,均无交互抗性。结果说明,对阿维菌素敏感品系与试验选择的 3 种药剂均无交互抗性;随着其抗性增至中等抗性水平,其与高效氯氟氰菊酯有交互抗性。

3 讨论

阿维菌素可有效防控多种害虫^[7-9],如使用不规范,害虫易对其产生抗药性或敏感性下降^[10]。笔者在本研究中发现,梨园现有使用技术条件下(阿维菌

表3 梨小食心虫不同品系对3种杀虫剂的交互抗性

Table 3 Cross-resistance of three insecticides to different strains of *G. molesta*

药剂 Insecticide	种群 Population	斜率 Slopea	卡方值(自由度) $\chi^2(df)$	P	LC ₅₀ (95%置信区间) 95% confidence interval)/(mg·L ⁻¹)	抗性倍数 RR
高效氯氟氰菊酯 Lambda-cyhalothrin	SS	0.571±0.046	27.320(19)	0.097	2.859(1.879~4.350)	1.000
	FS	0.558±0.045	21.269(23)	0.565	4.827(3.571~6.541)	1.688
	FR	0.901±0.059	18.349(22)	0.685	24.263(19.294~31.455)	8.487
吡虫啉 Imidacloprid	SS	1.886±0.116	16.055(22)	0.813	25.841(22.677~28.984)	1.000
	FS	1.808±0.114	31.600(22)	0.084	24.849(20.784~28.847)	0.962
	FR	2.398±0.119	35.049(25)	0.087	38.430(34.345~42.541)	1.487
氯虫苯甲酰胺 Chlorantraniliprole	SS	0.869±0.058	28.856(22)	0.149	3.035(2.374~3.903)	1.000
	FS	0.868±0.059	31.202(22)	0.092	3.772(2.910~4.973)	1.243
	FR	1.029±0.067	33.843(25)	0.111	11.957(9.808~14.655)	3.940

素用药5~7次),试验采集的梨小食心虫田间种群已对阿维菌素敏感性降低;对该种群连续使用阿维菌素半致死剂量处理2代后,梨小食心虫由低敏感性升至低等抗性水平,当进一步用药至第4代时,其抗性水平升至中等抗性水平;而未接触阿维菌素4代后其抗性从4.608倍降至2.802倍,由低敏感性提高至敏感性。因而,在田间使用时,阿维菌素不仅从农药残留和食品安全间隔期来考虑其使用次数,也要从抗性变化角度来考虑其间隔使用技术,保证其处于敏感性或低敏感性水平,来保障其较好防治效果。

药剂抗性现实遗传力是其抗性风险评估的重要参数。阿维菌素对不同害虫抗性现实遗传力不同,对易产生抗性的小菜蛾和不易产生抗性的橘全爪螨,其抗性现实遗传力分别为0.130和0.0475,在50%~99%选择压力下两种害虫对其抗性上升10倍分别需要3~16代^[20]和12~26代^[21];笔者在本研究中发现,阿维菌素对梨小食心虫抗性现实遗传力 $h^2=0.186$,在50%~90%选择压力下,梨小食心虫对阿维菌素抗性上升10倍需4~9代。说明阿维菌素对梨小食心虫抗性上升快,风险较大。这可能与梨小食心虫化学防控技术要求有关,梨小食心虫化学防治时,要求在成虫盛发期后3~5 d时施药,此时初孵幼虫接触农药的浓度较高,这可能是其抗性增加快速原因之一。同时,阿维菌素汰选6代, $F_0\sim F_2$ 汰选阶段的 h^2 为0.242, $F_4\sim F_6$ 汰选阶段 h^2 为0.196,表现出汰选前期现实遗传力大于汰选后期的现实遗传力,这与甲氨基阿维菌素苯甲酸盐、虱满脲对草地贪夜蛾^[22]、Bt^[17]和溴氰虫酰胺^[23]对小菜蛾抗性的筛选结果相似,说明梨小食心虫初始种群中可能存在抗性基因,子代表现型可能由遗传变异来实现,抗性发展较快;

随着抗性筛选持续,敏感基因可能被淘汰,抗性发展减慢。

现有研究结果表明,高等抗性水平鳞翅目害虫易对其他杀虫剂产生交互抗性,在小菜蛾^[24~25]、二化螟^[26]、黏虫^[27]、草地贪夜蛾^[28]、斜纹夜蛾^[29]等害虫中均有发现。笔者在本研究中发现,田间种群未接触阿维菌素的对照品系对高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺均无交互抗性;而汰选6代的抗性品系对氯虫苯甲酰胺的抗性倍数明显增加,对高效氯氟氰菊酯存在交互抗性;随着梨小食心虫对阿维菌素抗性增加,其对梨园常用药剂可能存在交互抗性风险。因而,在田间梨小食心虫化学防治中,在使用阿维菌素时不仅要考虑使用次数,也要科学安排使用间隔时间,减少或限制高效氯氟氰菊酯和氯虫苯甲酰胺使用次数,避免或延缓其抗药性产生和发展,保证药剂防治效果。

4 结 论

连续使用阿维菌素半致死剂量处理2代后,梨小食心虫由低敏感性升至低等抗性水平,进一步用药至第4代时,其抗性水平升至中等抗性水平;而未接触阿维菌素的4代后其由低敏感性提高至敏感性。阿维菌素对梨小食心虫抗性现实遗传力 $h^2=0.186$,在50%~90%选择压力下,梨小食心虫对阿维菌素抗性上升10倍需4~9代。田间种群未接触阿维菌素的对照品系对高效氯氟氰菊酯、吡虫啉和氯虫苯甲酰胺均无交互抗性;而汰选6代的抗性品系对氯虫苯甲酰胺的抗性倍数增加,对高效氯氟氰菊酯存在交互抗性。田间使用阿维菌素时可通过间隔用药或与无交互抗性药剂轮换使用来减缓抗性发展。

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