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The Effectiveness of Mixed Food Attractant for Managing *Helicoverpa armigera* (Hübner) and *Agrotis ipsilon* (Hufnagel) in Peanut Fields

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Abstract: Peanut is one of the widely cultivated oil-bearing and nut crops worldwide, so its stable production is crucial for oil supply and nuts, as well as socioeconomic development. Noctuid pests, such as *Helicoverpa armigera* (Hübner) and *Agrotis ipsilon* (Hufnagel), are the major pests in peanut. With growing resistance to chemical pesticides, there is an urgent need for advanced biocontrol solutions for peanut productions. We evaluated the control effect of Bioattract®, combined with the insecticide Coragen, a 'mixed food attractant', on noctuid pests through large-scale applications in four main peanut-producing provinces, Henan, Hebei, Shandong and Liaoning, of China from 2019 to 2023 in succession. The main types of insects attracted and killed by the mixed food attractant were noctuid pests, of which *H. armigera*, *A. ipsilon* and other pests were 84.2%, 10.4% and 5.4%, respectively. The female/male ratio of *H. armigera* was 1.04. In the mixed food attractant treatment fields, the average adjusted decrease rates of *H. armigera* were 68.74% ± 1.43% for the eggs and 66.84% ± 1.59% for the larvae; meanwhile, those of *A. ipsilon* were 59.24% ± 1.56% for the eggs and 51.06% ± 1.89% for the larvae. In addition, the damage rate of the new leaves of the peanut plants in the mixed food attractant treatment fields was significantly lower than that in the control fields, with an adjusted declined rate of 78.26% ± 0.80%. Compared with using conventional chemicals, applying biological food attractants could reduce costs by USD 43.85 ± 1.14 per hectare. These findings provide a basis for the large-scale promotion and application of Bioattract® for peanut pest management.

Keywords: noctuid moth; adult control; food bait; biocontrol

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1. Introduction

Peanut is one of the four major oil-bearing crops widely grown worldwide. The global peanut harvest area in 2022 is 30.536 million hectares, with a total yield of 54.239 million tons [1]. In China, peanut is widely planted as an oil-bearing crop, except in Tibet and Qinghai Province. In 2022, the sown area of peanut in China was 4.684 million hectares, accounting for 38.6% of the total sown area of all oil-bearing crops, and total yield was 18.329 million tons, accounting for 50.2% of total yield of oil-bearing crops [2]. Under the background of building a 'dual-circulation' development pattern in which the domestic economic cycle plays a leading role while the international economic cycle remains as its extension and supplement, the development of the peanut industry has played an important role in adjusting the planting structure, ensuring supplies, increasing farmers' income, promoting a virtuous cycle of agricultural production and enhancing the competitiveness in the oil industry internationally [3,4]. Being an important source of high-quality plant oils and proteins, peanut has the following advantages: high yield, high oil yield, good economic benefit, dual use of oil and food, high value of biological nitrogen fixation and high by-product value [5]. Therefore, the peanut industry plays a crucial role in ensuring the world's oil supplies as well as promoting socioeconomic development.

The black cutworm, *Agrotis ipsilon* (Hufnagel), and the cotton bollworm, *Helicoverpa armigera* (Hübner), are the main pests of peanut fields in China, and they cause the direct economic loss of up to USD 720 million every year [6–9]. The cotton bollworm is a widespread agricultural pest feeding and damaging over 200 host species, such as cotton, peanut and maize [10]. The newly hatched larvae of the cotton bollworm feed on the flesh of peanut leaves, while the older larvae often feed on the edges of the leaves or pierce through the tender leaves to form gaps. Also, its larvae feed on peanut flower buds, and in severe cases, they can eat all the newly growing flower buds every day, causing a significant reduction in yield or even total crop failure [6,11]. The larva of a black cutworm is a polyphagous pest that feeds on many arid host species, such as peanut, cotton, maize, beans, vegetables and weeds [9]. In recent years, the population of *A. ipsilon* in China has been sustained to increase with climate change and the adjustment in agricultural structure [8]. The *A. ipsilon* larvae mainly bite off the tender stems or young roots of peanut, causing the death of the entire plant, and they can also burrow into the pods to feed on the kernels. Without proper monitoring and preventative actions, this pest can lead to a shortage of seedlings and ridges in the fields and even a significant yield loss [9].

Peanut fields are supposed to be gathering places for migratory pests, like *H. armigera* and *A. ipsilon.* In 1997, the commercial cultivation of Bt cotton kept the population of *H. armigera* on cultivated crops such as cotton, peanut, maize, beans and vegetables in the Yellow River Basin area of China at a low level [12]. Since 2010, the sharp decrease in the planting area of Bt cotton in the Yellow River Basin of China has weakened the regional control effect of Bt cotton, resulting in an aggravation of the occurrence of *H. armigera* in the fields, which led to an increase in its damage to peanut [13]. At present, managing noctuid pests in peanut fields mainly relies on spraying chemicals at the larva initiation stage, for example, chlorpyrifos and indoxacarb [8]. However, the long-term and large-scale application of chemicals does not only pollute the environment and induce resistance but also leads to problems, such as pesticide residues, a worse quality of peanuts or even the restriction of the sound development of the entire industry, especially the export of homegrown peanuts [8,14]. Therefore, developing new biocontrol technologies has become an urgent need in peanut production. Biological food attractants are at the leading edge of this effort [15,16].

Biological food attractants, also known as adult behavior regulators, are volatiles that emulate the scents of host plants, which attract both female and male adults [17–21]. Currently, the biological food attractant Magnet ® has been widely used in cotton, maize and other crops in countries such as Australia, the United States and South Africa and has obvious population control on Lepidoptera pests, such as *Spodoptera frugiperda* (J.E. Smith) and *H. armigera* [15,22–25]. It also has great potential for application in the resistance management of *H. armigera* and *Helicoverpa punctigera* (Wallengren) on Bt cotton [26]. In China, the control efficiency of the biological food attractant Bioattract® varies on crops [27–29]. Kong et al. [30] and Lu et al. [8] reported the monitoring and trapping effects of Bioattract ® on *H. armigera*, *Spodoptera exigua* (Hübner), *Spodoptera litura* (Fabricius) and *A. ipsilon* adults in peanut fields in Zoucheng and Junan, Shandong Province, China. However, further studies are needed on the control effects of biological food attractants on *A. ipsilon* and *H. armigera* in peanut fields over different regions. Henan, Hebei, Shandong and Liaoning provinces are the main planting areas of peanuts in China. In 2022, the peanut planting area in the above-mentioned provinces was 2.438 million hectares, accounting for 52.1% of the total peanut planting area in China, with a yield of 10.906 million tons, accounting for 59.5% of the total peanut production [2]. Accordingly, we assessed the application of the biological food attractant Bioattract® through continuous large-scale field trials in these four provinces on *A. ipsilon* and *H. armigera* in peanut fields to provide a basis for the promotion and application of such biological food attractant technology in the future.

2. Materials and Methods

2.1. Study Locations

Six different locations were selected to carry out the experiments in the Henan, Hebei, Shandong and Liaoning provinces from 2019 to 2023 (Table 1 and Figure 1), which were representative peanut-producing areas in China. There were two treatments: control and the mixed food attractant [29]. The mixed food attractant was made up of the biological food attractant Bioattract® (Shenzhen Bioglobal Agricultural Science Co., Ltd., Shenzhen, China) [31] and Coragen (Chlorantraniliprole 200 g/L, SC, FMC, origin: Singapore, sub package: Shanghai, China). The mixed food attractants were sprayed on the top leaves by strips with a spacing of 50 m, a bait strip length of 20 m and a width of 0.05–0.1 m. The mixed food attractants were applied in the experiment fields by local professional pests and diseases control organizations. Considering the experiment size, unmanned aerial vehicles were adopted (XAG's P30; Guangzhou XAIRCRAFT Technology Co., Ltd., Guangzhou, China) with the following flight parameters: flight speed 7 m/s, translation width 50 m and flight height 1.5 m from the ground, with a dose rate of 1000 mL/ha. In total, 5 hectares in the mixed food attractant-treated fields were sampled for investigation, and in a selected area with a 2 km distance, 5-hectare peanut fields with similar planting patterns were used as the controls. During the experiment, six different locations applied the mixed food attractant twice a year in the peanut field (Table 1). The main varieties, row spacing and plant spacing of the experiment fields varied in the six locations (Table 2).

Table 1. Field application details of biological food attractant.

Location	Application Area (ha)	Sampling Sites		Sampling Plots Area (ha)	Application Frequency	Application Date in Different Years				
		Toxicant-Infused Food Bait	Control			2019	2020	2021	2022	2023
Daming County, Handan City, Hebei Province (HD)	667	Zhengzai Village (115.312636° E, 36.292088° N)	Qianxiancheng Village (115.409660° E, 36.234650° N)	5	First time	17 June	13 June	14 June	16 June	17 June
	667	Zhengzai Village (115.312636° E, 36.292088° N)	Qianxiancheng Village (115.409660° E, 36.234650° N)	5	Second time	19 July	17 July	16 July	17 July	19 July
Jing County, Hengshui City, Hebei Province (HS)	67	Xingzhuang Village (116.049957° E, 37.733050° N	Xizhaozhuang Village (116.117763° E, 37.745064° N)	5	First time	9 June	10 June	10 June	13 June	11 June
	67	Xingzhuang Village (116.049957° E, 37.733050° N	Xizhaozhuang Village (116.117763° E, 37.745064° N)	5	Second time	13 July	12 July	13 July	15 July	14 July
Guan County, Langfang City, Heibei Province (LF)	67	Houying Village (116.249042° E, 39.361543° N)	Ligezhuang Village (116.192436° E, 39.344121° N)	5	First time	24 June	22 June	24 June	24 June	26 June
	67	Houying Village (116.249042° E, 39.361543° N)	Ligezhuang Village (116.192436° E, 39.344121° N)	5	Second time	27 July	24 July	26 July	27 July	29 July
Ningling County, Shangqiu City, Heinan Province (SQ)	667	Lilou Village (115.235574° E, 34.534178° N)	Hezhuang Village (115.203257° E, 34.555523° N)	5	First time	12 June	11 June	10 June	13 June	11 June
	667	Lilou Village (115.235574° E, 34.534178° N)	Hezhuang Village (115.203257° E, 34.555523° N)	5	Second time	15 July	14 July	14 July	15 July	13 July
Kalaqinzuoyi Mongolian Autonomous County, Chaoyang City, Liaoning Province (CY)	667	Baitazi Village (119.663944° E, 40.864848° N)	Zhangjiayao Village (119.670303° E, 40.672755° N)	5	First time	25 June	27 June	27 June	28 June	30 June
	667	Baitazi Village (119.663944° E, 40.864848° N)	Zhangjiayao Village (119.670303° E, 40.672755° N)	5	Second time	27 July	31 July	28 July	31 July	2 August
Laixi County, Yantai City, Shaodong Province (YT)	67	Taipingshan Village (120.559813° E, 36.781083° N)	Nanhouzai Village (120.562248° E, 36.766392° N)	5	First time	19 June	17 June	16 June	19 June	15 June
	67	Taipingshan Village (120.559813° E, 36.781083° N)	Nanhouzai Village (120.562248° E, 36.766392° N)	5	Second time	21 July	18 July	17 July	22 July	17 July

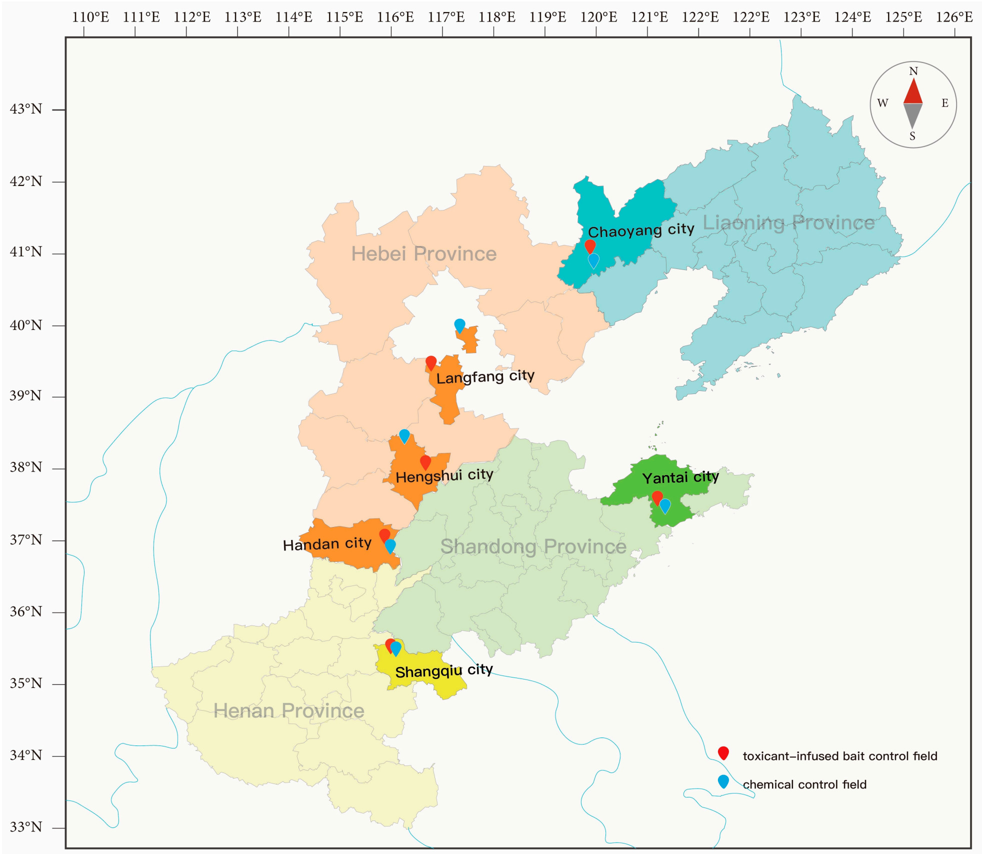

Figure 1. Geographical locations of application of the mixed food attractant in Henan, Shandong, Hebei and Liaoning provinces, China, during 2019 to 2023.

Table 2. Peanut varieties and planting patterns of different experiment sites.

Experiment Sites	Variety	Row Spacing	Plant Spacing	Plants/ha.
Handan City, Hebei Province	Jihua 915 (Daming Xinxin Seed Co., Ltd., Handan, China)	37.5 cm	22 cm	242,430
Chaoyang City, Liaoning Province	Fuhua 12 (Peanut Research Institute, Liaoning Academy of Agricultural Sciences)	15 cm	45 cm	148,000
Shangqiu City, Henan province	Huayu 25, Shanghua 4, Luohua 4087 (Henan Huameng Seed Co.,Ltd, Shangqiu, China)	33 cm	20 cm	270,000
Hengshui City, Hebei province	Huayu 23 (Peanut Research Institute, Shandong Academy of Agricultural Sciences)	60 cm	12 cm	135,000
Langfang City, Hebei province	Jihua 5, Jiyou 4 (Hebei Haohaijianong Seed Co., Ltd., Shijiazhuang, China)	40 cm	15 cm	150,000
Yantai City, Shandong province	Huayu 963 (Shandong Luhua Agricultural Science Co., Ltd., Laiyang, China)	20 cm	20 cm	250,000

2.2. Method for Population Dynamics Monitoring and Dissecting the Internal Reproductive System for the Adults Attracted and Killed by the Mixed Food Attractant in Peanut Fields

Five strips in the mixed food attractant treatment fields were randomly chosen and marked to collect and record the number of male and female *H. armigera*, *A. ipsilon* and other pest adults attracted to and killed by the baits on Day (D) 1, D4, D7 and D10 after the application. The pest species that were attracted to and killed by the baits were identified based on the insect's morphology. To avoid duplicate recordings, the remains of all the pests were cleaned out at the end of each field investigation. At Handan City, Hebei Province and Yantai City, Shandong Province, 10 male and female cotton bollworms were collected in plastic bags and frozen before dissection during every investigation of the population dynamics monitoring for the adult attracted to and killed by the mixed food attractant. The method for dissecting the testes of male moths was referenced in He et al. [28]. And then, the testes were placed on the carrier of the OLD-SG microscope and the major axis length was measured by the OLD-SGsho system (Shanghai Laoshangguang New Optics Technology Co., Ltd., Shanghai, China). In contrast to the major axis length of the testes, the age of the male moths was determined [28]. For the females, the times of mating were estimated by the number of spermatophores in the bursa copulatrix [29]. The ovarian development progress of the cotton bollworm was divided into 5 levels. And the division criteria for the ovarian development levels were referenced in Zhang and Mou [32].

2.3. Population Dynamics Monitoring Method for Eggs and Larvae in Peanut Fields

The diagonal five-point sampling method was employed to collect the data of the eggs and larvae of *H. armigera* and *A. ipsilon* in the 5-hectare sampling area of both treatment fields, with 20 peanut plants at each point. After spraying the mixed food attractant, the eggs and larvae of *H. armigera* and *A. ipsilon* were investigated on D3, D6 and D10. The same as the adult's investigation method, all the remains of the eggs and larvae were promptly removed. Control effect (the decline rate of eggs) = (average number of eggs in the control field—average number of eggs in the mixed food attractant treatment field)/average number of eggs in the control field $\times$ 100%. Control effect (the decline rate of larvae) = (average number of larvae in the control field—average number of larvae in the mixed food attractant treatment field)/average number of larvae in the control field $\times$ 100% [29,33].

2.4. Damage Rate of New Leaves in Peanut Fields

The diagonal five-point sampling method was adopted for investigating the number of damaged new leaves in both the mixed food attractant treatment fields and the control fields. The new leaves were recorded as damaged new leaves in the case that there were obvious gaps or holes. On the 13th and 20th days after applying the mixed food attractant, the number of damaged new leaves in both treatments were recorded, with 20 new peanut leaves investigated at each point. The damage rate of new leaves = the number of damaged new leaves/the number of total investigated leaves $\times$ 100%. Control effect (the decline rate of damaged new leaves) = (average number of damaged new leaves in the control field—average number of damaged new leaves in toxicant-infused food bait treatment field)/average number of damaged new leaves in control field $\times$ 100% [29,33].

2.5. The Costs of Conventional Chemical Control and Biological Food Attractant Control

Coragen (Chlorantraniliprole 200 g/L, SC, FMC, origin: Singapore, sub package: Shanghai, China) at a dose of 150 g/ha was applied in the control fields. The market price of the biological food attractant (Bioattract®, produced by Shenzhen Bioglobal Agricultural Science Co., Ltd., Shenzhen, China) is approximately USD 42 per liter, at a dose of 0.5 L/ha. The labor cost per hectare is calculated based on the hourly rates of different years in different regions, as well as the application area that each unmanned aerial vehicle can work per day.

2.6. Data Analyses

The differences in the population dynamics, sex ratio, decline rate of the population of eggs and larvae of lepidopteran pests and the percentage of damaged plants and decline rate of damaged new leaves were observed at different experimental sites, years, investigation times between treatments in the peanut field and the damage rate of the peanut tender tips at the different experimental sites, years, growing seasons or between treatments, which were analyzed using the multifactorial variance (ANOVA) followed by Duncan's new multiple range test (MRT), with the proportional data first arcsine square-root-transformed to meet the assumptions of normality and heteroscedasticity. A two-way ANOVA was used to examine the cost-saving of pest control in the peanut fields among the different years and between generations. Duncan's MRT was performed when the difference was significant. All the analyses were conducted using SPSS version 26 (IBM, Armonk, NY, USA).

3. Results

3.1. The Attract-and-Kill Effect of Toxicant-Infused Food Bait on Noctuid Pests in Peanut Fields

3.1.1. The Species and Ratio of the Pests Attracted by the Biological Food Attractants

A total number of 385,815 dead Lepidoptera adults were discovered in the baited strips of the six experiment sites from 2019 to 2023, with 324,939 *H. armigera* (84.2%), 40,106 *A. ipsilon* (10.4%) and 20,770 others (5.4%). The other pests mainly were *Agrotis segetum* (Schiffermiiller), *Spodoptera exigua* (Hübner) and *Spodoptera litura* (Fabricius). The number of Lepidoptera adults that were observed dead in the peanut fields varied significantly among the different pest species ($F_{2,709}$ = 161.274, $p < 0.001$; Table S1; and Figure 2A), application frequency of toxicant-infused food bait ($F_{1,709}$ = 32.934, $p < 0.001$; Table S1; and Figure 2B) and investigation times after application ($F_{3,709}$ = 47.345, $p < 0.001$; Table S1; and Figure 2C). There was no difference in the number of Lepidoptera pests captured by the baited strips among the different years ($p > 0.05$; Table S1). The proportion of *H. armigera* was significantly higher than that of *A. ipsilon* and the other pests ($F_{2,709}$ = 8099.344, $p < 0.001$; Table S1; and Figure 2D). The differences in the proportions of the attracted pests in the different experiment sites, years, application frequency and investigation times after application were not significant ($p > 0.05$; Table S1).

3.1.2. The Attract-and-Kill Effect of Toxicant-Infused Food Bait on Cotton Bollworm Adults

The cotton bollworm adults were strongly attracted to the biological food attractant. A total number of 324,939 dead cotton bollworm adults were discovered in the baited strips of the six experiment sites from 2019 to 2023, with 167,341 female moths (51.49%) and an average female/male ratio of 1.0524 $\pm$ 0.0070. Both the number and proportion of *H. armigera* adults attracted to and killed by the biological food attractant in the peanut fields varied significantly among the different application frequency (number: $F_{1,231}$ = 34.753, $p < 0.001$; Table S1; and Figure 3B; proportion: $F_{1,231}$ = 10.543, p = 0.001; Table S1; and Figure 3E) and investigation times after application (number: $F_{3,231}$ = 50.138, $p < 0.001$; Table S1; and Figure 3C; and proportion: $F_{3,231}$ = 7.056, $p < 0.001$; Table S1; and Figure 3F). There was no difference in the number of *H. armigera* adults captured by the baited strips in the different years ($p > 0.05$; Table S1; and Figure 2A;), but the proportion difference in the *H. armigera* adults was significant ($F_{4,231}$ = 2.434, p = 0.048; Table S1; and Figure 3D). The differences in the female/male ratio in the different years ($p > 0.05$; Table S1; and Figure 3G) was not significant. However, significant differences were observed in the investigation times after application ($F_{3,231}$ = 14.880, $p < 0.001$; Table S1; and Figure 3I) and application frequency ($F_{1,231}$ = 13.556, $p < 0.001$; Table S1; and Figure 3H). During the experimental observation period, the number (Figure 3C), proportion (Figure 3F) and female/male ratio (Figure 3I) of the *H. armigera* adults captured by the baited strips showed a decreasing trend with the increase in the investigation time. In peanut fields, the number of adults (Figure 3B), proportion (Figure 3E) and female/male ratio (Figure 3H) of the *H. armigera* captured by the baited strips at the first time of biological food attractant application were higher than those of the second time.

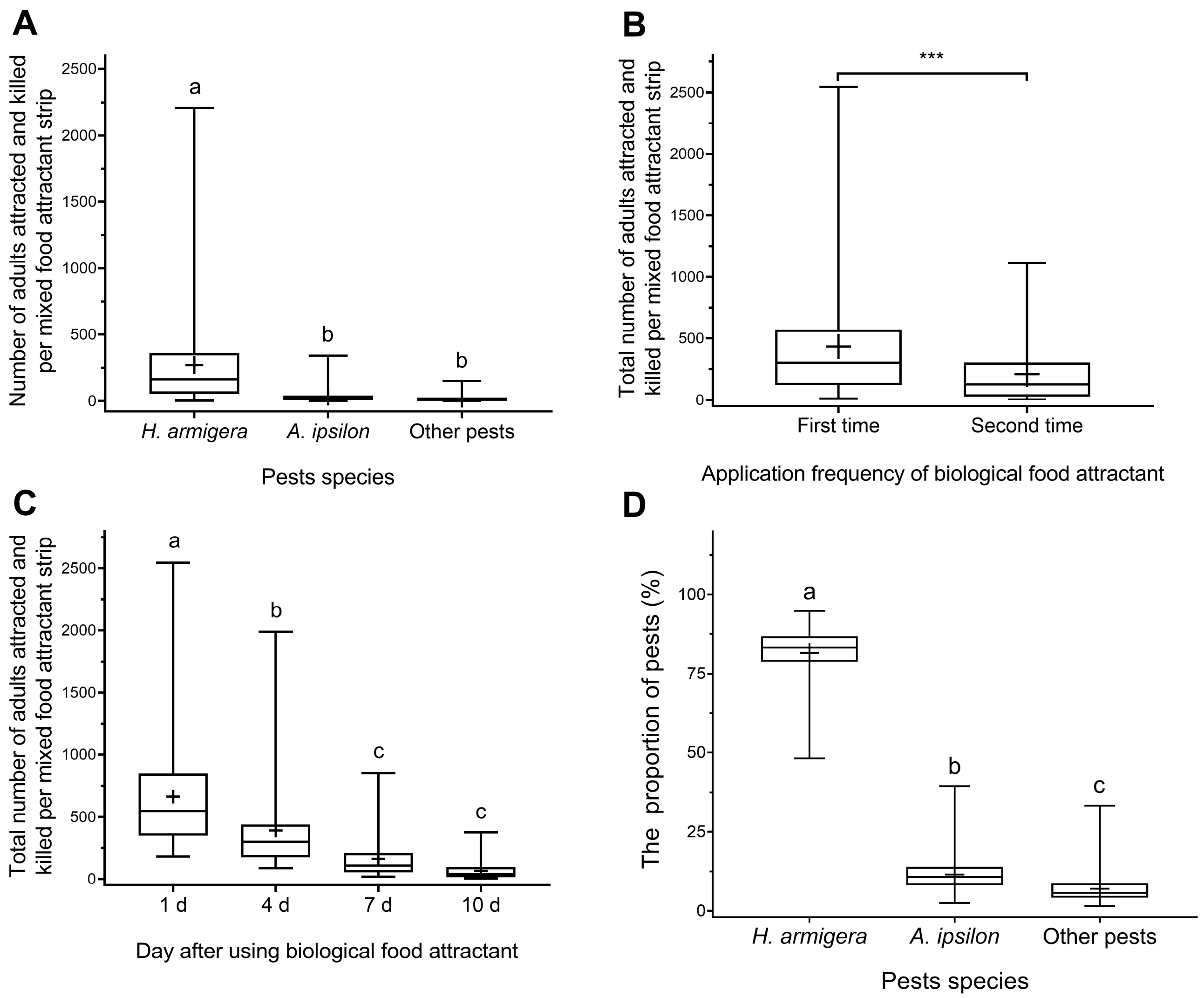

Figure 2. The box plot of the number (**A**–**C**) and proportion (**D**) of the pest's adults caught in the peanut fields by the biological food attractant Bioattract®. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars represent the minimum and maximum. The asterisks (***: $p < 0.001$) and different lowercase letters above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

The differences in the mating frequencies and ovarian development levels of the cotton bollworm females among the different investigation times after application (ovarian development levels: $F_{3,791} = 263.779$, $p < 0.001$; Table S2; and Figure 4A; and mating frequencies: $F_{3,791} = 211.592$, $p < 0.001$; Table S2; and Figure 4B) were significant. However, no significant difference was observed in the different years ($p > 0.05$; Table S2) and application frequency ($p > 0.05$; Table S2).

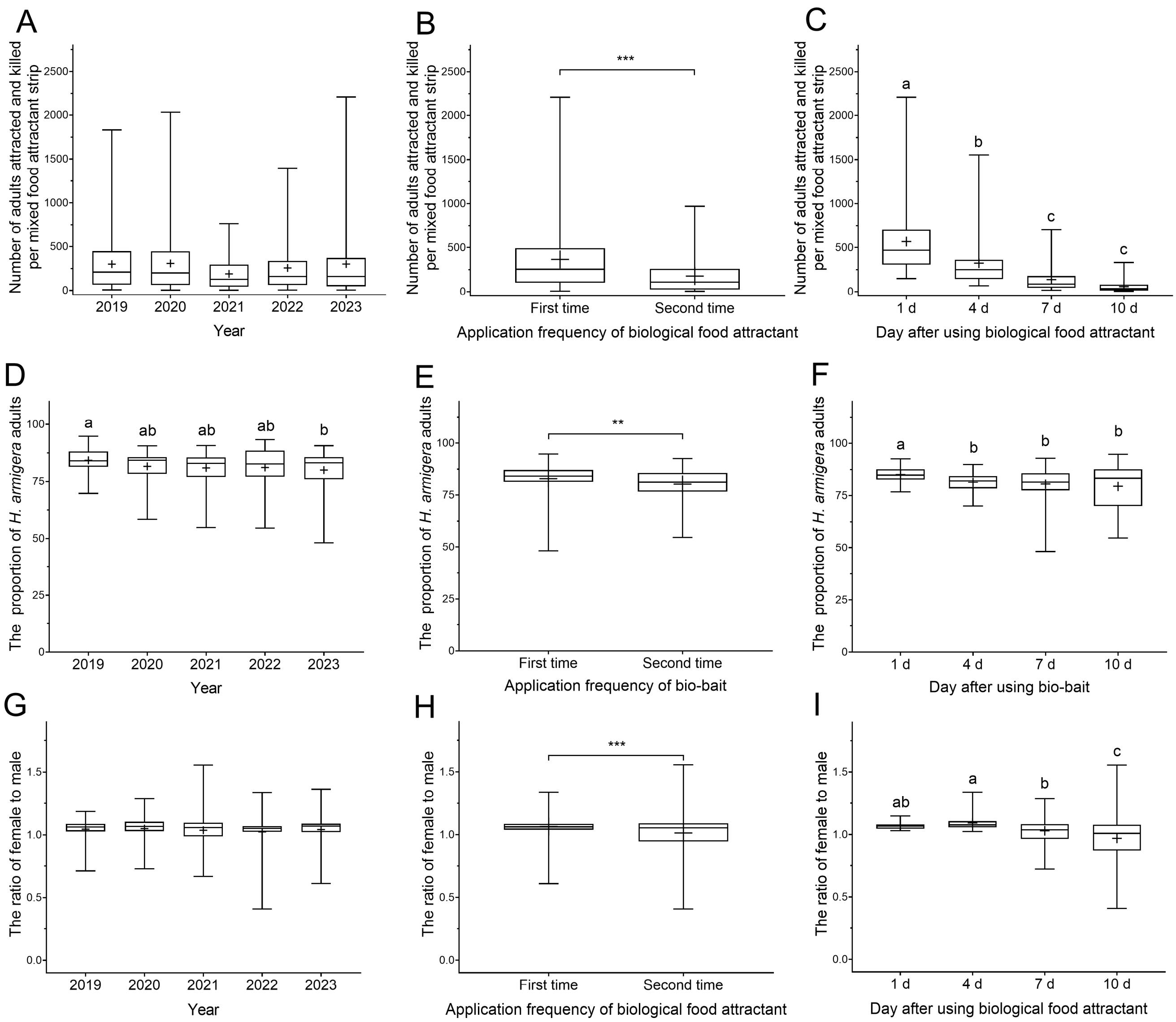

Figure 3. The box plot of the number (**A**–**C**), proportion (**D**–**F**) and sex ratio (**G**–**I**) of the cotton bollworm adults attracted and killed in the peanut fields. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars represent the minimum and maximum. The asterisks (**: $p < 0.01$; ***: $p < 0.001$) and different lowercase letters above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

The age and testis size of the cotton bollworm males displayed a difference in the investigation times after application (testis size: $F_{3,791} = 74.978$, $p < 0.001$; Table S2; and Figure 4C; and male age: $F_{1,791} = 68.507$, $p < 0.001$; Table S2; and Figure 4D), while there was no significant difference in the different years ($p > 0.05$; Table S2) and application frequency ($p > 0.05$; Table S2).

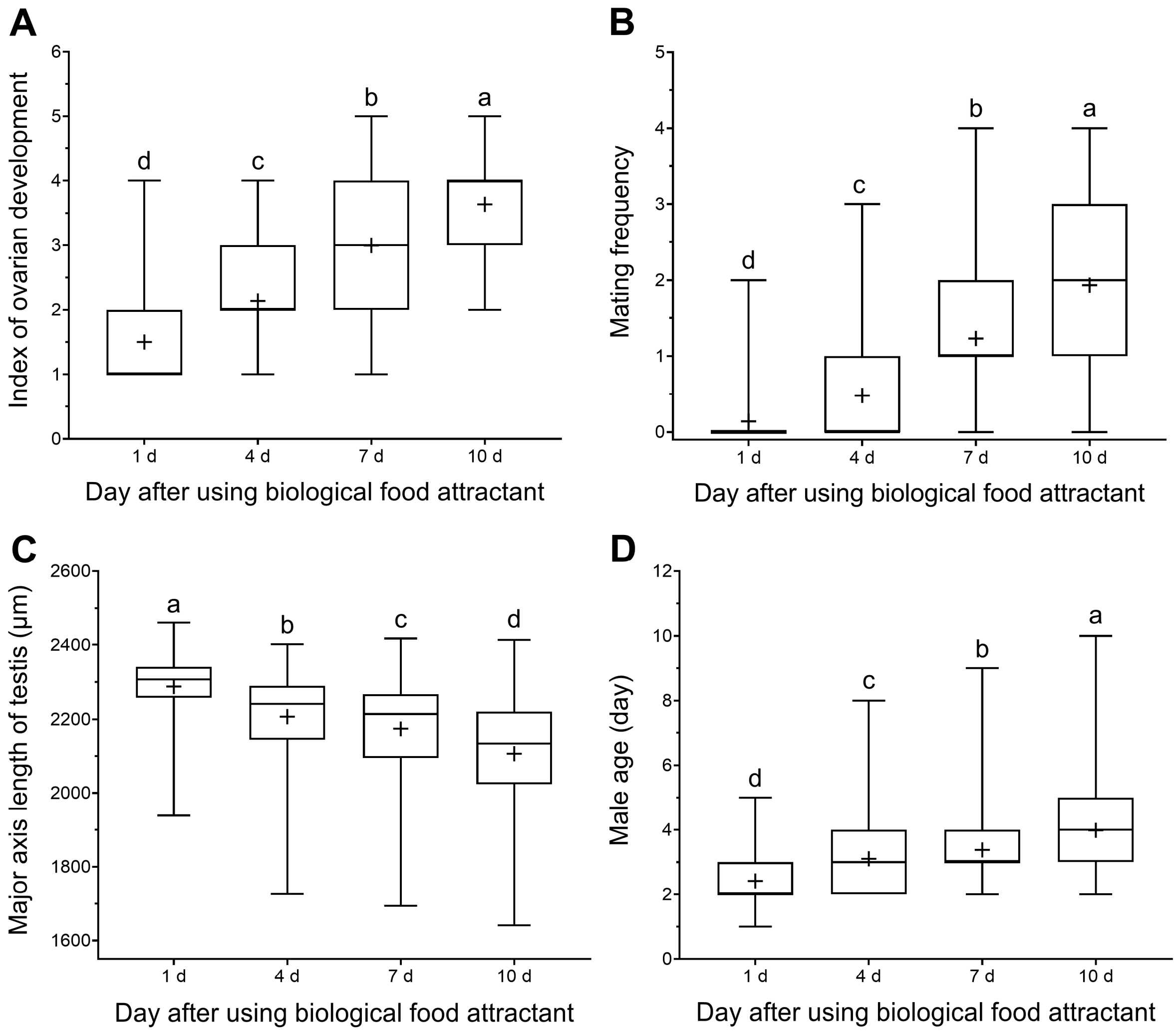

Figure 4. The ovarian development level (**A**) and mating frequency (**B**) of the female, major axis length of testis (**C**) and male age (**D**) for the cotton bollworm adults in the peanut fields. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars indicate the minimum and maximum. The different lowercase letters above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

3.1.3. The Attract-and-Kill Effect of Toxicant-Infused Food Bait on Black Cutworm Adults

The biological food attractant had similar attractive activity on the *A. ipsilon* adults in these experiments. A total number of 40,106 dead *A. ipsilon* adults were discovered in the baited strips of the six experiment sites from 2019 to 2023. The number of *A. ipsilon* adults attracted and killed in the peanut fields differed significantly among the different years ($F_{4,231} = 2.615$, $p = 0.036$; Table S1; and Figure 5A), application frequency ($F_{1,231} = 23.272$, $p < 0.001$; Table S1; and Figure 5B) and investigation times after application ($F_{3,231} = 28.705$, $p < 0.001$; Table S1; and Figure 5C). There was no difference observed in the proportion of *A. ipsilon* adults in the different years ($p > 0.05$; Table S1; and Figure 5D) and application frequency ($p > 0.05$; Table S1; and Figure 5E), while there was a significant difference among the different investigation times after application ($F_{3,231} = 4.157$, $p = 0.007$; Table S1; and Figure 5F).

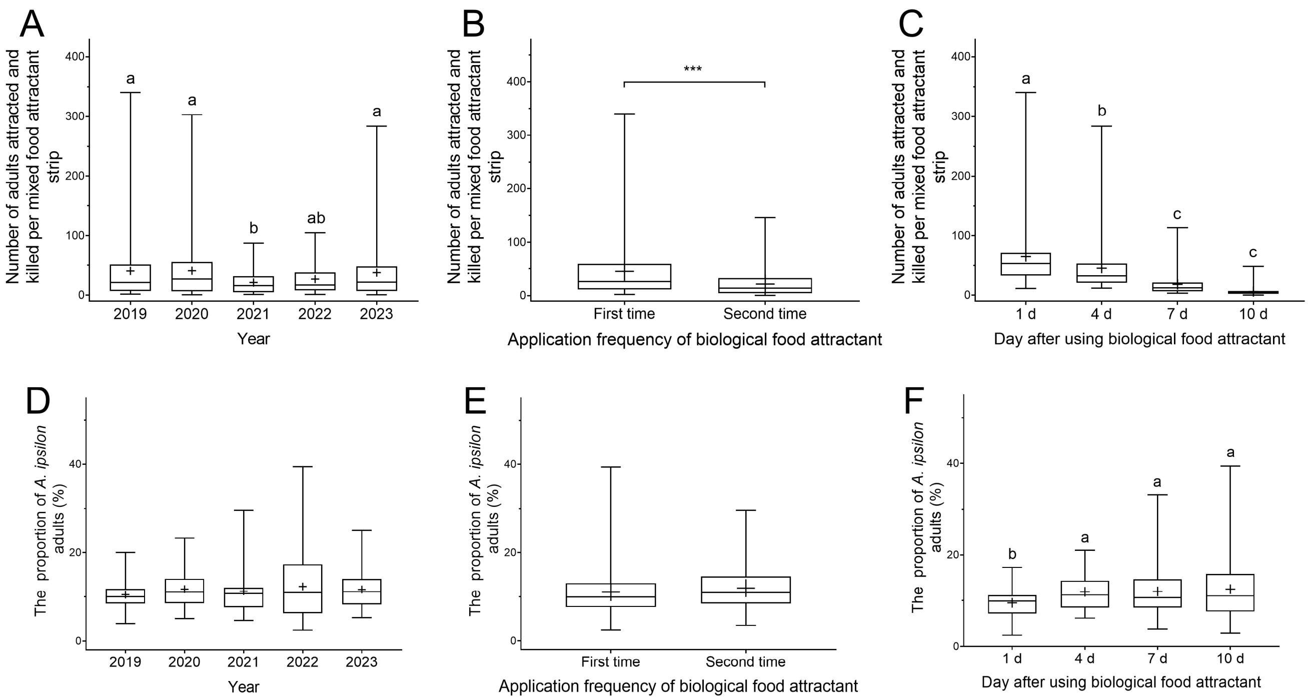

Figure 5. The box plot of the number (**A**–**C**) and proportion (**D**–**F**) of the black cutworm adults caught in the peanut fields. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars represent the minimum and maximum. The asterisks (***: $p < 0.001$) and different lowercase letters above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

3.2. The Control Effect of Toxicant-Infused Food Baits on Cotton Bollworm and Black Cutworm Eggs and Larvae in Peanut Fields

3.2.1. The Control Effect of Toxicant-Infused Food Baits on Cotton Bollworm Eggs and Larvae in Peanut Fields

The number of *H. armigera* eggs per 100 plants in the peanut fields showed significant differences between the treatments ($F_{1,351} = 155.325$, $p < 0.001$; Table S3; and Figure 6A), as well as across years ($F_{4,351} = 2.822$, $p = 0.025$; Table S3; and Figure 6D), application frequency ($F_{1,351} = 36.314$, $p < 0.001$; Table S3; and Figure 6B) and investigation times after application ($F_{2,351} = 35.908$, $p < 0.001$; Table S3; and Figure 6C).

The number of *H. armigera* larvae per 100 plants in the peanut fields differed significantly between the treatments ($F_{1,351} = 348.116$, $p < 0.001$; Table S3; and Figure 6E), as well as in the different application frequency ($F_{1,351} = 35.125$, $p < 0.001$; Table S3; and Figure 6F) and investigation times after application ($F_{2,351} = 27.803$, $p < 0.001$; Table S3; and Figure 6G). But there was no significant difference in the years ($p > 0.05$; Table S3).

Significant differences were observed in the decline rate of the cotton bollworm eggs and larvae across the different investigation times after application (eggs: $F_{2,169} = 5.689$, $p = 0.004$, Table S3; and Figure 6H; larvae: $F_{2,171} = 3.895$, $p = 0.022$, Table S3; and Figure 6I), while there was no difference in the years ($p > 0.05$; Table S3) and application frequency ($p > 0.05$; Table S3).

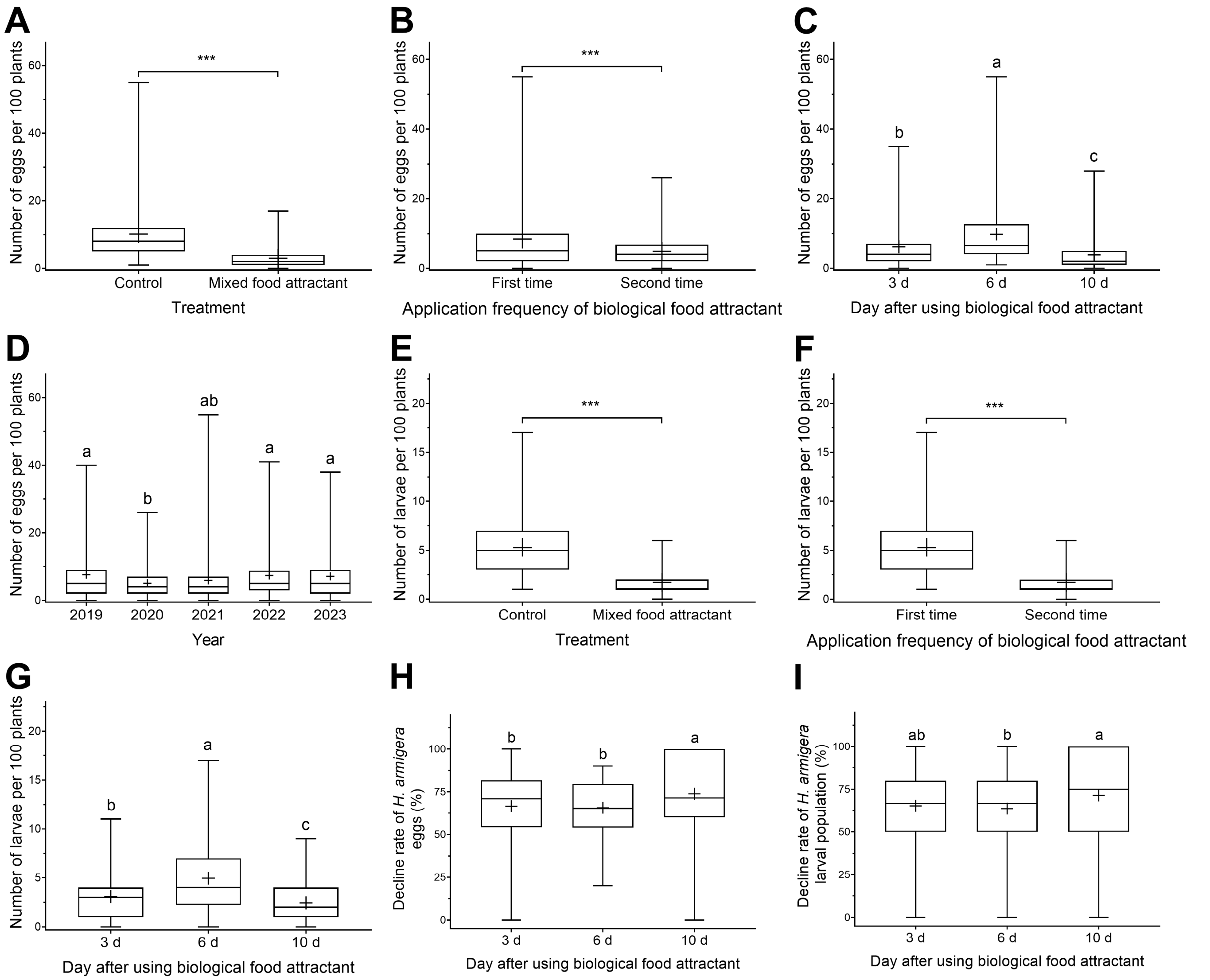

Figure 6. The number of eggs (**A**–**D**) and larvae (**E**–**G**) and the decline rate of eggs (**H**) and larval population (**I**) of the cotton bollworm in the peanut fields. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars indicate the maximum and minimum. The different lowercase letters and asterisks (***: $p < 0.001$) above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

3.2.2. The Control Effect of Toxicant-Infused Food Baits on Black Cutworm Eggs and Larvae in Peanut Fields

The number of *A. ipsilon* eggs per 100 plants in the peanut fields differed significantly between the treatments ($F_{1,351} = 233.090$, $p < 0.001$; Table S3; and Figure 7A), as well as among the application frequency ($F_{1,351} = 20.463$, $p < 0.001$; Table S3; and Figure 7C) and investigation times after application ($F_{2,351} = 37.482$, $p < 0.001$; Table S3; and Figure 7B). And there was no difference in the years ($p > 0.05$; Table S3).

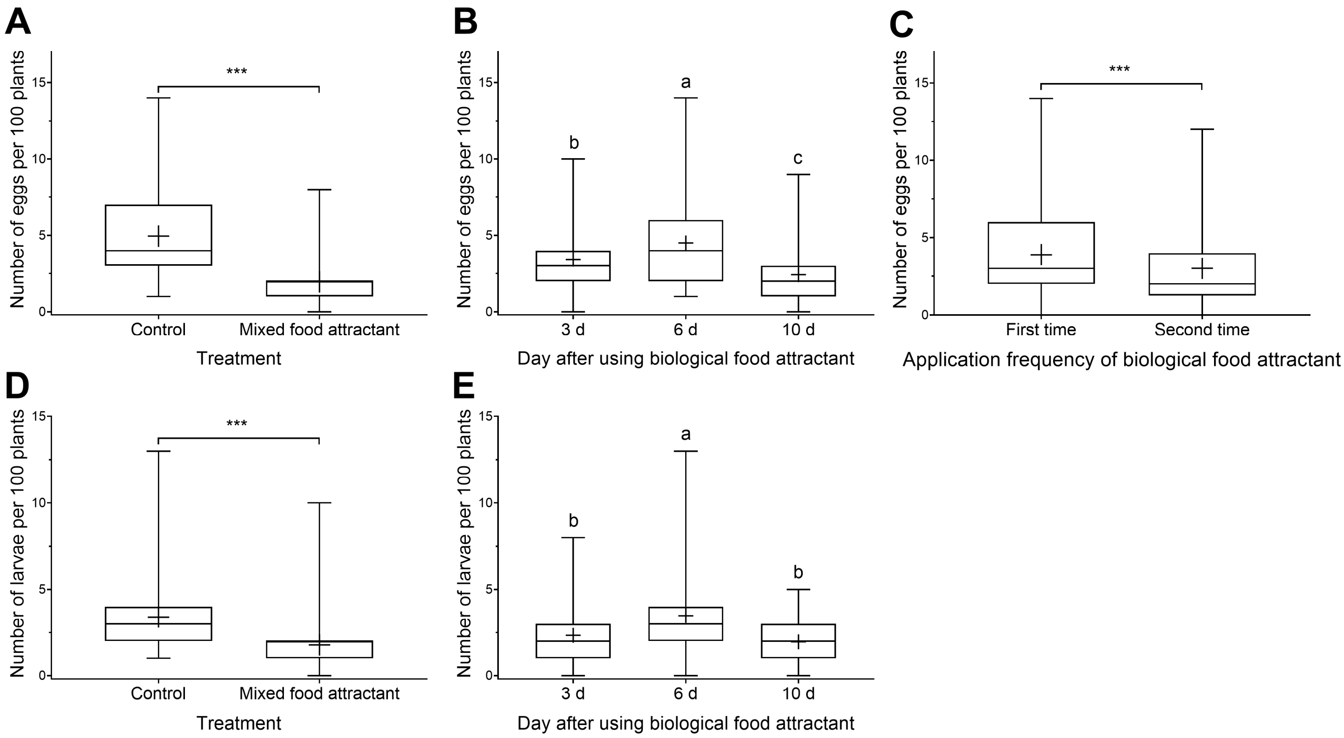

Figure 7. The number of eggs (**A**–**C**) and larvae (**D**,**E**) of the black cutworm in the peanut fields. The top and bottom of the black box show the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars indicate the minimum and maximum. The different lowercase letters and asterisks (***: $p < 0.001$) above the bar indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

The number of *A. ipsilon* larvae per 100 plants in the peanut fields showed differences between the treatments ($F_{1,351} = 86.677$, $p < 0.001$; Table S3; and Figure 7D), as well as across the investigation times after application ($F_{2,351} = 27.542$, $p < 0.001$; Table S3; and Figure 7E). However, no difference was observed among the years ($p > 0.05$; Table S3) and application frequency ($p > 0.05$; Table S3).

There was no difference in the decline rate of the *A. ipsilon* eggs and larvae per 100 plants in the different years, application frequency and investigation times after application ($p > 0.05$; Table S3).

3.3. Impacts of Toxicant-Infused Food Baits on Damage Rate of New Leaves in Peanut Fields

The damage rate of the new leaves in the peanut fields varied significantly for the investigation times after application ($F_{1,232} = 151.521$, $p < 0.001$; Table S4; and Figure 8B) and application frequency ($F_{1,232} = 56.455$, $p < 0.001$; Table S4; and Figure 8C), as well as between treatments ($F_{1,232} = 506.336$, $p < 0.001$; Table S4; and Figure 8A), while the difference among the different years ($p > 0.05$; Table S4) was not significant. The damage rate of the new leaves in the mixed food attractant treatment field was significantly lower than that in the control fields (Figure 8A). And the difference in the decline rate of the damaged new leaves was not significant in the different years, investigation times after application and application frequency ($p > 0.05$; Table S4).

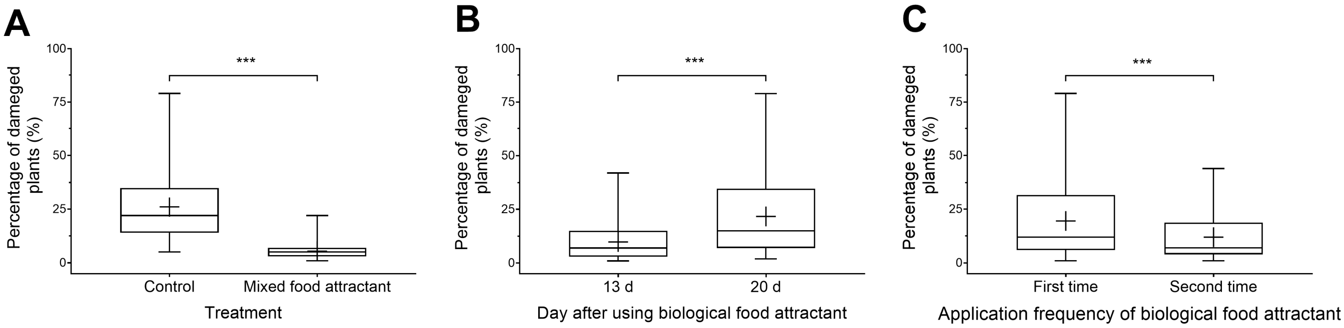

Figure 8. The box plot plant damage rate in different treatment (**A**), investigation times after application (**B**) and application frequency (**C**). The top and bottom of the black box represent the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars show the minimum and maximum. The asterisks (***: $p < 0.001$) indicate a significant difference (multifactorial ANOVA and Duncan's MRT; $p < 0.05$).

3.4. Cost-Savings

Compared with the control group, which was sprayed with conventional chemicals, applying the biological food attractant Bioattract® could save USD 34.55 to 69.10 per hectare, and the average value was USD 43.85 ± 1.14 per hectare. The amount of cost-savings showed a significant difference across the years ($F_{4,54} = 8.384$, $p < 0.001$; Table S5; and Figure 9A), while there was no significant difference in the application frequency ($p > 0.05$; Table S5; and Figure 9B).

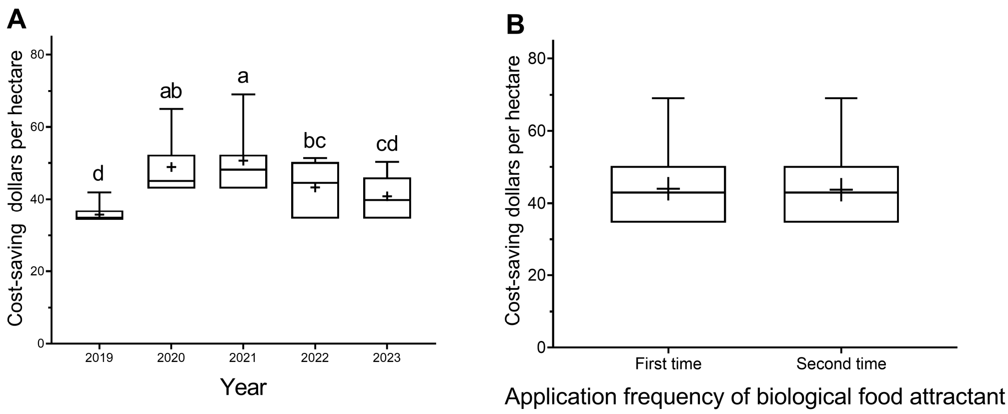

Figure 9. The box plot of the percentage of the cost-saving of pest control in the peanut fields plotted by the year (**A**) and application frequency of the mixed food attractant (**B**). The top and bottom of the black box mean the third and first quartile values, respectively; the cross (+) represents the mean for each category; the horizontal solid line indicates the median for each category; and the bars indicate the minimum and maximum. The different lowercase letters above the bar indicate a significant difference (two-way ANOVA and Duncan's MRT; $p < 0.05$).

4. Discussion

Phytophagous insects often receive and perceive a mixture of volatile compounds or pheromones, which play an important role in locating host plants or places to oviposit, and other behaviors [34–37]. Using plant volatiles to monitor and control agricultural pests becomes an important part of integrated pest management [16,25,26,29]. Cotton bollworm and black cutworm are polyphagous pests with high reproducibility and long-distance mobility, which are main factors leading to their population dispersions and regional break-outs [9,10,38,39]. Therefore, managing their adults can reduce the overwintering population base to a great extent and then helps to achieve effective regional control of *H. armigera* and *A. ipsilon* [29,40]. Our results have indicated the following: the biological food attractant Bioattract® had a strong attractiveness to *H. armigera* and *A. ipsilon* adults, which resulted in a markable decrease in the population of these two pests and their offspring in the peanut fields; biological food attractants could attract both male and female adults, with the female/male ratio of 1.05 for the attracted *H. armigera*; and compared with conventional chemical control, the application of biological food attractants could reduce the costs by USD 34.55 to 69.10 per hectare. In other words, biological food attractants based on plant volatiles have great potential for application in the IPM of *H. armigera* and *A. ipsilon*.

The results of the field experiments showed that the main lepidopteran pests attracted by the biological food attractant Bioattract® in peanut fields were *H. armigera* and *A. ipsilon*, accounting for 96.4% of the total amount, which was consistent with the research results of Kong et al. [30] and Lu et al. [8]. As 51.49% of the attracted *H. armigera* adults were females, the biological food attractants presented a strong attractiveness to all the female moths in different oviposition stages and mating frequencies, including those at the early oviposition stage, oviposition stage, late oviposition stage and the one mated or virgin, which was consistent with the results of other crops, such as maize, cotton and soybean [28,29]. The long axis length of the testes of male cotton bollworm adults attracted by the biological food attractants showed a significant downward trend over time. Baited strips could attract and kill male *H. armigera* moths aged from 1 to 10 days, which were also found in maize fields [29]. After applying the biological food attractants, the decline rates of the cotton bollworm eggs and larvae in peanut fields were 68.74% ± 1.43% and 66.84% ± 1.59% and that of *A. ipsilon* were 59.24% ± 1.56% and 51.06% ± 1.89%, respectively. The decline rate of the damaged new leaves was 78.26% ± 0.80%, which was similar to the research results of Kong et al. [30] and Lu et al. [8] in peanut fields and Wang et al. [29] in maize fields. The above research indicated that biological food attractants had a strong attraction activity toward both young and old Lepidoptera adults. Being one of the 'attract-and-kill' technological means, the biological food attractant Bioattract® significantly reduced the population quantity of Lepidoptera adults and their offspring in peanut fields, thereby reducing the infestation of the crops.

In China, peanuts are grown in the summer–autumn seasons under high heat and humidity and are vulnerable to various pests, such as the cotton bollworms, black cutworms and aphids. Improper management would lead to serious yield reduction. Hence, effective management of the pests is an important prerequisite to ensure healthy peanut production [9]. Starting from Songnen Plain in the north to Hainan Island in the south, from Tarim Basin in the west to the coastal area in the east, peanuts are planted all over China except in Tibet and Qinghai Province. Due to the complex geographic environments of the peanut production areas, the suggested plant protection rules are that prevention comes first, combined with integrated pest management, adapting to local conditions, which are safe, effective and economic [9]. The following suggestions are made for the sustainable development of the peanut industry: Firstly, establish and improve the pest monitoring and early-warning system in order to forecast and control the possible damage; second, good management of cultivation can help to form the insect resistance capacity of the crop; third, use chemical insecticides reasonably and scientifically to reduce the impact of excessive use on the environment and human health; and fourth, research and develop more biocontrol technologies [9,41].

Chemical pesticides have played a significant role in protecting crops from pest damage and saving yield losses; at the same time, however, they have also brought some ecological and food safety issues, such as environmental pollution, pesticide resistance and residues [42,43]. Today, with the increasing voice for environmental protection and stronger demand for the quality and safety of agricultural products, developing biocontrol technologies is conducive to the sustainable development of agriculture and thus the 'attract-and-kill' strategy has great application potential for integrated pest management [16]. The sex pheromone lures are used commonly to monitor and control the adult population of pests such as *H. armigera* and *A. ipsilon* in production [28,44,45]. However, the control effect of sex pheromone lures is limited by the multiple mating capability of male moths and the migration of mated females to nearby fields. Biological food attractants, as attractants, can attract both female and male moths, with the advantages of less environmental pollutes and less harm to natural enemies [16,22,23,29]. With their strong migratory behaviors, the key to prevent and manage *H. armigera* and *A. ipsilon* is the timing of when adults migrate into the fields [8]. Our research results indicated that the infusion of the biological food attractant Bioattract® and the pesticide Coragen significantly reduced the population quantity of the adults and offspring of *H. armigera* and *A. ipsilon* in peanut fields. In practical production, the biological food attractants can be used to monitor the population dynamics of noctuid pests on peanuts, maize and soybeans. Further, following the monitoring data, farmers can apply biological food attractants to manage the pests. Compared with the traditional model of relying on chemical pesticides to kill larvae, biological food attractants help to improve the control effectiveness and reduce the usage of the chemicals.

Nutrients in the adult stage provide the necessary energy for the reproductive system development, flight, courtship and mating activities for the agricultural insects [46]. As migratory pests, *H. armigera* and *A. ipsilon* adults visit flowers and feed on pollen or nectar, such as rapeseed, sunflower, purple aster, rose, pine and other plants [39,47]. As the adults need nutritional supplement, setting up biological food attractants as migration barriers for migratory pests to migrate north and south is supposed to significantly reduce the quantity of adults, and keep the pests damage under the economic thresholds, to achieve regional control of migratory pest populations. The biological food attractants, being a part of integrated pest management, could compensate for the shortcomings of other bio-control technologies, such as sex pheromone lures, light traps, Bt crops and so forth, which just meets the demands for the green, safe, effective and sustainable development of modern agriculture.

Biological food attractants are widely applied to manage agricultural pests such as *S. frugiperda* and *H. armigera* [16,25,28,29], and further improvements are still needed in practices. Heat would accelerate the releasing rate of biological food attractants, resulting in a sharp decrease in the attracted target moths. Therefore, it is suggested to optimize the specificity of the formulas, and develop better releasing carriers, thereby improving the control effect of biological food attractants toward target pests. In addition, more work on the standardization and automation of biological food attractants is expected in the future [48]. It was reported that combining biological food attractants with aggregation and sex pheromones could observably increase the efficiency of trapping [49–51]. And setting biological food attractants and repellent volatiles together to form a 'push–pull' system to regulate pest behaviors is also a very promising biocontrol technology [50].

5. Conclusions

In this study, we concluded that a mixed food attractant significantly reduced the population quantity of cotton bollworm and black cutworm adults and their offspring. The application of the mixed food attractant also brought a notable reduction in the damage rate of new leaves of peanut plants. Compared with using conventional chemicals, applying biological food attractants could reduce the cost ranging from USD 34.55 to 69.10 per hectare. Overall, the mixed food attractant showed an excellent control efficiency on cotton bollworm and black cutworm in peanut fields, implying that toxicant-infused food bait has immense potential for application in the integrated pest management of peanut.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy14050986/s1, Table S1: Summary of multifactorial analysis of variance (ANOVA) on the species, population quantity and sex ratio of pests caught in peanut fields by the mixed food attractant Bioattract®; Table S2: Summary of multifactorial analysis of variance (ANOVA) on reproductive parameters and male age of *Helicoverpa armigera* adults in peanut fields; Table S3: Summary of multifactorial analysis of variance (ANOVA) on the population dynamics of *Helicoverpa armigera* and *Agrotis ipsilon* in peanut fields; Table S4: Summary of multifactorial analysis of variance (ANOVA) on percentage of damaged plants and decline rate of damaged plants in peanut fields; Table S5: Summary of two-way analysis of variance (ANOVA) on cost-saving of pest control in peanut fields.

Author Contributions: K.W. designed the experiment. T.W., T.X., Z.Z., M.W., X.C., B.Y. and Y.Y. collected the data. L.W., L.H. and K.W. wrote the paper. L.W. and L.H. drew the figures and tables. All the authors contributed to this manuscript's editing and revision. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Dataset available on request from the authors.

Conflicts of Interest: All authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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