agriculture

MDPI

Article

Response of Natural Enemies toward Selective Chemical Insecticides; Used for the Integrated Management of Insect Pests in Cotton Field Plots

Amir Nadeem [1], Hafiz Muhammad Tahir [1], Azhar Abbas Khan [2], Atif Idrees [3,*], Muhammad Faisal Shahzad [4], Ziyad Abdul Qadir [5,6], Naveed Akhtar [1], Arif Muhammad Khan [7], Ayesha Afzal [3,8] and Jun Li [3,*]

1 Department of Zoology, Government College University Lahore, Lahore 54000, Pakistan
2 College of Agriculture, Bahauddin Zakariya University Multan, Bahadur Campus, Layyah 31200, Pakistan
3 Guangdong Key Laboratory of Animal Conservation and Resource Utilization, Guangdong Public Laboratory of Wild Animal Conservation and Utilization, Institute of Zoology, Guangdong Academy of Sciences, Guangzhou 510260, China
4 Department of Entomology, Gomal University, Dera Ismail Khan 29220, Pakistan
5 Honeybee Research Institute, National Agricultural Research Centre, Park Road, Islamabad 45500, Pakistan
6 Department of Entomology and Wildlife Ecology, University of Delaware, Newark, DE 19716, USA
7 Department of Biotechnology, University of Sargodha, Sargodha 40100, Pakistan
8 Institute of Molecular Biology and Biotechnology, The University of Lahore, 1-Km Defense Road, Lahore 54000, Pakistan
* Correspondence: atif_entomologist@giabr.gd.cn (A.I.); junl@giabr.gd.cn (J.L.)

check for updates

Citation: Nadeem, A.; Tahir, H.M.; Khan, A.A.; Idrees, A.; Shahzad, M.F.; Qadir, Z.A.; Akhtar, N.; Khan, A.M.; Afzal, A.; Li, J. Response of Natural Enemies toward Selective Chemical Insecticides; Used for the Integrated Management of Insect Pests in Cotton Field Plots. *Agriculture* **2022**, *12*, 1341. https://doi.org/10.3390/agriculture12091341

Academic Editors: Mubshar Hussain, Sami Ul-Allah, Shahid Farooq and Stanislav Trdan

Received: 12 July 2022
Accepted: 26 August 2022
Published: 30 August 2022

Publisher's Note: MDPI stays neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © 2022 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

Abstract: Sucking pests of cotton (*Gossypium hirsutum* L.), such as thrips, or *Thrips tabaci* Lindeman, and jassid, or *Amrasca biguttula* Ishida, are among the most threatening insect pests to young cotton plants in Pakistan. New chemical insecticides have been trialed to control their damage in commercial fields. Formulations that show good suppression of these pest's populations, while sparing bio-controlling agents, are always preferred for obtaining better crop yield. Six different commercially available insecticides, namely Fountain® (fipronil and imidacloprid), Movento Energy® (spirotetramat and imidacloprid), Oshin® (dinotefuran), Concept Plus® (pyriproxyfen, fenpyroximate, and acephate), Maximal® (nitenpyram), and Radiant® (spinetoram) were evaluated in the present study to shortlist the best available insecticide against targeted pests. Harmful impacts of selected insecticides were also evaluated against naturally occurring predators, such as spiders and green lacewings (*Chrysoperla carnea*). Radiant® (spinetoram) and Movento Energy®, respectively, were best at controlling thrips (with 61% and 56% mortality, respectively) and jassid (62% and 57% mortality, respectively) populations during 2018 and 2019. Radiant® proved itself as the best option and showed minimal harmful effects on both major arthropod predators of cotton fields i.e., spiders (with 8–9% mortality) and green lacewings (with 12–16% mortality). Movento Energy® also showed comparatively less harmful effects (with 15–18% mortality) towards natural predatory fauna of cotton crops, as compared to other selective insecticides used in the study. The findings of current study suggest that the judicious use of target-oriented insecticides can be an efficient and predator-friendly management module in cotton fields. However, the impact of these chemicals is also depended on their timely application, keeping in consideration the ETL of pests and the population of beneficial arthropods.

Keywords: biological control; sustainable; natural predation; habitat management; sucking pests

1. Introduction

Currently, *Bt* cotton, *Gossypium hirsutum* L., is officially authorized in Pakistan since 2010 due to its better yield and high profitability [1], which are why it is named the "golden cash crop" of Pakistan [2]. In Pakistan, the cotton crop is attacked by a variety of insect pests which are reported to be as many as ~162 species [3]. The major insect pests of *Bt* cotton include sap-feeding pests, of which jassid, or *Amrasca biguttula* Ishida (Hemiptera: Cicadellidae), and thrips, or *Thrips tabaci* Lindeman (Thysanoptera: Thripidae), are more common. As such, they have emerged as a serious threat to the crop yield for cotton growers [4].

Most of these sap-feeding pests attack the crop at its early phenological growth stage [5]. The insect pests of cotton usually cause a 5 to 10% percent yield loss [6,7], but in favorable environmental conditions, they may pull down crop yield by 35 to 50% [7]. They stunt plant growth by sipping sap from soft tissues and also from the undersides of young leaves of growing plants; they may also deface them [8]. Thrips are the first among different sucking pests which invade cotton fields at the seedling stage of the crop and, hence, cause an adverse effect on the overall yield of the crop. Similarly, jassids are known as the most critical pest at the growing stage of cotton plants. They not only suck the plant's sap, but they also inject poisonous saliva into the plant tissues during its feeding. Early attack by jassid reduces the photosynthetic area of plants by affecting their young leaves [9]. This may cause a 23.67% reduction in the overall cotton yield if goes unchecked [10].

Two different strategies can be used to avoid major cotton yield losses i.e., biological and chemical control to keep these pest species below economic threshold level (ETL). In the early phenological stages when the plants are too young to face these severely damaging pest species, cotton growers mainly rely upon different types of insecticides, which give them quick relief against sudden pest outbreaks. For this purpose, pesticides worth 10 billion rupees are imported and, of these, almost 70–80% are applied to cotton crops alone [11]. Such massive use of these pesticides results in different types of health hazards for farmers, including environmental and soil pollution. Furthermore, insects are developing resistance to these insecticides [12].

Resistance is developed in insect pests against generally used insecticides, which become less effective over time. To overcome this issue, the discovery of some already existing molecules and the invention of new synthetic chemicals is an ongoing process. Spirotetramat (Movento Energy®) is a wide-ranging insecticide suitable for all crops. Newly developed insecticides exhibit excellent results in controlling not only thrips but other sucking pests as well [13]. Thus, the usage of innovative chemicals molecule, such as pyridine carboxamide and neonicotinoids is increasing. These synthetic molecules are required in lower quantities and are also cost-effective for the regulation of sucking pests of the cotton crop [14]. Neonicotinoids are usually applied as foliar sprays and are also broadly used for seed treatments in *Bt* cotton to reduce pest attacks [15]. As with neonicotinoids, fipronil and some other pesticides are also used as foliar sprays to control various pests which appear at different phenological stages of the crop [16].

This study aimed to evaluate the efficacy of two comparatively newer insecticides (Radiant® and Movento Energy®) and conventionally used formulations (Fountain®, Concept Plus®, Oshin®, and Maximal®) against two of the major sucking insect pests, as well as their impact on major natural predatory fauna. The experiments were conducted in cotton fields under natural agricultural conditions for the evaluation of six selective insecticides as a foliar application at their recommended field rates. Their effects on naturally occurring bio-control agents i.e., spiders and green lacewings were also evaluated.

2. Materials and Methods

The present study was conducted at the Agricultural Research Farms of Bahauddin Zakariya University, Bahadur Sub-Campus, located in a semi-arid zone in the Layyah District (70.98401° N, 31.17979° E), Punjab Pakistan. The area has an elevation of 148 m and the soil texture is sandy loam. The present experiments were conducted during the summers of 2018 and 2019. Randomized complete block design (RCBD) was used for the applications of selected insecticides in experimental plots. A total of 10 blocks (10 replications) were selected for the experiment. The block size was 42.5 m × 30 m. Each block was further divided into seven plots in which six different commercial pesticides were evaluated, while the seventh plot was left untreated as a control. Every treatment plot (12 square meters) was separated from the next plot by a buffer zone area of 9 square meters. Plant to plant and row to row distances of 23 cm and 75 cm were maintained, respectively. Each experimental block was divided into a cultivated area, water channels for irrigation purposes, and the paths of the experiment. A main water channel of a 2 m width was made along one side of the field plot. Four sub-water channels (1 m wide), linked to the main water channel, were established to irrigate every treatment plot. Three paths, each of 1 m width, were also made. A single cotton cultivar (*Bt* FH-142) was selected for evaluating the efficacy of the short-listed insecticides (Table 1). The pest and predator data were taken before and after the application of commercial insecticides on the designed dates. The seeds were collected from the Food Machinery Chemical Corporation (FMC), Pakistan. Delinted seeds of *Bt* cotton were used at the amount of 19.77 kg per hectare.

Table 1. List of insecticides used in experimental field plots and their rates of application to the cotton crop.

Product Name	Active Ingredient (IRAC Class)	Application Rate (per Acre)	Company Name
(Fountain® 80% WDG)	Fipronil (GABA-gated chloride channel blockers) + imidacloprid (nicotinic acetylcholine receptor competitive modulators)	50 g	Four Brothers Chemicals (Pvt.) Ltd. Lahore-Pakistan
(Movento Energy® 48% SC)	Spirotetramat 12% (inhibitor of acetyl CoA carboxylase) + imidacloprid 36% (nicotinic acetylcholine receptor competitive modulators)	150 mL + 250 mL adjuvant	Bayer Crop Science, Karachi-Pakistan
(Oshin® 20SG)	Dinotefuran (nicotinic acetylcholine receptor competitive modulators)	100 g	Arysta Life Sciences Pvt. Ltd. Karachi-Pakistan
(Concept Plus® 35% EC)	Pyriproxyfen (juvenile hormone mimics) + fenpyroximate (mitochondrial complex 1 electron transport inhibitors) + acephate (acetylcholinesterase inhibitors)	750 mL	Kanzo AG Multan-Pakistan
(Maximal®)	Nitenpyram (nicotinic acetylcholine receptor competitive modulators)	150 g	FMC Karachi-Pakistan
(Radiant® SC)	Spinetoram (nicotinic acetylcholine receptor allosteric modulators—Site 1)	100 mL	Dow Agro Sciences, Karachi-Pakistan
(Untreated)	Control	-	-

Cotton sowing was carried out on May 20th and May 15th in the years 2018 and 2019, respectively, on ridges created through proper plowing of field plots. The recommended fertilizers i.e., DAP, nitrogen, phosphorous, and potash were applied according to the cotton cultivation technology [16]. Irrigation was carried out weekly or when it was required according to field moisture conditions, but not extended to the interval of more than two weeks. No herbicides were applied and, instead, handpicking or plowing was performed for weed control.

Manual counting of seedlings was carried out after 15 days of cotton sowing in the field plots. To keep the recommended plant × plant (6–9 inches) and row × row (2.5 feet) distance, thinning was performed accordingly [17]. The treatments were applied when thrips or jassid populations reached their economic threshold level (ETL) (the ETL of jassid is 1 adult or nymph per leaf, while the ETL of thrips is 8–10 adults or nymphs per leaf), after taking pre-application data. All insecticides were liquefied in water according to the label directions before their application. For applications of treatments, a hand-operated knapsack sprayer (UK Registered Design No. 2025702) was used. The control plot was left untreated. Pests and bio-control agents were monitored regularly on a weekly basis by making direct observations, and pre-application data was recorded a day before the application of the insecticides. During each visit, adult pest populations were recorded from three leaves of five randomly selected plants. From every randomly selected plant, the first leaf was taken from slightly above the ground level, the second leaf from the middle portion of it, and the third leaf from its top canopy. Similarly, data on arthropod predators were also recorded [18].

The normality and distribution of data were checked before the statistical analysis. A generalized linear model (GLM) under a one-way analysis of variance (ANOVA) was performed, leading to the LSD to discern the means at $p < 0.05$. Correlations of thrips and jassid populations with each other and with temperature and humidity at different dates were also calculated using Spearman's correlation. The statistical package SPSS® version 16 was used for the analyses of data.

3. Results

Before the application of selected insecticides, significant differences were observed in the populations of *T. tabaci* in all experimental plots during both study years ($F_{6,63}$ = 2.55; p = 0.0283 for 2018 and $F_{6,63}$ = 3.39; p = 0.0059 for 2019). A significant decline in the *T. tabaci* populations of all treated groups was recorded as compared to the control for both years after first application (Table 2). Radiant® caused a maximum reduction in thrip population (0.65 ± 0.08) two days after treatment (2 DAT) ($F_{6,63}$ = 8.08; p < 0.001), as compared to the pre-treatment during 2018. The same treatment showed the maximum population reduction (0.50 ± 0.08) on 2 DAT ($F_{6,63}$ = 8.62; p < 0.001), as compared to pre-treatment in 2019.

Table 2. Effect of selective insecticides on number (mean ± SEM) of adult thrips per leaf on cotton plants during 2018 and 2019. The data were recorded pre-24 h and 2, 9, and 16 days after treatment (DAT).

Treatments	Pre-24 h		2 DAT		9 DAT		16 DAT	
	2018	2019	2018	2019	2018	2019	2018	2019
The first application (1 July 2018, and 26 June 2019)								
Fountain®	2.08 ± 0.25 ^{ab}	1.78 ± 0.21 ^{ab}	1.10 ± 0.13 ^{bc}	0.94 ± 0.11 ^{bc}	1.33 ± 0.16 ^{ab}	1.14 ± 0.13 ^{ab}	1.83 ± 0.23 ^{ab}	1.57 ± 0.19 ^{ab}
Movento Energy®	2.66 ± 0.43 ^{a}	2.61 ± 0.40 ^{a}	1.15 ± 0.19 ^{bc}	1.13 ± 0.17 ^{bc}	1.46 ± 0.24 ^{ab}	1.43 ± 0.22 ^{ab}	2.13 ± 0.35 ^{ab}	2.09 ± 0.32 ^{a}
Oshin®	1.87 ± 0.20 ^{ab}	1.72 ± 0.19 ^{ab}	1.19 ± 0.13 ^{bc}	1.09 ± 0.12 ^{bc}	1.38 ± 0.15 ^{ab}	1.28 ± 0.14 ^{ab}	1.75 ± 0.19 ^{ab}	1.62 ± 0.17 ^{ab}
Concept Plus®	1.27 ± 0.24 ^{b}	1.18 ± 0.22 ^{b}	0.61 ± 0.11 ^{c}	0.56 ± 0.56 ^{c}	0.76 ± 0.14 ^{b}	0.71 ± 0.13 ^{b}	1.05 ± 0.20 ^{b}	0.98 ± 0.18 ^{b}
Maximal®	2.61 ± 0.47 ^{ab}	2.39 ± 0.44 ^{ab}	1.50 ± 0.26 ^{ab}	1.37 ± 0.24 ^{ab}	1.80 ± 0.33 ^{a}	1.65 ± 0.30 ^{a}	2.35 ± 0.43 ^{a}	2.16 ± 0.39 ^{a}
Radiant®	1.70 ± 0.22 ^{ab}	1.32 ± 0.22 ^{b}	0.65 ± 0.08 ^{c}	0.50 ± 0.08 ^{c}	0.88 ± 0.12 ^{b}	0.68 ± 0.11 ^{b}	1.27 ± 0.17 ^{ab}	0.99 ± 0.16 ^{b}
Control	2.35 ± 0.28 ^{ab}	2.14 ± 0.26 ^{ab}	2.07 ± 0.24 ^{a}	1.89 ± 0.23 ^{a}	2.15 ± 0.25 ^{a}	1.96 ± 0.24 ^{a}	2.30 ± 0.27 ^{a}	2.09 ± 0.26 ^{a}
The second application (20 July 2018, and 15 July 2019)								
Fountain®	1.71 ± 0.24 ^{bc}	1.72 ± 0.24 ^{bc}	0.90 ± 0.12 ^{bc}	0.91 ± 0.12 ^{bc}	1.09 ± 0.15 ^{bc}	1.10 ± 0.15 ^{bc}	1.51 ± 0.21 ^{bc}	1.52 ± 0.21 ^{bc}
Movento Energy®	2.31 ± 0.24 ^{bc}	2.33 ± 0.24 ^{bc}	1.00 ± 0.10 ^{bc}	1.01 ± 0.10 ^{bc}	1.27 ± 0.13 ^{bc}	1.28 ± 0.13 ^{bc}	1.86 ± 0.20 ^{bc}	1.87 ± 0.20 ^{bc}
Oshin®	1.99 ± 0.40 ^{bc}	2.00 ± 0.40 ^{bc}	1.26 ± 0.25 ^{bc}	1.26 ± 0.25 ^{bc}	1.47 ± 0.30 ^{bc}	1.49 ± 0.30 ^{bc}	1.87 ± 0.38 ^{bc}	1.88 ± 0.38 ^{bc}
Concept Plus®	1.56 ± 0.22 ^{bc}	1.57 ± 0.22 ^{bc}	0.75 ± 0.11 ^{bc}	0.75 ± 0.11 ^{bc}	0.94 ± 0.13 ^{bc}	0.95 ± 0.13 ^{bc}	1.30 ± 0.19 ^{c}	1.31 ± 0.19 ^{c}
Maximal®	2.85 ± 0.37 ^{ab}	2.87 ± 0.37 ^{ab}	1.64 ± 0.20 ^{b}	1.65 ± 0.21 ^{b}	1.97 ± 0.25 ^{b}	1.98 ± 0.25 ^{b}	2.57 ± 0.33 ^{b}	2.59 ± 0.34 ^{b}
Radiant®	1.35 ± 0.07 ^{c}	1.36 ± 0.07 ^{c}	0.52 ± 0.02 ^{c}	0.52 ± 0.03 ^{c}	0.70 ± 0.03 ^{c}	0.71 ± 0.03 ^{c}	1.01 ± 0.05 ^{c}	1.02 ± 0.05 ^{c}
Control	4.16 ± 0.48 ^{a}	4.19 ± 0.48 ^{a}	3.67 ± 0.43 ^{a}	3.70 ± 0.43 ^{a}	3.80 ± 0.44 ^{a}	3.83 ± 0.44 ^{a}	4.07 ± 0.49 ^{a}	4.10 ± 0.49 ^{a}

Note: The values in the columns with different superscripts are significantly different when compared by LSD.

The minimum population reduction was recorded by the Oshin® on 2 DAT (1.19 ± 0.13 and 1.09 ± 0.12 for 2018 and 2019, respectively) as compared to the population before treatment (1.87 ± 0.20 and 1.72 ± 0.19 for 2018 and 2019, respectively). A similar trend was also recorded against the second application of insecticide treatments on 20 July 2018, and 15 July 2019. The differences in the populations of *T. tabaci* at 9 DAT ($F_{6,63}$ = 5.30; p = 0.0002) and 16 DAT ($F_{6,63}$ =3.26; p = 0.0074) of 2018 and 9 DAT ($F_{6,63}$ = 5.92; p = 0.001) and 16 DAT ($F_{6,63}$ = 4.04; p = 0.0017) of 2019 were also statistically significant.

After the application of various insecticides, a significant reduction in the jassid population was observed in all treated plots. The results given in Table 3 showed mean population reduction in jassid by various insecticide treatments in both applications during the years 2018 and 2019. The data indicated that maximum mortality (0.87 ± 0.09 and 0.56 ± 0.05) was recorded with the Radiant® at 2 DAT ($F_{6,63}$ = 20.4; p < 0.001) in 2018. A similar trend was also recorded at 2 DAT ($F_{6,63}$ = 21.6; p < 0.001) for the year 2019. In the second application, the difference at 9 DAT ($F_{6,63}$ = 5.71; p < 0.0001) and 16 DAT ($F_{6,63}$ = 3.38; p = 0.0059) of 2018, and 9 DAT ($F_{6,63}$ = 5.58; p = 0.0001) and 16 DAT ($F_{6,63}$ = 3.29; p = 0.0071) of 2019 were also significant.

Table 3. Effect of selective insecticides on number (mean ± SEM) of adult jassids per leaf on cotton plants during 2018 and 2019. The data was recorded pre-24 h and 2, 9, and 16 days after treatment (DAT).

Treatments	Pre-24 h		2 DAT		9 DAT		16 DAT	
	2018	2019	2018	2019	2018	2019	2018	2019
The first application (1 July 2018, and 26 June 2019)								
Fountain®	1.48 ± 0.17 c	1.53 ± 0.18 c	0.79 ± 0.09 c	0.81 ± 0.09 c	0.95 ± 0.11 c	0.98 ± 0.11 c	1.30 ± 0.15 c	1.35 ± 0.15 cd
Movento Energy®	2.85 ± 0.40 bc	2.94 ± 0.41 bc	1.24 ± 0.18 bc	1.28 ± 0.18 bc	1.57 ± 0.22 bc	1.62 ± 0.23 bc	2.29 ± 0.33 bc	2.36 ± 0.33 bcd
Oshin®	3.39 ± 0.49 ab	3.49 ± 0.50 ab	2.15 ± 0.31 b	2.21 ± 0.32 b	2.51 ± 0.36 b	2.59 ± 0.37 b	3.18 ± 0.46 ab	3.28 ± 0.48 ab
Concept Plus®	1.52 ± 0.19 c	1.58 ± 0.20 c	0.73 ± 0.09 c	0.76 ± 0.10 c	0.91 ± 0.12 c	0.95 ± 0.12 c	1.26 ± 0.16 c	1.32 ± 0.17 d
Maximal®	3.13 ± 0.36 bc	3.23 ± 0.37 abc	1.79 ± 0.20 bc	1.85 ± 0.20 bc	2.16 ± 0.25 bc	2.23 ± 0.25 bc	2.82 ± 0.32 bc	2.91 ± 0.33 bc
Radiant®	2.29 ± 0.24 bc	2.36 ± 0.25 bc	0.87 ± 0.09 c	0.90 ± 0.10 c	1.19 ± 0.13 bc	1.23 ± 0.13 c	1.71 ± 0.18 bc	1.77 ± 0.19 bcd
Control	4.88 ± 0.69 a	4.92 ± 0.65 a	4.29 ± 0.60 a	4.33 ± 0.57 a	4.46 ± 0.63 a	4.50 ± 0.60 a	4.76 ± 0.67 a	4.80 ± 0.63 a
The Second application (20 July 2018, and 15 July 2019)								
Fountain®	1.59 ± 0.16 ab	1.75 ± 0.17 ab	0.85 ± 0.09 cd	0.93 ± 0.09 bcd	1.02 ± 0.10 bc	1.12 ± 0.11 bc	1.40 ± 0.14 ab	1.53 ± 0.15 ab
Movento Energy®	1.70 ± 0.27 ab	1.85 ± 0.29 ab	0.73 ± 0.11 cd	0.80 ± 0.12 cd	0.94 ± 0.15 c	1.02 ± 0.16 c	1.36 ± 0.21 b	1.48 ± 0.23 b
Oshin®	1.80 ± 0.20 ab	1.95 ± 0.22 ab	1.14 ± 0.13 abc	1.24 ± 0.14 abc	1.33 ± 0.15 abc	1.45 ± 0.17 abc	1.69 ± 0.19 ab	1.83 ± 0.21 ab
Concept Plus®	1.83 ± 0.25 ab	1.98 ± 0.26 ab	0.88 ± 0.11 bcd	0.95 ± 0.12 bcd	1.10 ± 0.15 abc	1.19 ± 0.16 abc	1.52 ± 0.21 ab	1.65 ± 0.22 ab
Maximal®	2.46 ± 0.27 a	2.66 ± 0.29 a	1.41 ± 0.16 ab	1.53 ± 0.17 ab	1.70 ± 0.18 a	1.84 ± 0.20 a	2.22 ± 0.24 a	2.40 ± 0.26 a
Radiant®	1.47 ± 0.12 b	1.60 ± 0.13 b	0.56 ± 0.05 d	0.61 ± 0.05 d	0.76 ± 0.06 c	0.84 ± 0.07 c	1.10 ± 0.09 b	1.20 ± 0.10 b
Control	1.80 ± 0.23 ab	1.96 ± 0.25 ab	1.58 ± 0.20 a	1.73 ± 0.22 a	1.64 ± 0.21 ab	1.79 ± 0.23 ab	1.76 ± 0.23 ab	1.92 ± 0.26 ab

Note: The values in the columns with different superscripts are significantly different when compared by LSD.

The preliminary data analysis showed an almost similar trend of both predator (green lacewings and spiders) densities during both years of the study period and, hence, the data was pooled together for further statistical analysis. The selected insecticides affected both green lacewings and spiders in the following trends i.e., Oshin® > Maximal® > Fountain® > Concept Plus® > Movento Energy® > Radiant®. The results indicated that maximum population reduction in the beneficial arthropod, *C. carnea* was recorded against the application of Oshin® before pre-treatment (0.649), ($F_{6,63}$ = 0.85; p = 0.5348) followed by post-treatment i.e., 2 DAT (0.189), ($F_{6,63}$ = 24.7; p = 0.0000) in 2018, which caused maximum mortality among all treatments. Radiant®, on the other hand, caused minimum mortality of the *C. carnea* (pre-treatment, 0.656 ± 0.0741 and post-treatment, 0.577 ± 0.0645) having ANOVA values ($F_{6,63}$ = 0.85; p = 0.5348) and 2 DAT ($F_{6,63}$ = 24.7; p = 0.0000), and spiders (pre-treatment, 1.062 ± 0.0783 and post-treatment, 0.987 ± 0.0745) with ANOVA values ($F_{6,63}$ = 3.27; p = 0.0073) and 2 DAT ($F_{6,63}$ = 35.1; p = 0.0000), during the year 2018. The varying effect of these insecticides on these beneficial arthropods was also revealed by post-hoc test results (Figures 1 and 2).

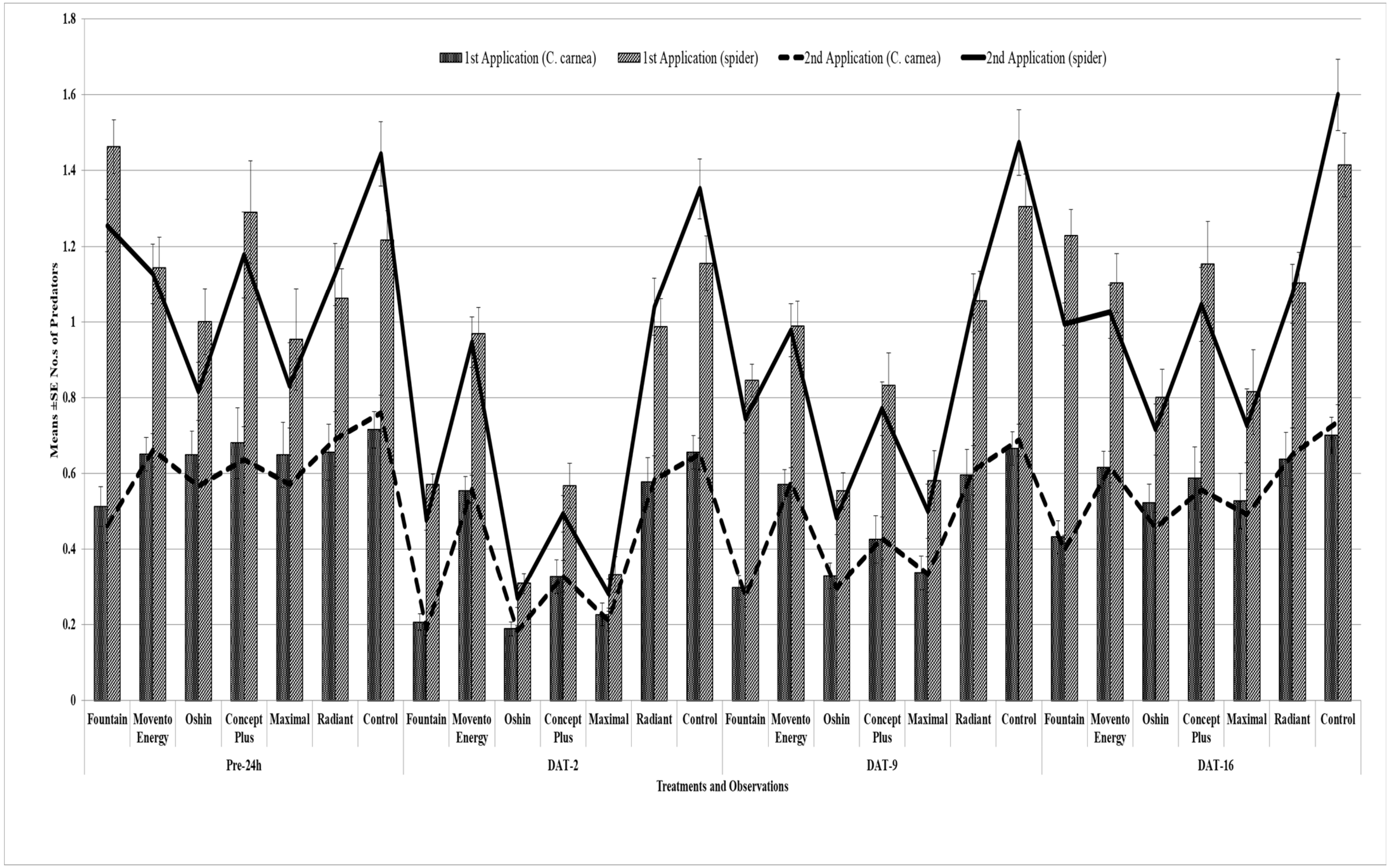

Figure 1. Effect of different insecticides on numbers of *C. carnea* and predatory spiders per plant. Mean (±SEM) in *Bt* cotton field plots on 1 July 2018 and 20 July 2018, observed at pre-24 h, 2 DAT, 9 DAT, and 16 DAT (days after treatment).

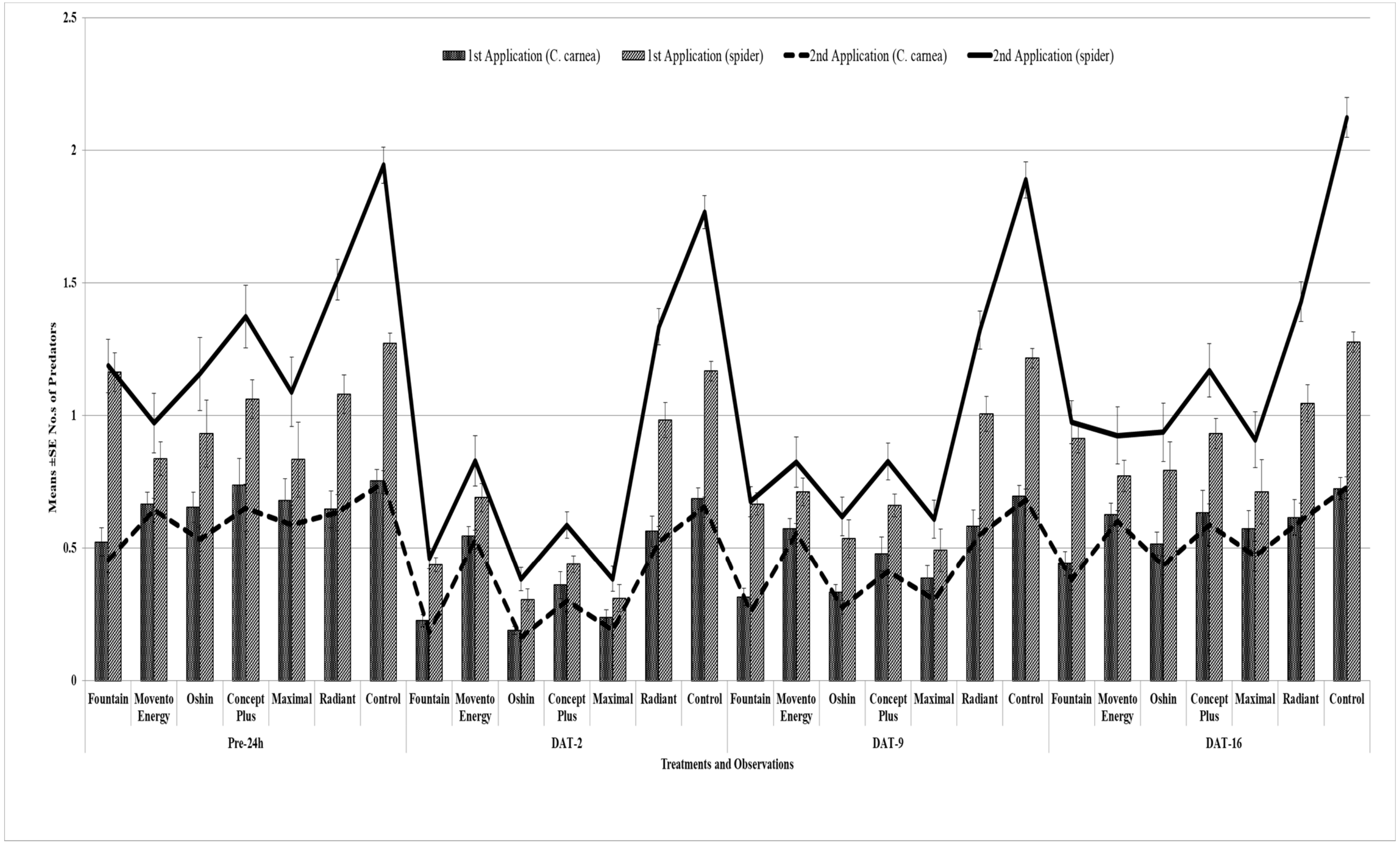

Figure 2. Effect of different insecticides on numbers of *C. carnea* and predatory spiders per plant. Mean (±SEM) in *Bt* cotton field plots on 26 June 2019 and 15 July 2019, observed at pre-24 h, 2 DAT, 9 DAT, and 16 DAT (days after Treatment).

4. Discussion

Cotton growers used a wide range of commercially available insecticides against sucking pests but, due to their regular usage, pests can develop resistance against these insecticides, meaning that they become less effective in controlling pests [19]. Moreover, their impact on beneficial fauna like common predators including beetles (coccinellids), green lacewings, ants, and parasitoids (wasps), along with environmental contamination, are major issues related to the unjust usage of these broad-spectrum insecticides [20]. Therefore, there is a need to evaluate and select those insecticide formulations and active ingredients which are more target-specific in their mode of action against sucking insect pests of cotton and are friendly towards the environment and beneficial predators. Recently, it has been proposed that controlling these pests biologically is eco-friendlier than using synthetic insecticides [21].

Results of the present study showed that all selected insecticides imposed a significant reduction in the populations of two major sucking pests (thrip and jassid) in treated field plots of respective treatments when compared to the pest populations found in untreated control plots, suggesting their efficacy. However, Radiant® proved itself as the most bio-friendly insecticide among all the selected chemical insecticides for the study. All selected treatments work efficiently and showed a reduction in *T. tabaci* populations for both years of study as compared to control (untreated). Radiant®, Movento Energy®, and Concept Plus® showed more of a reduction in *T. tabaci* populations at their first and second applications as compared to other insecticides during the years 2018–2019. Chloridis et al. [22] also reported that spinetoram proved more efficient against many insect pests as compared to the plots sprayed with spinosad formulations.

Maximum mortality (percentage) of thrips was observed in the field plots treated with Radiant® after 2 DAT (61.76% and 61.48%) to 16 DAT (25.29% and 25.18%) after its first and second application, respectively, during the experiment year 2018 (Table 2). Spinetoram was described by Dripps et al. [23] as an active ingredient of a semi-synthetic nature that demonstrated higher levels of efficacy than spinosad, especially against lepidopteran larvae, thrips, and leaf miners on a variety of crops and horticultural plants. Waters and Walsh [24] reported spinetoram as an efficacious insecticide against onion thrips, while spirotetramat provides satisfactory control of the thrip population. Ghelani et al. [25] also evaluated the effectiveness of different insecticides of both chemical and botanical origin and documented that all of the evaluated botanicals and insecticides were effective against thrips and other major sucking insect pests.

All of the six tested insecticides showed significant mortality in jassid populations observed post-treatment for both experimental years 2018–2019. However, two insecticides, namely Radiant® and Movento Energy®, gave the highest mortality ratios of jassid. Gogi et al. [26], also mentioned that, in cotton fields, rapid control of different pest species through chemical insecticides is the best strategy, and it plays an important role in different integrated pest management (IPM) programs. In the present study, all selected chemical insecticides showed control against the major sucking pests of the crops.

All of the selective insecticides reduced the total number of beneficial fauna (non-target) to almost one-half of their total population. However, in the present study, Radiant® proved to be the much more friendly option towards the beneficial fauna of the crops, especially towards green lacewings and spiders. Some new insect growth regulators, such as buprofezin and pyriproxyfen, proved themselves to be quite target-specific and showed minimal impact on beneficial predatory fauna [27].

5. Conclusions

At the vegetative stage of the cotton crop, a repeated spray of chemical insecticides for controlling different sucking pests, especially jassid and thrip, is of great importance. However, to provide a safeguard for the environment, beneficial predatory fauna, as well as cotton growers, safe and more specific insecticides should be developed and tested regularly. The results of our tested chemicals showed that two bio-based chemical insecticides, namely Radiant® and Movento Energy®, showed less harm to beneficial predatory fauna while controlling the sucking pest populations. These insecticides could be selected as the first choice for future IPM strategies and also in places where usage of conventional insecticides is restricted, for example in organic farming land areas. The findings of pests' resistance against commonly practiced broad-spectrum insecticides, such as neonicotinoid and acephate, show the need for their low usage, and also the need to integrate them with some milder insecticides.

Author Contributions: Conceptualization, A.N., H.M.T., A.A.K. and A.I.; Investigation, A.N., H.M.T. and A.A.K.; Methodology A.N., H.M.T. and A.A.K.; Project administration, J.L.; Software, M.F.S., Z.A.Q. and A.A.; Supervision, A.A.K. and H.M.T.; Formal analysis, A.I. and A.M.K.; Writing—original draft, A.N. and A.I.; Writing—review and editing, H.M.T., A.A.K., M.F.S., Z.A.Q., N.A., A.M.K., A.A. and J.L.; Validation, A.M.K. and N.A.; Data curation, A.I. and A.A.; Funding acquisition, A.I. and J.L. All authors have read and agreed to the published version of the manuscript. All the authors have contributed substantially to the work reported.

Funding: This research work was supported by GDAS Special Project of Science and Technology Development (No. 2020GDASYL-20200301003) and GDAS Action Capital Project to build a comprehensive industrial technology innovation center (No. 2022GDASZH-2022010106).

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Acknowledgments: We are thankful to the local farmers for the provision of crop field's area for the current research. We are also grateful to Department of Entomology, College of Agriculture, Bahauddin Zakariya University, Bahadur Campus Layyah-Pakistan for providing entomological equipment and related facilities.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

References

1. Kouser, S.; Qaim, M. Valuing financial, health, and environmental benefits of *Bt* cotton in Pakistan. *Agric. Econ.* **2013**, *44*, 323–335. [CrossRef]
2. Iqbal, J.; Ali, Z.; Aasi, M.S.; Ali, A.; Rasul, A.; Begum, H.A.; Nadeem, M. Evaluation of some new chemistry insecticides against cotton whitefly (*Bemisia tabaci* Genn.) (Hemiptera: Aleyrodidae). *Pak. Entomol.* **2018**, *40*, 19–23.
3. Sarwar, M.; Sattar, M. An Analysis of Comparative Efficacies of Various Insecticides on the Densities of Important Insect Pests and the Natural Enemies of Cotton, *Gossypium hirsutum* L. *Pak. J. Zool.* **2016**, *48*, 131–136.
4. Vennila, S. Pest management for cotton ecosystems or ecosystem management for cotton protection? *Curr. Sci.* **2008**, *94*, 1351–1352.
5. Reed, J.T.; Jackson, C.S. *Thrips on Mississippi Seedling Cotton: Pest Overview and 15-Year Summary of Pesticide Evaluation*; Bulletin 1124; Mississippi State University Extension Service: Washington, DC, USA, 2002. Available online: https://lccn.loc.gov/2004356107 (accessed on 27 October 2019).
6. Central Cotton Research Institute (CCRI). *Annual Report*; CCRI: Multan, Pakistan, 2005; p. 23.
7. Ali, A. Physio-Chemical Factors Affecting Resistance in Cotton against Jassid, Amrasca Devastans (Dist.) and Thrips, Thrips Tabaci (Lind.) in Punjab, Pakistan. Ph.D. Thesis, Department of Entomology, University of Agriculture, Faisalabad, Pakistan, 1992. Volume 1. pp. 1–293.
8. Masood, A.; Arif, M.J.; Hamed, M.; Talpur, M.A. Field performance of *Trichogramma chilonis* against cotton bollworms infestation in different cotton varieties as a sustainable IPM approach. *PJAAEVS* **2011**, *27*, 176–184.
9. Sahito, H.A.; Shah, Z.H.; Kousar, T.; Mangrio, W.M.; Mallah, N.A.; Jatoi, F.A.; Kubar, W.A. Comparative efficacy of novel pesticides against Jassid, *Amrasca biguttula biguttula* (Ishida) on cotton crop under field conditions at Khairpur, Sindh, Pakistan. *Singap. J. Sci. Res.* **2017**, *1*, 1–8. [CrossRef]
10. Razaq, M.; Suhail, A.; Aslam, M.; Arif, M.J.; Saleem, M.A.; Khan, M.H.A. Evaluation of neonicotinoids and conventional insecticides against cotton jassid, *Amrasca devastans* (Dist.) and cotton whitefly, *Bemisia tabaci* (Genn.) on cotton. *Pak. Entomol.* **2005**, *27*, 75–78.
11. Government of Pakistan. *Economic Survey of Pakistan, 2007–2008*; Finance Division: Islamabad, Pakistan, 2008; pp. 17–37.

12. Mahmood, I.; Imadi, S.R.; Shazadi, K.; Gul, A.; Hakeem, K.R. Effects of Pesticides on Environment. In *Plant, Soil and Microbes*; Springer: Cham, Switzerland, 2016; pp. 253–269.
13. Udikeri, S.S.; Patil, S.B.; Hirekurubar, R.B.; Guruprasad, G.S.; Shailah, H.M.; Matti, P.V. Management of sucking pests in cotton with new insecticides. *Karnataka J. Agric. Sci.* **2009**, *22*, 798–802.
14. Gaurkhede, A.S.; Bhalkare, S.K.; Sadawarte, A.K.; Undirwade, D.B. Bio efficacy of new chemistry molecules against sucking pests of *Bt* transgenic cotton. *Int. J. Plant Protec.* **2015**, *8*, 7–12. [CrossRef]
15. Zhang, Z.; Wang, Y.; Zhao, Y.; Li, B.; Lin, J.; Zhang, X.; Liu, F.; Mu, W. Nitenpyram seed treatment effectively controls against the mirid bug *Apolygus lucorum* in cotton seedlings. *Sci. Rep.* **2017**, *7*, 8573. [CrossRef] [PubMed]
16. Bonmatin, J.M.; Giorio, C.; Girolami, V.; Goulson, D.; Kreutzweiser, D.P.; Krupke, C.; Liess, M.; Long, E.; Marzaro, M.; Mitchell, E.A.D.; et al. Environmental fate and exposure; neonicotinoids and fipronil. *Environ. Sci. Pollut. Res.* **2015**, *22*, 35–67. [CrossRef] [PubMed]
17. Government of Punjab. *Agriculture Department, Crop Advisory Wing, Sir Agha Khan Road*; Government of Punjab: Lahore, Pakistan, 2017; pp. 1–27.
18. Nadeem, A.; Tahir, H.M.; Khan, A.A. Plant age, crop stage and surrounding habitats: Their impact on sucking pests and predators complex in cotton (*Gossypium hirsutum* L.) field plots in arid climate at district Layyah, Punjab, Pakistan. *Braz. J. Biol.* **2021**, *82*, e236494. [CrossRef] [PubMed]
19. Luttrell, R.G.; Teague, T.G.; Brewer, M.J. Cotton Insect Pest Management. In *Cotton*, 2nd ed.; Agronomy Monographs 57; ASA, CSSA, and SSSA: Madison, WI, USA, 2015; pp. 509–546. [CrossRef]
20. Simon-Delso, N.; Amaral-Rogers, V.; Belzunces, L.P.; Bonmatin, J.M.; Chagnon, M.; Downs, C.; Goulson, D. Systemic insecticides (neonicotinoids and fipronil): Trends, uses, mode of action and metabolites. *Environ. Sci. Pollut. Res.* **2015**, *22*, 5–34. [CrossRef] [PubMed]
21. Haider, I.; Suhail, A.; Aziz, A. Toxicity of some insecticides against cotton jassid (*Amrasca devastans* Dist.) and its predator (*Chrysoperla carnea* Stephens). *J. Agric. Res.* **2017**, *55*, 311–321.
22. Chloridis, A.; Downard, P.; Dripps, J.E.; Kaneshi, K.; Lee, L.C.; Min, Y.K.; Pavan, L.A. Spinetoram (XDE-175): A new spinosyn. In Proceedings of the XVI International Plant Protection Congress, Scotland, UK, 15–18 October 2007; pp. 44–49.
23. Dripps, J.; Olson, B.; Sparks, T.; Crouse, G. Spinetoram: How artificial intelligence combined natural fermentation with synthetic chemistry to produce a new spinosyn insecticide. *Plant Health Progress* **2008**, *22*. Available online: http://www.plantmanagementnetwork.org/pub/php/perspective/2008/spinetoram/ (accessed on 27 October 2019).
24. Waters, T.D.; Walsh, D.B. Onion Thrips Control in Washington State. 2010. Available online: https://www.unce.unr.edu/ (accessed on 17 November 2019).
25. Ghelani, M.K.; Kabaria, B.B.; Chhodavadia, S.K. Field efficacy of various insecticides against major sucking pests of *Bt* cotton. *J. Biopestic.* **2014**, *7*, 27.
26. Gogi, M.D.; Sarfraz, R.M.; Dosdall, L.M.; Arif, M.J.; Keddie, A.B.; Ashfaq, M. Effectiveness of two insect growth regulators against *Bemisia tabaci* (Gennadius) (Hemiptera: Aleyrodidae) and *Helicoverpa armigera* (Hübner) (Lepidoptera: Noctuidae) and their impact on population densities of arthropod predators in cotton in Pakistan. *Pest Manag. Sci.* **2006**, *62*, 982–990. [CrossRef] [PubMed]
27. Naranjo, S.E.; Ellsworth, P.C.; Hagler, J.R. Conservation of natural enemies in cotton: Role of insect growth regulators in management of *Bemisia tabaci*. *Biol. Control* **2004**, *30*, 52–72. [CrossRef]