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Response of *Chilo partellus* (Swinhoe) and entomophagous arthropods to some granular and new chemistry formulations in *Zea mays* L.

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Abstract
Comparative efficacy of granular (Carbofuran, cartap and monomehypo) and new chemistry foliar insecticides (Chlorantraniliprole, fipronil, spinosad and flubendiamide) was evaluated against *C. partellus*. Effect of insecticides on entomophagous arthropods (coccinellids and spiders species) was also focused in maize (cultivar: AAS-9732). Maximum mortality was observed in carbofuran and fipronil i.e. 89.3±11.13 and 80.9±7.98 adults of *C. partellus* per five plants due to carbofuran and fipronil respectively. Minimum loss was recorded in carbofuran and fipronil treatments viz. minimum number of dead hearts i.e. 0.1±0.12 and 0.20±0.00 were found in carbofuran and fipronil treated plots respectively. Systemic nature of these broad-spectrum insecticides (carbofuran and fipronil) has significantly enhanced their toxicity. However the problem with these insecticides was significantly higher mortality of natural enemies in these treatments. Concluding, relatively safer and targeted insecticides like spinosad should be included in integrated pest management program to allow natural enemies to flourish well. Additionally, research should be conducted to explore targeted safer insecticides.

Keywords: *Chilo partellus*, insecticidal efficacy, maize, natural enemies

Introduction
Maize (*Zea mays* L.), member of family Poaceae, is the highest yielding and genetically diverse cereal crop in the world [1, 2]. It has great significance especially in developing countries like Pakistan. This crop accounts for 4.8 % of the total cropped area and 3.5 % of the value towards agricultural output in Pakistan [3, 1]. Its area under cultivation is around 0.9 million hectares while the annual production is nearly 1.3 million tons in Pakistan. The lesser yield is primarily due to its susceptibility to a wide range of insect pests and diseases in different ecological zones in Pakistan. The crop is infested by more than one hundred insect species. Among insect-pests, stem borers are most serious pests of maize [4, 5]. The spotted stem borer (*Chilo partellus* Swinhoe) is considered as the most notorious pests for its damage to this crop [6].

Infestation of *C. partellus* at seedling stage may cause total failure of crop [7, 8]. Its larvae bore into the midrib and stalk, feed inside the plant stems. Feeding behavior of this pest protects it from natural parasitoids and insecticides [9]. The *C. partellus* not only causes mechanical damage (lodging of plant due to weakened stem) but also causes characteristic perforation in leaves called fenestrations [10]. This kind of damage results in reduction of photosynthetic area of the leaves resulting in poor cereal yield. Estimated losses vary greatly in different regions and agro-ecological zones. Severe damage of this pest may lead to grain reduction upto 81 % [11, 12].

Higher infestation of *C. partellus* is also due to unavailability of resistant cultivars which play an important role in management of this pest. The cultural practices viz., removal and destruction of infested plants residues can be helpful in controlling this pest [5]. Although, biological control agents like ants, spiders, earwigs etc., play a key role in insect-pest management but to a limited extent [13, 14].

Chemical control is the mostly used method for control of insect-pests due to its quicker and immediate results [15, 16]. The use of contact and systemic insecticides is considered most effective [17, 18] at initial stage of infestation to get rid of the *C. partellus* larvae before burrowing into the stems [5, 12]. Insecticides particularly granular formulations are recommended as soil and/or whorl application after 25 and 45 days of sowing [19, 20].

Furthermore, the foliar application of insecticide instead of granular formulation is recommended for effective control [21]. This pest can also be managed through whorl application of insecticides (granular and foliar) in liquid formulations [22]. However, the great problem with the use of insecticides is their lethal or sub-lethal effect on non-target organisms especially bio-control agents [23].
Therefore, present study was conducted to investigate the efficacy of some granular and foliar insecticides to *C. partellus* along-with the reduction in post-treatment crop losses. Furthermore, the effect of these insecticides on entomophagous insects was also investigated.

Materials and Methods

The maize cultivar (AAS-9732) was sown at experimental area of the University of Agriculture Faisalabad, Pakistan (Latitude: 31.432852°; Longitude: 73.069406°) during spring season of the year 2011.

Insecticides

The granular insecticides used in experiment were carbofuran (Carbofuran® 3G; Arrow İnternational Lahore, Pakistan), cartap (Reject® 3G; Pakistan Agrochemicals Karachi, Pakistan) and monomehypo (C-Moon® 5G; Capricon Associated Karachi, Pakistan). While the tested new-chemistry foliar insecticides were chlorantraniliprole (Coragen® 20 SC; Bayer Crop Sciences, Karachi, Pakistan), fipronil (Regent® 80 WG; Bayer Crop Sciences, Karachi, Pakistan), spinosad (Tracer® 240 SC; Arysta Life Sciences Karachi, Pakistan) and flubindiamide (Belt® 48 SC; Bayer Crop Sciences, Karachi, Pakistan). These 8 insecticides were randomized

Treatments

The recommended Agronomic practices were done before sowing the crop. The crop was sown during the normal season of sowing in Randomized Complete Block Design (RCBD), maintaining row to row and plant to plant distance of 1 sq. ft and 0.9 sq. ft, respectively. The plot size was 1100m (3612sq.ft). Insecticides were applied at peak of vegetative stage when there was enormous population of test insect-pests. The experiment consisted of 8 insecticidal treatments which were randomized thrice so the total experimental units were 24 and these were separated from each other by a path as shown in the layout.

Data collection

Different parameters viz., larval density, mortality of *C. partellus* and natural enemies were measured in relation to stem tunneling, dead hearts and leaf holes. To determine the larval population five plants were randomly selected and dissected longitudinally, in each replication. While factors like population of entomophagous arthropods viz., coccinellids and spiders spp. were estimated by visual observation by selecting five randomly plants per treatment. Tunneling was assessed by dissecting the randomly selected stems while number of infested stems, dead hearts and leaf holes were observed visually in five randomly selected plants per replication. The data regarding infestation, larvae/plant, tunnel length inside stem, leaf holes, dead hearts and entomophagous arthropods were recorded at 3, 7 and 14 days post treatment period respectively [24, 25].

Statistical Analysis

The data were statistically analyzed using analysis of variance (ANOVA) and level of significance among treatments was determined using SAS software. The level of significance between treatments means were analyzed by LSD (Least Significance Difference) test using MSTAT-C program [47].

Results

Impact of insecticides on population density of insects

Chilo partellus

Significant variations were observed in population density of *C. partellus* after 3, 7 and 14 days of treatment. Among the granular insecticides, carbofuran was proved to be most effective while among foliar formulations, fipronil was the most effective insecticide in controlling *C. partellus* larvae. After carbofuran treatment larval density was 0.7±0.12, 0.40±0.20 and 0.10±0.12 larvae per 5 plants after 3, 7 and 14 days of treatment respectively. While, average larval density in plots treated with fipronil was 0.90±0.20, 0.50±0.12 and 0.20±0.12 larvae/5 plants after 3, 7 and 14 days of treatment respectively (Table 1).

Coccinellids

Among granular insecticides, minimum numbers of coccinellids were observed in carbofuran while among foliar formulations maximum mortality was found in fipronil. Population density of coccinellids in the plots treated with carbofuran was 0.7±0.12, 0.3±0.11 and 0.3±0.11 coccinellids/5 plants respectively. Whereas, population density of coccinellids spp. was 0.7 ±0.12, 0.5±0.23 and 0.4 ±0.2 coccinellids/5 plants after 3, 7 and 14 days in fipronil respectively (Table1).

Spider species

Minimum population of spiders was found in carbofuran (among granular insecticides) and spinosad (among new chemistry insecticides) treated plots. Average density of spider spp., in plots treated with carbofuran was 0.1±0.12, 0.4±0.31 and 0.26±0.12 spiders/5 plants after 3, 7 and 14 days of treatment. Whereas, in case of spinosad, average larval density was 0.5±0.42, 0.2±0.20 and 0.4±0.20 spiders/5 plants after 3, 7 and 14 days of treatment (Table I).

Results

Impact of insecticides on percent mortality of insects

Chilo partellus

Maximum percentage mortality of *C. partellus* larval was recorded in carbofuran (group of granular insecticides) and fipronil (group of new chemistry insecticides). Among the granular insecticides treated plots, minimum larval density of *C. partellus* was observed i.e. 40.00±20.00, 48.01±31.7 and 38.70±36.43 per 5 plants in case of cartap after 3, 7 and 14 days respectively. Maximum larval mortality viz., 63.33±5.77, 75.20±7.71 and 89.26±11.13 per 5 plants was observed in the carbufuran treated plots after 3, 7 and 14 days of treatment respectively. Whereas, minimum larval mortality recorded was 30.00±10.00, 43.56±8.96 and 46.90±19.05 per 5 plants in chlorantraniliprole treated plots. While the maximum mortality i.e. 56.67±5.77, 66.14±15.13 and 80.92±7.98 per 5 plants was found in the case of fipronil after 3, 7 and 14 days of treatment respectively (Table 2).

Coccinellids species

Percent mortality of coccinellids varied significantly among the treatments. Among the granular insecticides treated plots, minimum percent mortality of coccinellids species was

30. 07±15.25, 30.00±12.58 and 27.80±25.46 per 5 plants in plots treated with monomehypo after 3, 7 and 14 days respectively. Whereas, maximum mortality i.e. 54.23±3.75, 60.00±17.32 and 58.33±22.05 per 5 plants was found in case of carbofuran after 3, 7 and 14 days of treatment respectively. Minimum percent mortality was found in spinosad treatment i.e. 25.13±16.77, 23.33±16.07 and 27.80±25.46 per 5 plants after 3, 7 and 14 days of treatment respectively. Maximum percent mortality was recorded in fipronil i.e. 47.61±17.17 per 5 plants after 3 days of treatment, while highest mortality after 7 and 14 days of mortality was observed in flubendiamide viz., 53.33±5.77 and 47.22±24.06 per 5 plants respectively (Table 2).

Spider species

Among the granular insecticide treated plots, minimum observed percent mortality of spiders was 33.33±30.55 and 25.00±25.00 per 5 plants in monomehypo treated plot after 3 and 7 days respectively. Maximum percent mortality i.e. 71.66±10.40 and 55.60±9.60 after 3 and 7 days of treatment respectively was recorded in carbofuran treated plots. While, after 14 days there was no significant difference among the plots treated with granular insecticides.

Among the plots treated with new chemistry foliar formulations, minimum average percent mortality viz., 35.00±21.79, 52.77±21.00 was recorded in flubindiamide after 3 and 7 days of treatment. While minimum mortality 27.77±16.70 per 5 plants was recorded in spinosad treated plot after 14 days of treatment. Maximum percent mortality i.e. 63.30±15.28, 63.90±12.70 per 5 plants recorded in chlorantraniliprole after 3 and 7 days of treatment. While maximum mortality i.e. 61.10±25.50 per 5 plants was recorded in flubindiamide treated plot after 14 days of treatment respectively (Table 2).

Impact of insecticides on reduced losses

Reduction in stem tunneling

The results showed a non-significant variation among the treatments, on stem tunneling by *C. partellus*. Among the granular insecticides treated plots, minimum average stem tunneling done by *C. partellus* was 2.7±0.56 cm in carbufuran treated plots after 3 days of treatment. While after 7 and 14 days of treatment 1.90±0.35 and 1.70±0.55 cm tunnel was recorded in monomehypo treated plots. Whereas, maximum stem tunneling among granular insecticide treated plot was recorded in cartap treated plot i.e. 4.30±1.26 cm after 3 days, while after 7 days 3.70±1.12 cm tunnel was found in carbofuran and after 14 days of treatment 2.40±0.51 cm tunnel was recorded in cartap treated plots. Among the plots treated with new chemistry foliar formulation minimum stem tunneling was 2.70±1.01 cm in fipronil after 3 days, while 1.70±0.70 cm and 0.90±0.81 cm stem tunneling was recorded in chlorantraniliprole after 7 and 14 days of treatment. Whereas maximum stem tunneling 3.10±1.12 and 2.50±0.64 cm in spinosad after 3 and 7 days of treatment, while 2.10±0.82 cm stem tunneling was observed in fipronil treated plot after 14 days of treatment (Table 3).

Reduction in dead hearts

Among the granular insecticides treated plots minimum number of dead heart caused by *C. partellus* were 0.30±0.12, 0.20±0.00 and 0.10±0.12 dead hearts/5 plants after 3, 7 and 14 days of treatment respectively in carbufuran. Maximum dead hearts 0.50±0.00, 0.40±0.12 and 0.30±0.12 dead heart/5 plants were found in monomehypo after 3, 7 and 14 days of treatment respectively. Whereas in plots treated with foliar formulations minimum dead heart 0.20±0.00/5 plants were observed in spinosad after 3 days, while 0.20±0.00 dead hearts/5 plants were observed in flubendiamide treated plots after 7 days post treatment period. After 14 days, 0.20±0.00 dead hearts/5 plants were found in fipronil treated plots. Maximum dead hearts 0.40±0.12 dead heart/5 plants were found in chlorantraniliprole treated plots after 3 and 7 days of treatment. While 0.40±0.12 dead hearts/5 plants were observed in flubindiamide after 14 days of treatment (Table 3).

Reduction in leaf holes

Among the granular tested insecticide plots minimum leaf holes i.e. 0.33±0.12 leaf holes/5 plants in plots treated with cartap after 3 days of treatment, while 0.33±0.12 leaf holes/5 plants were observed in case of monomehypo after 7 days of treatment. After 14 days of treatment 0.20±0.00 leaf holes/5 plants were found in carbofuran treatment. Maximum 0.50±0.12 leaf holes/5 plants in monomehypo and cartap treated plots after 3 and 7 days of treatment, while 0.40±0.12 leaf holes/5 plants were found in monomehypo treated plots after 14 days of treatments. Among foliar formulation minimum number of leaf holes 0.26±0.12, 0.30±0.10 and 0.10±0.12 leaf holes/5 plants were found in spinosad treated plots after 3, 7 and 14 days of treatment respectively. Maximum number of leaf holes 0.30±0.10 and 0.40±0.23 were found in chlorantraniliprole after 3 and 7 days of treatment. While 0.30±0.12 leaf holes/5 plants were found in flubindiamide treated plots after 14 days of treatments (Table 3).

Table 1: Impact of insecticides on larval density of *Chilo partellus*, Coccinellids and spider species during 2011**.**

Treatments		Larval Density of *C. partellus*			Coccinellids spp. density			Spiders spp.		
		After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After 14 days
Granular Insecticides	Carbofuran	0.7±0.12e	0.4±0.2c	0.1±0.12b	0.7±0.12d	0.3±0.11c	0.3±0.11b	0.1±0.12b	0.4±0.31bc	0.26±0.12ab
	Cartap	1.2±0.4bcd	0.8±0.35bc	0.6±0.2b	0.8 ±0.2bcd	0.4±0.2bc	0.3 ±0.11b	0.3±0.12ab	0.5±0.12ab	0.3±0.12ab
	Monomehypo	1.1±0.12bcd	0.8±0.2bc	0.3±0.12b	1.0 ±0.2bc	0.5±0.11bc	0.5±0.11ab	0.6±0.20a	0.4±0.20bc	0.26±0.12ab
Foliar Insecticides	Chlorantraniliprole	1.4±0.2b	0.9±0.12b	0.6±0.2b	1.1±0.12b	0.6 ±0.2b	0.5±0.11ab	0.3±0.12ab	0.3±0.12bc	0.26±0.12ab
	Fipronil	0.9±0.2de	0.5±0.12bc	0.2±0.12b	0.7 ±0.12cd	0.5±0.23bc	0.4 ±0.2b	0.6±0.00a	0.3±0.12bc	0.26±0.23ab
	Spinosad	1.3±0.23bc	0.9±0.12b	0.5±0.23b	1.1±0.12b	0.6 ±0.2b	0.5±0.11ab	0.5±0.42ab	0.2±0.20c	0.4±0.20ab
	Flubindiamide	0.9±0.23cde	0.6±0.2bc	0.3±0.12b	0.9±0.12bcd	0.4 ±0.2bc	0.3 ±0.11b	0.6±0.20a	0.4±0.12bc	0.2±0.20b
Control		2.0±0a	1.7±0.44a	1.2±0.67a	1.5±0.31a	0.9±0.11a	0.7±0.11a	0.7±0.42a	0.7±0.12a	0.5±0.12a

Table 2: Impact of insecticides on percent mortality of *Chilo partellus*, Coccinellids and spider species

Treatments	Larval mortality of *C. partellus*			Mortality of Coccinellids spp.			Mortality of Spiders spp.		
	After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After14 days
Carbofuran	63.3±5.77a	75.2±7.41a	89.3±11.13a	54.2±3.75a	60.0±17.32a	58.3±22.05a	71.7±10.4a	55.6±9.6ab	50.0±16.7 a
Cartap	40.0±20.0bcd	48.0±31.7bc	38.7±36.43d	44.7±14.25ab	53.3±25.66ab	50.0±16.67a	65.0±8.66ab	25.0±25.0bc	38.9±9.7a
Monomehypo	43.3±5.77bcd	48.4±27.77bc	69.3±16.72abc	30.7±15.25bc	30.0±12.58bc	27.8±25.46ab	33.3±30.55b	41.7±38.0ab	50.0±16.7a
Chlorantraniliprole	30.0±10.0d	43.6±8.96c	46.9±19.05cd	26.1±8.58c	31.7±16.07bc	30.6±4.81ab	63.3±15.28ab	63.9±12.7a	50.0±16.7a
Fipronil	56.7±5.77ab	66.1±15.13ab	80.9±7.98a	47.6±17.17a	46.7±25.66abc	38.9±34.69a	58.3±17.56ab	63.9±12.7a	50.0±16.7a
Spinosid	36.7±11.55cd	46.9±13.34bc	49.4±35.37bcd	25.1±16.77c	23.3±16.07cd	27.8±25.46ab	51.7±20.21ab	63.9±12.7a	27.8±16.7ab
Flubindiamide	53.3±11.55abc	62.6±15.55abc	77.6±2.51ab	40.2±6.01abc	53.3±5.77ab	47.2±24.06a	35.0±21.79b	52.8±21.0ab	61.1±25.5a
Control	0.00 e	0.0±0.0d	0.0±0.0 e	0.0d	0.00±0d	0.0±0sb	00.0±c	0.0±0c	00.0±34.7b
Standard error for comparison	8.93	9.5	14.038	7.5471	12.404	15.35	15.401	15.92	16.00

Table 3: Impact of insecticides on stem tunneling dead heart and leaf holes produced by *C. partellus*

Treatments	Stem tunneling			Dead heart			Leaf holes		
	After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After 14 days	After 3 days	After 7 days	After 14 days
Carbofuran	2.7±0.56b	2.8±0.08bc	2.1±0.14bc	0.3±0.12bc	0.2±0.00b	0.1±0.12b	0.4±0.00ab	0.5±0.12ab	0.2±0.00b
Cartap	4.3±1.26ab	3.7±1.12ab	2.4±0.51ab	0.5±0.00ab	0.3±0.12b	0.2±0.20b	0.33±0.12ab	0.33±0.23b	0.3±0.12ab
Monomehypo	3.8±0.30ab	1.9±0.35c	1.7±0.55bcd	0.5±0.00ab	0.4±0.12b	0.3±0.12ab	0.5±0.12a	0.33±0.12b	0.4±0.12ab
Chlorantraniliprole	2.8±0.94b	1.7±0.70c	0.9±0.81d	0.4±0.12abc	0.4±0.12b	0.3±0.12ab	0.3±0.10ab	0.4±0.12b	0.1±0.12b
Fipronil	2.7±1.01b	2.1±0.65c	2.1±0.82bc	0.3±0.12abc	0.4±0.12b	0.2±0.00b	0.27±0.12b	0.33±0.12b	0.2±0.00b
Spinosid	3.1±1.12b	2.5±0.64bc	1.5±0.61bcd	0.2±0.00c	0.3±0.12b	0.3±0.12ab	0.26±0.12b	0.3±0.10b	0.1±0.12b
Flubindiamide	2.8±1.49b	2.3±0.60c	1.3±0.72cd	0.3±0.12bc	0.2±0.00b	0.4±0.12ab	0.3±0.10ab	0.4±0.23b	0.3±0.12ab
Control	5.5±1.3a	4.8±0.85a	3.3±0.96a	0.6±0.12a	0.5±0.12a	0.5±0.12a	0.6±0.12a	0.6±0.00a	0.5±0.15a

Discussion

Over-reliance on chemicals has created resistance in insect-pests, leading towards collapse of pest management programs [47, 48]. Additionally, various problems are also linked with excessive and uncontrolled usage of insecticides such as non-target effects, human health concern, adverse effects on environmental surroundings and many others. Eco-friendly compatible control methods and approaches must be adopted in order to manage the insect-pests such as integrated pest management. Concluding, chemical control is the main tool of controlling *C. partellus* but this tool can be synchronized with biological control for better management [48, 49].

Carbofuran, a widely used carbamate insecticide, has recently been banned in many countries [26, 27]. It has systemic anticholinergic actions in cortex and striatum regions of central nervous system by forming carbofuran acetylcholinesterase complex [28]. Along with various systemic effects many other abnormalities are also caused by this insecticide viz., sterility [29, 30, 31] congenital abnormalities [28, 32] hepatotoxicity, enhanced risk of dysfunctions on gastrointestinal [33, 34] neurological [35, 46], and endocrine systems [33]. Carbofuran was the most effective treatment which not only eliminated leaf injury but also significantly reduced the pest population [24, 25]. Lethal and sub-lethal effects of carbofuran on coccinellids are well known [36, 37]. Carbofuran also significantly affect the predatory spiders' population [38].

Fipronil (a phenylpyrazole compound) was developed in the mid-1990s and became an effective insecticide especially due to its high toxicity against insects resistant to conventional insecticides and its lower toxicity to mammalians [39]. Fipronil potently blocks the insect GABA-gated chloride channels at nanomolar concentrations [40]. It is clear from previous findings that fipronil significantly affects the population of borers due to susceptibility of insects to new chemistry insecticides like fipronil. Additionally, it also reduces damage of insect-pests [41, 42]. Fipronil also significantly affects non-target organisms like spiders, coccinellids etc. [43].

Chlorantraniliprole, a new chemistry insecticide (anthranilic diamide in nature), is effective to a number of insect-pests [44]. It is an activator of insect ryanodine receptors, causing rapid muscle dysfunction and paralysis [43, 45]. It is extensively being used for the effective management of lepidopteran pests and as a result preventing damages caused in different crops [44].

Conclusion

However, carbofuran and fipronil killed the maximum population of *C. partellus*, but they are also detrimental to the population of natural enemies. So, insecticides like spinosad should be included in integrated pest management programs owing to satisfactory pest control with minimum damage to predators' population. Additionally, research should be done to explore the potentially safer and targeted insecticides not only in maize crop but also for other crops. Insecticide rotation should be also included in pest management programs to manage resistance in insect-pests.

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