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Research Article

Enhancing pest management - Utilizing supplementary food spray to harness predatory insects against fall armyworm in maize crop of Vinh Phuc Province, Vietnam

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ABSTRACT: The effect of supplementary food spray on the fall armyworm (*Spodoptera frugiperda*) and beneficial insects (predominantly predatory insects) was studied in commercial maize field experiments from 2020 to 2022. The food spray formulation was developed from local ingredients in Vietnam, both with and without neem extract. The sugar-based rice dough product attracted and sustained beneficial insects, significantly reducing fall armyworm populations. Compared to conventional insecticide treatments, the net margin achieved in plots treated with food spray was higher ($3,467) to $3,394 in the conventional insecticide-treated plots demonstrating its economic viability (1 AUD=17.28 VND). Our study observed an average predator-to-prey ratio of 9.2:1 per plant in the food-spray-treated plots, and that was effective in managing the fall armyworm throughout the season. We propose that this ratio can serve as a valuable parameter and decision-making tool in food spray-based Integrated Pest Management (IPM) programs against fall armyworm in maize fields. Therefore, we suggest that food sprays can be incorporated into IPM strategies to successfully manage fall armyworm infestation in maize crop.

KEYWORDS: Azadirachtin, beneficial arthropods, predator-to-prey ratio, *Spodoptera frugiperda,* supplementary food spray

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INTRODUCTION

A myriad of pests occur on crops, spanning from cereals such as maize, sorghum, and millet to cotton and pulse crops. Many farmers rely on synthetic insecticides to control these pests, but despite their effectiveness, reliance on synthetic insecticides for pest control introduces its own set of challenges (Amera & Abate, 2008). Surveys by the Pesticide Action Network of the UK (PAN UK) in cotton-growing regions of Africa and central Asia since 2009 have revealed poisoning rates surpassing 30% (PAN-UK, 2009). The perilous toxicity of these chemicals, coupled with inadequate adherence to safety protocols among smallholder farmers and families in developing nations, poses grave environmental and health hazards. The United Nations Environment Program (UNEP) estimated that the toll of pesticide poisoning in sub-Saharan Africa alone reached a staggering US$6.3 billion, surpassing the entire aid budget allocated for basic healthcare in the region (UNEP, 2013). Furthermore, UNEP (2013) projects this economic burden to soar beyond US$90 billion between 2015 and 2020.

Hence, the imperative to diminish our reliance on pesticides for managing pests, diseases, and weeds cannot be overstated, given the multifaceted implications for health, the environment, and the economy. IPM stands out as a pivotal approach, leveraging beneficial insects as its cornerstone to curtail pest populations, reserving pesticide application as a measure of last resort. Demonstrated through various studies (Mensah, 2002a, b; Mensah *et al.*, 2012; Amera *et al.*, 2017), IPM emerges as an effective and economical strategy for pest control.

Spodoptera frugiperda (fall armyworm) causes serious damage to maize crops, resulting in billions of dollars in losses across Vietnam and other Asian nations (VDPP, 2019). The Vietnam Department of Plant Protection reports that approximately 15,000 hectares out of every 415,000 hectares of maize nationwide suffer from infestation (VDPP, 2019). Particularly affected are the southern coastal regions and central highlands of Vietnam, where over 7,000 hectares of maize have fallen prey to this voracious pest. Compounding the issue for maize farmers in Vietnam is the variance in maize-farming seasons among localities, complicating efforts to combat diseases and pests effectively. Furthermore, during the last three larval instars, when the fall armyworm burrows into the maize ear, its feeding behaviour shields it from synthetic insecticides, potentially diminishing the efficacy of chemical control methods during the later stages of crop growth.

A range of natural enemies, prey upon fall armyworm, including insect parasitoids (Molina-Ochoa J. & Carpenter, 2003; Sisay *et al.*, 2018), a diverse array of predators (Harrison *et al.*, 2019; Wyckhuys *et al.*, 2006; Koffi *et al.*, 2020) and entomopathogens such as fungi, bacteria, viruses and nematodes (Shylesha *et al.*, 2018; Molina-Ochoa J., 2003; Tendeng *et al.*, 2019). Wheeler *et al.* (1989) observed natural enemy complexes causing up to 42 per cent mortality among fall armyworm populations in maize crops in Honduras, underscoring their significance as mortality factors for the pest in its native habitat. However, there remains scant information on the natural enemies of the fall armyworm in Africa and Asia (Firake *et al.,* 2020). For instance, while Vietnamese farmers possess some knowledge of the arthropod natural enemies present in their fields, they often struggle to identify these insects and discern their roles. Consequently, the potential value of these beneficial insects remains largely untapped in maize pest management, owing to a lack of techniques to optimize both their abundance and effectiveness.

Generalist beneficial insects, such as predatory species, offer effective pest control in agricultural settings like maize or cotton crops when employing non-chemical insecticide regimes (Clark *et al.*, 1994), as their population dynamics are not solely reliant on target pests (Wratten, 1987). To ensure the long-term sustainability of maize production in Vietnam, it is imperative to develop an integrated pest management program that prioritizes the role of natural enemies, particularly in combating major pests like the fall armyworm, while minimizing insecticide usage. One promising approach in pest control is the utilization of supplementary food sprays, which harness and conserve the natural enemies of pests to mitigate their populations (Razaq *et al.*, 2019; Mensah *et al.*, 2013, 2014; Moore & Mensah, 2011; Mensah *et al.*, 2012; Amera *et al.*, 2017). By applying supplementary food, volatile compounds emitted from the food components attract natural enemies to the treated area, intensifying their search activity upon contact with the sprayed leaves. This increased predation on pests, including the consumption of pest eggs, leads to a reduction in the oviposition activity of female pest moths, who avoid laying eggs on the treated plant surfaces (Mensah *et al.*, 2000; Mensah *et al.*, 2012; Amera *et al.*, 2017). Such a strategy presents a commercially viable alternative to the reliance on synthetic insecticides, offering a sustainable solution to pest management (Mensah *et al.*, 2012; Amera *et al.*, 2017).

Before the commencement of this study in 2020, no research had explored the impact of supplementary food spray products on populations of the fall armyworm and its natural enemies in maize crops within Vietnam. Thus, our study, aimed to investigate whether the application of various food spray formulations onto maize crops could attract, sustain, and bolster the populations of natural enemies, particularly predatory insects, targeting the fall armyworm. Additionally, we sought to assess the feasibility of integrating these natural enemies into an IPM strategy for the effective management of this and other pests affecting maize crops.

Throughout the study, we developed a novel food spray formulation termed the "Vietnam Food Product" (VFP), utilizing locally available ingredients in Vietnam. While not commercially available, VFP was designed as a cost-effective and smallholder-friendly solution to combat an invasive pest. The development process for VFP mirrored that of previously established products such as the Envirofeast™ in Australia (Mensah & Harris, 1995; Mensah, 1996, 1997; Mensah *et al.*, 2002 a, b), the Benin Food Product (BFP); Mensah *et al.*, 2012), and the Ethiopia Food Product (EFP; Amera *et al.*, 2017).

Furthermore, we conducted an analysis of the cost-effectiveness of VFP within pest management programs tailored for smallholder maize crops in Vietnam, assessing its impact on yield and profitability.

MATERIALS AND METHODS

Descriptions of the food spray treatments

Unless otherwise stated, we developed and tested five different ingredients of food spray products based on sugar-based rice dough, brewers' yeast, and neem extract. The yeast was a liquid waste yeast from breweries after they had fermented the cereal grain ingredients for beer brewing and was obtained from a commercial brewing company (An Thinh Trade and Production Company Ltd, Tu Son Town, Vietnam). The rice dough consists mainly of coarsely ground rice seeds dissolved in water mixed with 2% w/v of sugar and filtered from a fine mesh. Research and field experience have shown that adding sugar into the food spray ingredients helps to arrest predatory insects (Mensah, 1997). The extract of powdered neem seeds (*Azadirachta indica*) was mixed with each mixture of sugar-based rice dough and brewers' yeast to create various treatments. Plots treated using a conventional insecticide (treated control) and unsprayed plots (untreated control) were used as the benchmarks against which we assessed the effects of the food spray ingredients on the populations of pests and their natural enemies on maize crops after the various treatments (Mensah *et al.*, 2012).

Three separate experiments were conducted over three seasons (seasons 1–3) on maize fields of small-holder farmers at the Trung Kien commune, Yen Lac district, in Vinh Phuc

Province (21°18′97″N, 105°61′06″E) of Vietnam. An organic fertilizer, such as dry cow, chicken, or horse manure, was applied to the fields containing the treated and untreated plots before the maize seeds were planted.

Experiment 1: Efficacy of formulations of food spray ingredients on fall armyworm and its natural enemies on conventional maize crop

The experiment was conducted on rain-grown maize crops of small-holder farmers in Vinh Phuc Province, Vietnam, over two seasons (seasons 1 and 2). The season 1 study commenced on 2020 September 15 and ended on 2021 January 22. The season 2 study commenced on 2021 January 24 and ended on 2021 May 31. The season 2 experiment was undertaken to confirm the results of the season 1 study. In both studies, the maize variety used was CP.111 (C.P. Việt Nam Livestock Co. Ltd, Bien Hoa City, Dong Nai Province, Vietnam). We evaluated the following 7 treatments:

(1) 2% (v/v) brewers' yeast alone

(2) 2% (v/v) brewers' yeast + 2% v/v neem (azadirachtin 0.3 EC) extract

(3) 2% (w/v) sugar-based rice dough alone

(4) 2% (w/v) sugar-based rice dough + 2% (v/v) neem (azadirachtin 0.3 EC) extract

(5) 2% (v/v) neem extract (azadirachtin 0.3 EC) alone

(6) Unsprayed (untreated control)

(7) Plots managed with conventional insecticide (farmers' practice)

The experimental plots were arranged in a randomized complete block design with three replications. Each replicate was 30 m long and 20 m wide. A 5 m-wide buffer zone of five rows of maize plants was used to separate the treatment replicates at the study sites. The untreated (unsprayed) control and conventional-insecticide-managed plots were not located at distances from the food spray plots, but there was a 5m buffer (Amera *et al.*, 2017) to prevent the volatiles from the plots treated with food spray from drifting onto the unsprayed and conventional insecticide plots. Knapsack spray was used with a cone shield around the nozzles to prevent insecticide drift onto the food spray and unsprayed plots. The unsprayed and conventionally treated fields were managed agronomically in the same way as the food-spray-treated plots, except that the conventional-insecticide-treated fields received synthetic insecticide for pest control, whereas the unsprayed plots received no synthetic insecticide or food spray treatment.

In the season 1 experiment, the foliar application of each food spray treatment was performed on 15 October, 14 November, 28 November, and December 11 2020 using knapsack spray equipment (Figures 1 and 2). In season 2, the treatments were applied on 2021 January 24, February 24, April 5, and April 16 using a knapsack. The synthetic insecticides were applied to the conventional-insecticide-treated plots on the same dates as the food spray treatments using a clean knapsack that had not been used for the application of food sprays. The conventional insecticides used were abamectin 18 g//L EC (600 L/ha), cypermethrin 200 g/L EC (600 L/ha), chlorantraniliprole 350 g/kg WDG (400 L/ha), and deltamethrin 27.5 g/L EC (600 L/ha).

In total, each treatment was applied four times based on the pest and predatory insect infestations. The decision to apply these treatments was made according to the calendar-based system used by local farmers, which is based on vegetative, reproductive stages of the crop and also fall armyworm adult moths, changes in densities of larvae and damage on specific dates. The fall armyworm and predatory insect populations were sampled visually on 20 randomly selected whole plants in each treatment replicate by examining the stems, leaves, ears, and tassels 24 h before the application of the treatments. After the application of the treatments, the armyworm and predatory insects were counted visually at 3, 5, 7, 14, 21, and 28 days after treatment. On average, a total of 60 plants were randomly selected and examined per treatment.

Overall, there was a significantly very low number of other pests on the maize crops throughout the experiment but fall armyworm and their natural enemies were abundant. The data for the fall armyworm and their natural enemy species were expressed as numbers per plant on each sampling date and were compared across treatments.

All agronomic practices were the same across the study sites. When the maize crops had matured, the treated plots and the unsprayed and conventionally managed plots were harvested separately by hand and the average seed yields (kg/ha) were calculated and compared. The cost-effectiveness (net margin) of each food-sprayed plot relative to the unsprayed and conventional-insecticide-treated controls was calculated for all treatments based on the maize seed yields per hectare and the total cost of pest control.

Experiment 2: Efficacy of sugar-based rice dough solution plus neem (azadirachtin 0.3 EC) on fall armyworm and their natural enemies on conventional maize crops

From the results of experiment 1, the most effective food spray formulation was sugar-based rice dough solution + neem, so it was selected for further field experiments to confirm the efficacy of this treatment against the target pest (fall armyworm) and its natural enemies.

The experiment was conducted on a commercial maize field of a small-holder farmer in Vinh Phuc Province. An organic fertilizer, such as dry cow, chicken, or horse manure, was applied to the fields containing the treated and untreated plots before the maize seed (PAC789 [Hybrid variety], C.P. Việt Nam Livestock Co, Ltd.) was planted on 18 January 2022. Each field was 3 ha. The conventional-insecticide-treated plots and unsprayed plots (untreated control) were used as benchmarks against which to assess the effects of the food spray product on the fall armyworm and its natural enemies on a maize crop.

Experiment 2 used the same layout design and standardized agronomic practices as experiment 1, with the difference being just the 3 treatments compared with the conventional insecticide (farmer practice treatments) but more focused on assessing pest densities and predator groups. We assessed the densities of the fall armyworm and predatory beetles, bugs, and spiders, which were the dominant species detected in experiment 1. The treatments were (1) 2% [w/v] sugar + rice dough + 2% [v/v] neem extract [azadirachtin 0.3 EC]), (2) no treatment (untreated control) and (3) conventional insecticide. The conventional insecticides used were abamectin 18 g/L EC (600 L/ha), cypermethrin 200 g/L EC (600 L/ha), chlorantraniliprole 350g/kg WDG (400 L/ha), and deltamethrin 27.5 g/L EC (600 L/ha).

Foliar applications of the food spray and the conventional insecticide treatments were made four times on 2022 Feb 10, Mar 9, Mar 26, and Apr 16 using knapsack spray equipment. The synthetic insecticide spray was applied using a knapsack that had not been used for the application of the food spray.

Pre-treatment counts were taken visually in each treated plot 24 h before the application of food spray and the conventional insecticide treatments on 2022 Feb 9, Mar 8, Mar 16, Mar 25, Apr 15, May 6, May 18, and May 31 2022 before the crops were harvested. The fall armyworm and its predatory insects (mostly coccinellid species and spiders) were counted in all treatments.

Data for FAW larvae and their natural enemy species were expressed as numbers per plant for each sampling date and were compared across treatments. In the season 3 trials, the predator-to-prey ratio based on the ratio of the number of fall armyworm and predatory insects per plant after each treatment was calculated for each sampling date.

When the maize crops were mature, the treated plots and the unsprayed and conventionally managed plots (untreated and treated controls) were harvested separately by hand and the average seed yields (kg/ha) were calculated and compared as in experiment 1. The cost-effectiveness (net margin) of each food-sprayed plot relative to the untreated and conventional-insecticide-treated controls was calculated for all treatments.

Data analysis

Data was tested for Gaussian or normal distribution using the Kolmogorov-Smirnov test and used to compute a P-value. All experimental data were analyzed using repeated-measures Analysis Of Variance (ANOVA) using Instat version 3 (GraphPad Software Inc., La Jolla, CA, USA). The treatments and sample dates were independent variables. The Tukey–Kramer multiple comparisons test (if $q>4.267$, then $p<0.05$) was used to separate the means.

RESULTS

Experiment 1: Efficacy of formulations of food spray ingredients on Fall Armyworm (FAW) and natural enemies in conventional maize crop

Table 1. Effect of different food sprays with or without neem extract on the number of *Spodoptera frugiperda* (fall armyworm) per plant by treatment in plots of commercial maize grown on smallholder farms at Vinch Phuc, 2020 Sep 15 – 2021 Jan 22 (Season 1) and 2021 Jan 24 to 2021 May 31 (Season 2)

Treatments	No. of fall armyworm per plant (Season 1)	No. of fall armyworm per plant (Season 2)
Yeast extract alone	0.33 ± 0.10 a	1.48 ± 0.32 ab
Yeast extract + Neem	0.19 ± 0.14 a	0.86 ± 0.24 a
Sugar-based rice dough alone	0.32 ± 0.10 a	1.00 ± 0.32 a
Sugar-based rice dough + Neem	0.05 ± 0.05 a	0.67 ± 0.23 a
Neem extract alone	1.74 ± 0.50 b	1.76 ± 0.64 b
Unsprayed	3.05 ± 0.41 b	3.76 ± 1.08 b
Conventional insecticide	2.57 ± 0.35 b	2.81 ± 0.86 b
p (ANOVA)	p<0.0001	p<0.0001

Means within a column followed by the same letter are not significantly different (ANOVA with significant treatment effect, followed by Tukey-Kramer multiple comparison test: p>0.05).

Table 2. Effect of different food sprays with or without neem extract on the number of predatory insects per plant by treatment in plots of commercial maize grown on smallholder farms at Vinch Phuc, 2020 15 Sep to 2021 Jan 22 (season 1)

Treatments	**Predators per plant**			
	Coccinellidae (Other Coccinellids)	***Coccinella trans-versalis* (transverse lady beetles)**	**Araneidae (Wolf and other Spiders)**	***Araneus inustus* (Orb spiders)**
Yeast extract alone	8.24 ± 1.88 ab	5.29 ± 1.47 ab	7.81 ± 1.10 a	5.43 ± 1.03 a
Yeast extract + Neem extract	7.33 ± 1.55 ac	4.33 ± 1.25 ac	7.48 ± 1.03 a	5.85 ± 0.98 a
Sugar-based Rice dough alone	7.91 ± 1.63 a	4.67 ± 1.14 ac	8.05 ± 1.33 ab	5.43 ± 0.94 a
Sugar-based rice dough + Neem extract	9.24 ± 1.88 b	6.28 ± 1.8 b	9.05 ± 1.23 b	6.67 ± 1.04 b
Neem extract alone	6.47 ± 1.84 c	4.76 ± 1.53 ac	7.91 ± 1.21 a	5.71 ± 0.98 a
Unsprayed plot	6.52 ± 1.31 c	3.57 ± 1.03 c	6.43 ± 0.84 c	4.43 ± 0.81 c
Conventional insecticide	6.91 ± 1.44 c	3.57 ± 0.89 c	5.62 ± 0.83 c	4.28 ± 0.91 c
p (ANOVA)	p<0.0001	p<0.0001	p<0.0001	p<0.0001

Means within a column followed by the same letter are not significantly different (ANOVA with significant treatment effect, followed by Tukey-Kramer multiple comparison test: p>0.05).

The dominant pest identified in the treated and control plots in season 1 was the fall armyworm (Table 1). Other pests such as maize aphids (*Rhopalosiphum maidis*) were not recorded because the populations were extremely low and very patchy. Plots treated with different food spray products had significantly fewer (p<0.0001) fall armyworm per plant than unsprayed (control), neem-only-treated, or conventional-insecticide-treated plots (Table 1). However, no significant difference was detected in the number of fall armyworm per plant (p>0.05) among the different food-spray-treated plots (Table 1).

The results of the season 2 experiments were like those in season 1, with the number of fall armyworm per plant being significantly lower (p<0.001) on the food-spray-treated plots than on the neem-extract-treated, conventional-insecticide-treated, or untreated plots. However, the plots treated with brewers' yeast alone were an exception, in that the number of fall armyworm per plant on them did not differ significantly from the untreated plots (p>0.05; Table 1). Overall, the plots treated with sugar-based rice dough + neem had the lowest numbers of fall armyworm of all the treatments (Table 1).

The natural enemies of the fall armyworm that predominated at the study sites in seasons 1 and 2 were predatory insects, mainly coccinellid species and spiders (Tables 2 and 3).

In the season 1 study, the number of predatory beetles (coccinellid species) per plant per sampling date was significantly higher on the plots treated with sugar-based rice dough + neem than on the plots treated with other food sprays (p<0.001; Table 2). In general, all plots treated with food spray products had significantly more predatory beetles per plant per sample date than those treated with neem extract alone, conventional insecticide (farmers' practice), or no treatment (p<0.0001; Table 2). In particular, the number of *Coccinella transversalis* per plant per sampling date was significantly higher on plots treated with sugar-based rice dough + neem than on those treated with the other food sprays, conventional insecticide, neem extract, or no treatment (p<0.0001; Table 2).

The predominant spiders identified at the study sites in season 1 were *Araneus inustus* (orb spider), wolf spiders, and other spiders (Araneidae) (Table 2). The number of spiders per plant per sample date was higher on the plots treated with sugar-based rice dough + neem extract than on those treated with the other food sprays (p<0.0001) but was not significantly different (p>0.05) from the plots treated with rice dough alone (Table 2). Overall, plots treated with food spray products had significantly more spiders (Araneidae) per plant per sampling date than those treated with conventional insecticide or not treated (untreated control) (p<0.0001; Table 2). In particular, the number of *A. inustus* per plant per sampling date was significantly higher on plots treated with sugar-based rice dough + neem than on the other food-sprayed plots (p<0.001; Table 2). Overall, the plots treated with food spray + neem extract had significantly higher *A. inustus* populations than the plots treated with conventional insecticide or not treated (p<0.0001; Table 2).

As in the season 1 experiment, coccinellid species and spiders were the predominant predators at the season 2 study site (Table 3). The number of other coccinellid species per plant per sampling date was higher in the sugar-based rice dough + neem treated plots than in the other food spray plots, except the brewers' yeast alone treated plots (Table 3).

Table 3. Effect of different food sprays with or without neem extract on the number of predatory insects per plant by treatment in plots of commercial maize grown on smallholder farms at Vinch Phuc, 2021 January 24 to 2021 May 31 (season 2)

Treatments	Predators per plant			
	Coccinellidae (Other Coccinellids)	*Coccinella transversalis* (transverse lady beetles)	Araneidae (Wolf and other Spiders)	*Araneus inustus* (Orb spiders)
Yeast extract alone	8.81 ± 1.82 a	5.86 ± 1.44 ab	7.81 ± 1.42 a	5.38 ± 1.21 a
Yeast extract + Neem extract	8.19 ± 1.52 ac	5.65 ± 1.25 ab	7.67 ± 1.28 a	5.19 ± 1.37 a
Sugar-based rice dough alone	8.81 ± 1.59 ab	5.78 ± 1.19 ab	8.29 ± 1.57 ab	5.38 ± 1.10 a
Sugar-based rice dough + Neem extract	9.90 ± 1.78 b	6.76 ± 1.56 b	9.14 ± 1.59 b	6.48 ± 1.28 a
Neem extract alone	8.34 ± 1.68 ac	4.10 ± 1.55 ac	7.67 ± 1.48 a	5.57 ± 1.10 a
Unsprayed plot	7.29 ± 1.30 c	4.29 ± 0.98 c	6.62 ± 1.11 c	4.43 ± 1.00 b
Conventional insecticide	7.05 ± 1.32 c	4.19 ± 1.05 c	5.95 ± 1.10 c	4.33 ± 1.07 b
p (ANOVA)	p<0.0001	p<0.0001	p<0.0001	p<0.0001

Means within a column followed by the same letter are not significantly different (ANOVA with significant treatment effect, followed by Tukey-Kramer multiple comparison test: p>0.05).

However, the number of other coccinellid species per plant was not significantly different in the brewers' yeast alone, yeast + neem, and sugar-based rice dough alone treated plots (p>0.05). Generally, the food spray-treated plots had significantly higher coccinellid species per plant than those on the conventional-insecticide-treated and untreated (control) plots (p<0.0001; Table 3). Similar results were obtained for the numbers of *C. transversalis* per plant per sampling date, except for the plots treated with neem extract only, which did not differ significantly from the conventionally treated and untreated plots (p>0.05; Table 3). The number of wolf and other spiders (Araneidae) per plant per sampling date at study site 2 was higher on the plots treated with sugar-based rice dough + neem than on the other food-spray-treated plots (p<0.0001; Table 3). In contrast, the numbers of *A. inustus* per plant per sampling date did not differ significantly among the food spray treatments (p>0.05) but differed significantly from those on the conventional-insecticide-treated and untreated plots (p<0.0001; Table 3).

Effect of food spray products on maize yield: 2020–2021 experiments

The maize yields (kg/ha) harvested from the plots treated with sugar-based rice dough alone or sugar-based rice dough + neem extract did not differ significantly (p>0.05) but were significantly higher than the yields from the conventional-insecticide-managed, neem-extract-treated, and unsprayed plots (p<0.0001; Table 4). The yields from the plots treated with yeast extract alone, sugar-based rice dough alone, or yeast extract + neem extract did not differ significantly from one another (p>0.05; Table 4). The yields harvested from the unsprayed, neem-extract-treated, and conventionally treated plots were significantly different (p>0.05) (Table 4).

The total pest control cost per hectare in season 1 was highest in the conventional-insecticide-treated plots (A$165), followed by the plots treated with yeast + neem extract (A$149), sugar-based rice dough + neem extract (A$125), neem extract ($89), and yeast extract (A$60) (Table 4). The highest net margin per hectare was achieved on plots treated with sugar-based rice dough alone (A$2,590), followed by those treated with sugar-based rice dough + neem (A$2,517), yeast extract alone (A$2,511), and yeast extract + neem extract (A$2,374) (Table 4). Plots treated with conventional insecticides had a lower net margin (A$2,189) than those treated with neem extract alone ($2,277) or the unsprayed plots ($2,366) (Table 4).

The economic yields of the food spray treatments in the second season are given in Table 5. The results were similar to those in season 1 for the plots treated with sugar-based rice dough + neem extract, which recorded the highest yields and net margin (Table 5). The lowest net margin of $2,232 was recorded on the unsprayed plots (Table 5).

Experiment 2: Efficacy of sugar-based rice dough solution plus neem (azadirachtin 0.3EC) on fall armyworm and their natural enemies on conventional maize crops at Trung Kien commune in Vinh Phuc province

Pests: 2022 January 18 – 2022 May 25

The dominant pest identified in the food-spray-treated and control plots was the fall armyworm. After the first treatment on 10 February 2022, the number of fall armyworm larvae per plant recorded on plots treated with food spray, conventional-insecticide-treated (farmers' practice) and unsprayed plots were not significantly different (p>0.371;

Table 4. Economic yields (kg/ha) for maize crops managed with food sprays at Vinch Phuc in Vietnam (season 1 trial) in 2020

Treatments	Maize yield (kg/ha)	Total Revenue from maize	Total pest control (AUD/ha)	Net margin (Return on investment) (AUD/ha)
Yeast extract alone	47.70 ± 0.52 a	2,571.00	60.00	2,511.00
Yeast extract + Neem extract	46.81 ± 0.58 a	2,522.00	149.00	2,374.00
Sugar-based Rice dough alone	48.72 ± 0.66 ab	2,626.00	36.00	2,590.00
Sugar-based Rice dough + Neem extract	49.02 ± 0.57 b	2,642.00	125.00	2,517.00
Neem extract alone	43.91 ± 0.84 c	2,366.00	89.00	2,277.00
Unsprayed plot	43.82 ± 0.62 c	2,366.00	0	2,366.00
Conventional insecticide	43.66 ± 0.32 c	2,353.00	165.00	2,189.00
p (ANOVA)	p<0.0001			

Means within a column followed by the same letter are not significantly different (ANOVA with significant treatment effect, followed by Tukey-Kramer multiple comparison test: p>0.05).

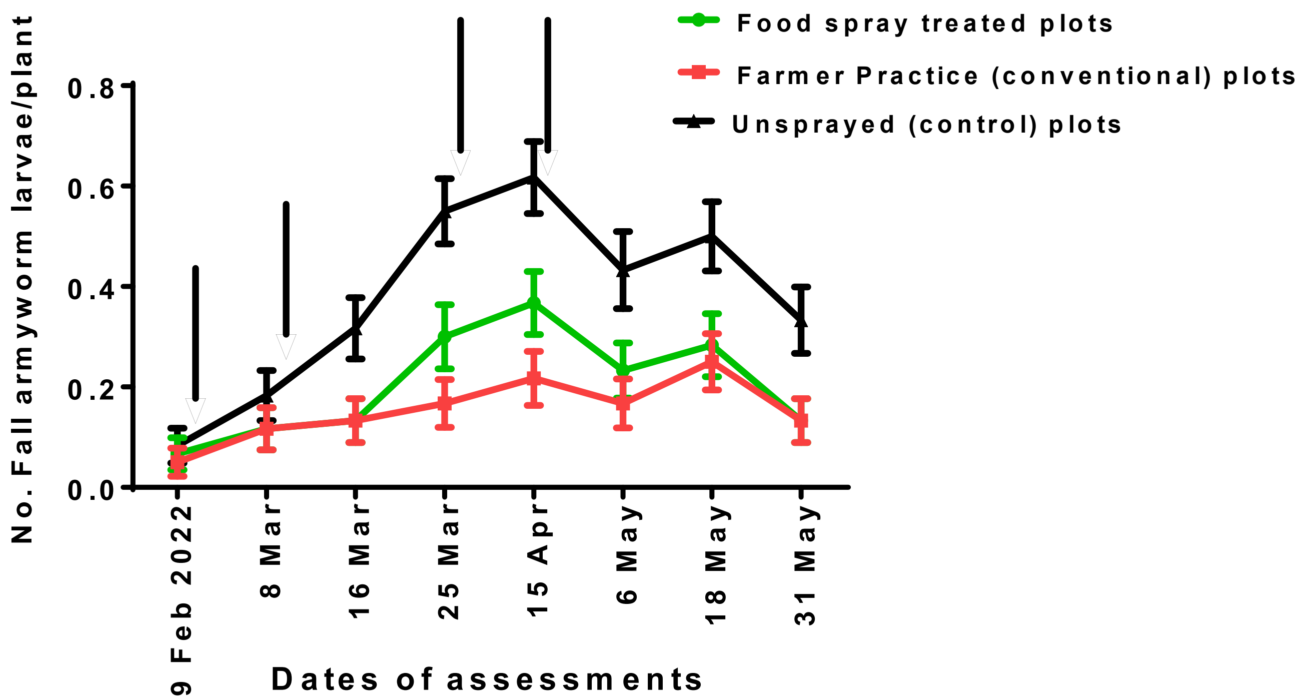


Figure 1. Mean (± SE) number of *Spodoptera frugiperda* (FAW) larvae recorded in maize crop treated with Food spray product and conventional insecticides at Vinh Phuc grower farm, 2022 Feb 9 to 2022 May 31. The arrows indicate the dates of treatment.

Figure 1). Similarly, after the second treatment, the fall armyworm larval numbers per plant were not significantly different (p>0.05) on the food-spray-treated and conventional-insecticide-treated plots, but were significantly lower than those on unsprayed plots (p<0.05; Figure 1). However, after the third treatment on 2022 Mar 26, the food-spray-treated plots had significantly higher (p<0.05) numbers of fall armyworm larvae per plant than the conventional insecticide-treated plots (Figure 1). In contrast, after the fourth treatment application on 16 April 2022, the number of fall armyworm larvae per plant on the food-spray-treated and conventional-insecticide-treated plots were not significantly different (p>0.05) on 2022 May 6, 18, and 31, which were significantly lower than those on the unsprayed plots (Figure 1).

Predatory insects: 2022 Jan 18 - 2022 May 25 study

The predominant beneficial insects at the study site were predatory beetles (mainly Coccinellidae, including *Coccinella transversalis* [transverse lady beetles] and other coccinellid species) and predatory spiders (*Araneus inustus* and *Salticidae* spp.).

Table 5. Economic yield (kg/ha) of maize crop managed with food sprays at Vinch Phuc in Vietnam (season 2 trials) in 2020

Treatments	Maize yield (kg/ha)	Total Revenue from maize	Total pest control (assuming all agronomic practices were the same) (AUD/ha)	Net margin (Return on investment) (AUD/ha)
Yeast extract alone	49.64 ± 0.36 a	2,585.00	58.00	2,380.00
Yeast extract + Neem extract	47.41 ± 0.34 b	2,469.00	143.00	2,325.00
Sugar-based Rice dough alone	48.65 ± 0.58 ab	2,533.00	35.00	2,499.00
Sugar-based Rice dough + Neem extract	51.48 ± 0.55 a	2,680.00	120.00	2,560.00
Neem extract alone	47.30 ± 0.41 b	2,466.00	86.00	2,380.00
Unsprayed plot	44.70 ± 0.46 c	2,232.00	0	2,232.00
Conventional insecticide	47.35 ± 0.51 b	2,466.00	159.00	2,306.00
p (ANOVA)	p<0.0001			

Means within a column followed by the same letter are not significantly different (ANOVA with significant treatment effect, followed by Tukey-Kramer multiple comparison test: p>0.05).

Beetles: Following the first and second treatments on 2022 February 10 and 2022 March 9, respectively, the number of transverse lady beetles per plant on food-spray-treated plots was not significantly different (p>0.05) from the conventional-insecticide-treated and unsprayed plots (p>0.05) on 2022 March 16 (Figure 2). However, on 25 March 2022, we recorded significantly higher numbers of transverse lady beetles per plant on food-spray-treated plots than on conventional-insecticide-treated (p<0.001) and unsprayed plots (p<0.041). No significant differences were detected between the conventional-insecticide-treated and unsprayed plots on 2022 March 16 or 25 (Figure 2).

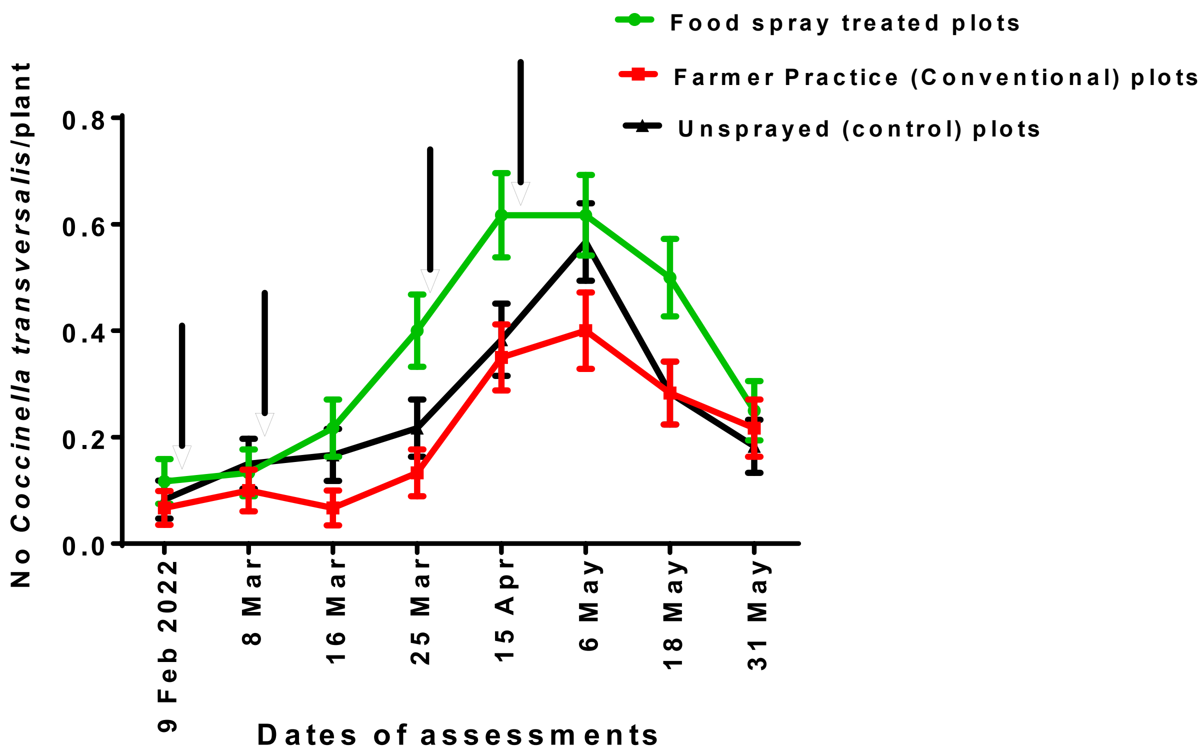
After the third treatment application on 2022 March 26, the number of transverse lady beetles per plant recorded on 2022 Apr 15 was significantly higher on food-spray-treated plots than on conventional-insecticide-treated (p<0.01) and unsprayed plots (p<0.05; Figure 2). Similar results were found for the number of other coccinellid species per plant among the treatments (Figure 2).

After the fourth treatment application on 2022 April 16, the number of transverse lady beetles and other coccinellids per plant was also significantly higher on food-spray-treated plots than on conventional-insecticide-treated plots (p<0.01; Figure 2), indicating that the food spray attracted and maintained predatory beetles.

Spiders: The predominant spiders identified in the study site were *Araneus inustus* and *Salticidae* spp. (Figure 3). After the first and second treatments on 2022 Feb 10 and 2022 March 9, the number of *A. inustus* and *Salticidae* spp. per plant recorded on plots treated with food spray was not significantly different from the conventional-insecticide-treated and untreated plots on both 2022 March 8 and 2022 March 16 (p>0.497 and p>0.05, respectively; Figure 3). However, on 2022 Mar 25, the number of *A. inustus* and *Salticidae* spp. recorded on food-spray-treated plots were not significantly different from the untreated plots (p>0.05), but it was significantly higher (p<0.01) than that on conventional-insecticide-treated plots (Figure 3). No significant difference was detected between conventional-insecticide-treated and untreated plots on 2022 May 25 (Figure 3).

Following the third treatment application on 2022 March 26, the number of *A. inustus* and *Salticidae* spp. per plant on 2022 April 15 was significantly higher on food-spray-treated plots than on either conventional-insecticide-treated or untreated plots (p<0.001; Figure 3). The fourth spray treatment was applied on 2022 Apr 16, and the field was assessed on 2022 May 6 and 18. The numbers of *A. inustus* and *Salticidae* spp. per plant were significantly higher on food-spray-treated plots than on conventional-insecticide-treated (p<0.001) or untreated (p<0.05, p<0.01, Figure 3) plots. The conventional insecticide-treated plots had significantly lower numbers of *A. inustus* and Salticidae spp. per plant than the untreated plots (p<0.05) on 2022 May 6 and 18 (Figure 3). As the number of fall armyworm declined on food-spray-treated plots from 2022 Apr 15 (Figure 1), reaching a lowest density of 0.10 per plant on 2022 May 31, the number of *A. inustus* and *Salticidae* spp. per plant also declined (Figure 3).

Predator-to-prey ratios: The predator-to-prey ratio was calculated as the total number of predators per fall armyworm per plant per sampling date (Figure 4). Following the first treatment on 2022 Feb 10, the predator-to-prey ratio was significantly higher on food-spray-treated plots than on conventional-insecticide-treated or untreated plots (p<0.001; Figure 4). The ratios recorded for the conventional-insecticide-treated and untreated plots were not significantly



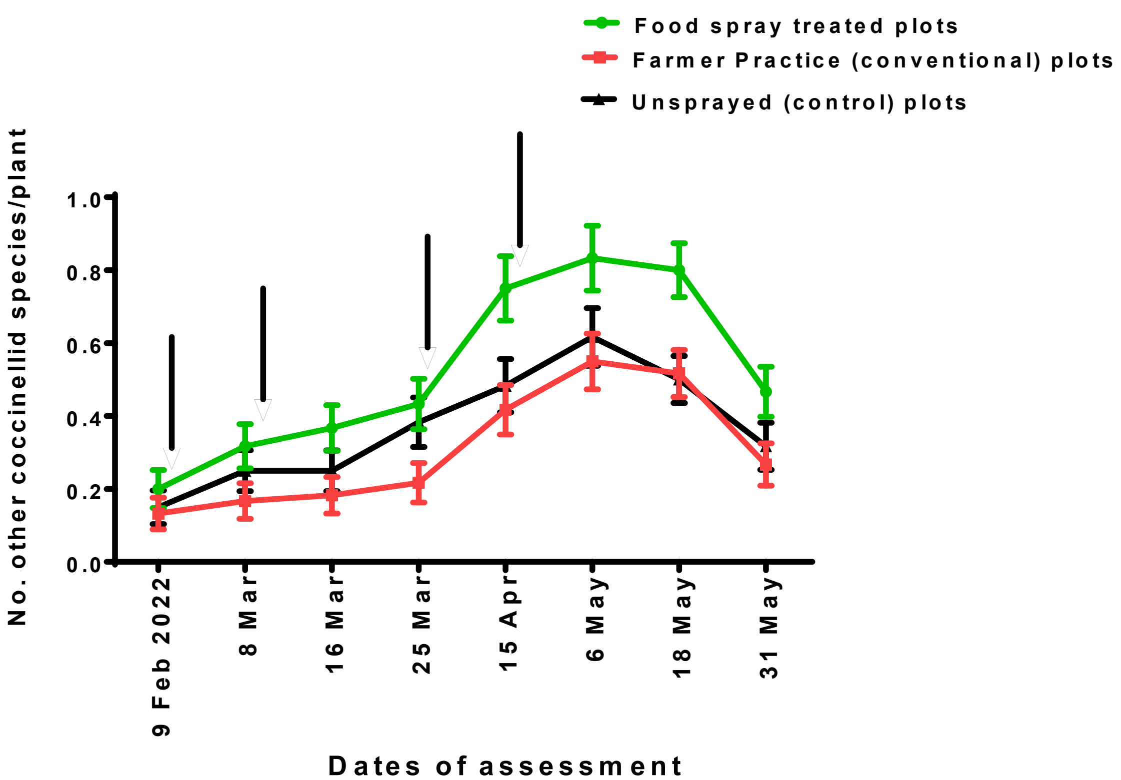


Figure 2. Mean (± SE) number of *Coccinella transversalis* (transverse ladybird beetle) and other coccinellid species recorded on maize crops treated with Food spray product and conventional insecticides at Vinh Phuc grower farm, 2022 Feb 9 to 2022 May 31. The arrows indicate the dates of treatment. The arrows indicate the dates of treatment applications.

Figure 3. Mean (± SE) number of *Araneus inustus* and *Salticidae* spp. (predatory spiders) recorded on maize crops treated with Food spray product and conventional insecticides at Vinh Phuc grower farm, 2022 Feb 9 to 2022 May 31. The arrows indicate the dates of treatment applications.

different ($p>0.05$) (Figure 4). After the application of the second, third, and fourth treatments (2022 Mar 9 – 2022 Apr 16), there was an increase in the predator-to-prey ratio on food-spray-treated plots that were significantly higher than those on conventional-insecticide-treated and untreated plots ($p<0.001$; Figure 4). The predator-to-prey ratios recorded on conventional-insecticide-treated and untreated plots continued to decline after the first treatment until the end of the study (Figure 4). Overall, the average predator-to-prey ratio recorded on the food-spray-treated plots was 9.19 per plant, compared with 5.49 and 3.86 per plant on the conventional-insecticide-treated and untreated plots, respectively (Figure 4). Therefore, in maize fields infested with fall armyworm and in which the predominant predators are predatory beetles and spiders, a consistent predator-to-prey ratio of approximately 9.2:1 per plant may be required to manage the pest.

Economics of yield: 2022 Jan 18 – 2022 May 25

The maize yield (kg/ha) harvested from the food-spray-treated plots (61.40 ± 1.41) was not significantly different from the conventional-insecticide-treated plots (60.98 ± 1.96; $p>0.05$) but was significantly higher than the yield from the untreated plots (53.17 ± 0.59; $p<0.01$).

The total pest control cost per hectare in the food-spray-treated plots was $120, but that in the conventional-insecticide-treated plots was $159. The net margin achieved in the food-spray-treated plots was $3,467, whereas it was $3,394 in the conventional-insecticide-treated plots and $3,186 in the untreated plots

DISCUSSION

In this study, we demonstrated that applying a supplementary food spray to maize crops increased the abundance of beneficial insects, leading to a natural reduction in the damage caused by the fall armyworm (*S. frugiperda*), resulting in higher maize yields and net margins. The predominant pest found throughout the study was fall armyworm. The natural enemies detected in the food-spray-treated plots were coccinellid species and spiders. Across the first, second, and third season experiments, the numbers of coccinellid species and spiders per plant were significantly higher on plots treated with sugar-based rice dough + neem formulation compared to other food-spray-treated, conventional-insecticide-treated, or untreated plots.

Amera *et al.* (2017) reported that the addition of neem extract to an Ethiopian food spray product consisting of maize

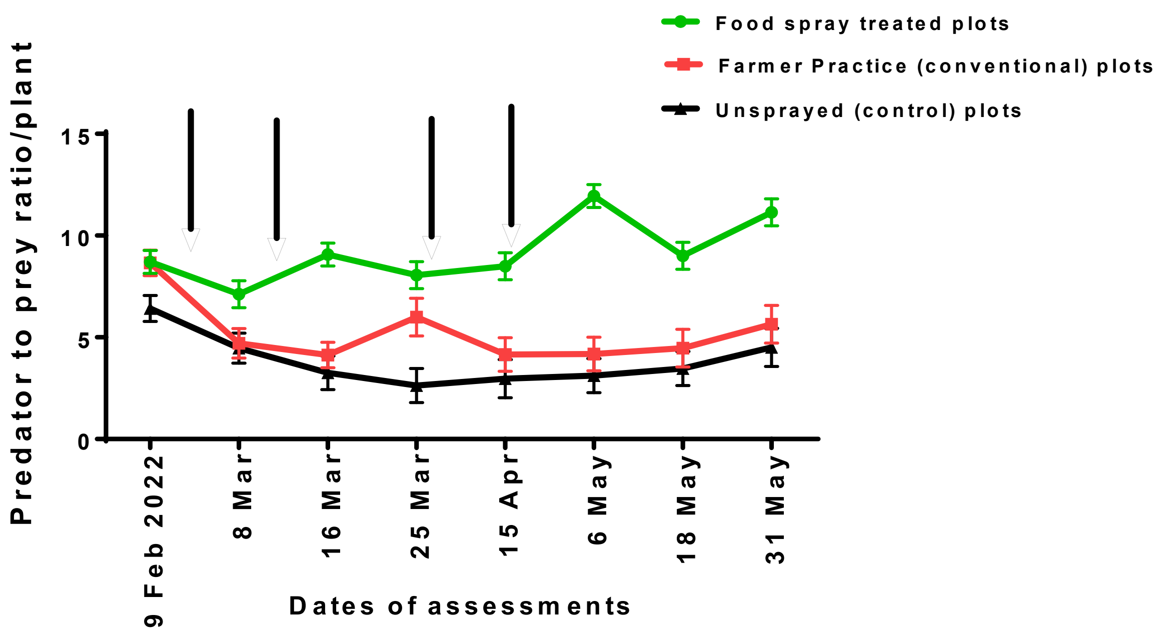


Figure 4. Predator to prey ratio per plant based on a mean number of coccinellids and predatory spiders recorded on maize crops treated with Food spray product and conventional insecticides at Vinh Phuc grower farm, 9 February to 31 May 2022. The arrows indicate the dates of treatment applications.

dough reduced the number of predatory insects in cotton fields. In our present study, when we mixed a sugar-based rice dough with neem extract, there was no significant change in the number of predators, but the number of fall armyworm per plant decreased. Therefore, at a low predator-to-prey ratio, especially when the number of pests (particularly the fall armyworm) is high and strongly affects the ratio, it is important to add neem extract to the sugar-based rice dough formulation to reduce pest numbers.

Applying supplementary food sprays against pests such as *Helicoverpa* spp. on commercial cotton crops or fall armyworm on maize crops can change the ratio of natural enemies to pests by attracting, sustaining, and increasing the searching ability and consumption rate of the natural enemies of these pests (Hagen, 1986; Mensah, 1997; Jervis *et al.*, 2004; Mensah *et al.*, 2012; Amera *et al.*, 2017; Razaq *et al.*, 2019). The food spray technology can be classified as a behaviour-modifying strategy, which enhances the natural biological control and management of pests such as the fall armyworm and other pests on maize crops, similar to the application of plant extracts to commercial cotton crops (Mensah, 2002 a, b; Del Socorro *et al.*, 2003; Del Socorro & Gregg, 2004; Grundy *et al.*, 2006; Gregg *et al.*, 2010 a, b; Mensah *et al.*, 2013, 2014). The behavior-modifying effects of the food spray are exerted through the odour from the food spray ingredients, which attract natural enemies (mainly predators) to the area. Once in the treated area, these predators may remain in the area following their contact with and subsequent consumption of the food supplement, thereby increasing their searching activity and consumption of the target pest (Mensah *et al.*, 2000). The application of supplementary food spray products can also deter the oviposition activity of female pest moths in response to the presence of the food product on the plant's foliage (Amera *et al.*, 2017; Mensah, 1996, 1997).

Studies of *Helicoverpa* spp. on cotton crops have shown the positive impact of application of supplementary food spray products to manage pests by conserving their natural enemies (Mensah *et al.*, 2012; Jervis *et al.*, 2004; Slosser *et al.*, 2000). For example, studies by Razaq *et al.* (2019), Amera *et al.* (2017), and Mensah *et al.* (2012) reported that the application of food supplements such as foliar sprays, with sugar syrup, brewers' yeast, and maize dough, to cotton fields conserved beneficial insects and managed *Helicoverpa* spp. on those crops.

In the second set of experiments (season 3 experiments), we evaluated the efficacy of the most promising food spray formulation (sugar-based rice dough + neem extract identified in experiment 1) against the fall armyworm and determined the optimal predator-to-prey ratio for managing the pest in commercial maize fields (Figure 4). The predator-to-prey ratio was significantly higher in the food-spray-treated plots compared to conventional-insecticide-treated or untreated plots (Figure 4). A decline in predator numbers per plant on unsprayed plots coincided with food spray or synthetic insecticide application. The food sprays likely attracted predatory insects from unsprayed plots and surrounding areas, while synthetic insecticides may have diminished predator populations across the study site. Nonetheless, the impact of synthetic insecticide application on food-spray-treated plots was minimal, as the food spray consistently drew beneficial insects from untreated plots and the general landscape. On average, the predator-to-prey ratio per plant in food-spray-treated plots throughout the study was 9.2:1, compared to 5.5:1 and 3.9:1 per plant in untreated and conventional-insecticide-treated plots respectively (Figure 4), resulting in higher yields and net margins on food-spray-treated plots without the need for synthetic insecticide sprays.

Although predator numbers in food-spray-treated plots were significantly higher than in untreated or conventional-insecticide-treated plots in this study, it's plausible that the numbers of beneficial insects in untreated and conventional-insecticide-treated plots would have been higher if these plots were located farther from the food-spray-treated plots. Mensah (1997, 2002 a, b), Mensah *et al.* (2012), and Amera *et al.* (2017) have suggested that unsprayed and conventional-insecticide-treated (control) plots should be situated 400 meters away from food-spray-treated plots due to the non-directional spread of food spray odours after application. However, in this study (experiment 2), we lacked sufficiently large fields to implement this distance. Despite the proximity of the untreated and conventional insecticide plots to the food spray plots densities of natural enemies were reasonably high on the food-sprayed plots (Figures 2, 3 and 4).

In experiment 2, maize yields from plots treated with the sugar-based rice dough + neem extract formulation were significantly higher than those from untreated and conventional-insecticide-treated plots. Plots treated with sugar-based rice dough + neem extract recorded net margins of \$3,467, compared to \$3,394 and \$3,186 in the conventional-insecticide-treated and untreated plots, respectively.

The food spray strategy is recommended for use as part of IPM because beneficial insects in surrounding landscapes can be low in abundance, especially during droughts when vegetation is dry and sparse. However, during seasons like rainy seasons, when surrounding vegetation is abundant and green, it supports beneficial insects and can attract them in large numbers onto crops using food spray technology for effective pest management. Conversely, in dry seasons when the surrounding vegetation may be sparse and devoid of beneficial insects, applying a highly concentrated sugar-based rice dough food spray early in the season can attract beneficial insects from farther away and enhance their buildup before fall armyworm pest infestation in maize crops.

The sugar-based rice dough + neem product developed in this study can be considered a low-input technology, offering an alternative to synthetic insecticides and minimizing their use. In the context of IPM, the food spray technology can be employed alone or in combination with other nonchemical techniques (e.g., botanicals or biopesticides) or synthetic insecticides on an as-needed basis against fall armyworm to maximize yields and profitability. While most IPM programs rely solely on pest numbers for decision-making, in food-spray-based IPM programs, using the predator-to-prey ratio to decide when to apply a food spray product is crucial. In this study, the average predator-to-prey ratio of approximately 9.2:1 per plant on food-spray-treated plots, with coccinellid species and spiders as predominant beneficial insect species effectively managed fall armyworm on maize fields.

Various studies on *Helicoverpa* spp. by Mensah (2002 a, b), Mensah *et al.* (2012), and Amera *et al.* (2017) on commercial cotton crops have shown that the most effective predator-to-prey ratio for managing the pest on cotton is >0.5 per metre row of cotton crops. In the present study, a ratio of >9.2:1 per plant was sufficient to manage fall armyworm in maize fields when coccinellid and spider species were predominant predators. Smallholder farmers, who typically schedule insecticide applications by crop growth stage and fall armyworm damage, would benefit from training in using the predator-to-prey ratio as a decision-making tool to time food sprays to coincide with periods of egg laying, hatching, and before fall armyworm larvae become inaccessible within whorls.

The current insecticide use by smallholder farmers against fall armyworm on maize crops is often unnecessary and ineffective because farmers calendarized sprays and miss the narrow window of the pest-susceptible period when eggs and very small larvae are still exposed to chemical reach. Applying food spray based on predator-to-prey ratio can build up enough beneficial insects early in the season before fall armyworm arrives on the crop, lays eggs that hatch into very small larvae, and then prey on them before the pest's larvae enter the plant's whorls.

In conclusion, fall armyworm was successfully managed using food spray products, particularly sugar-based rice dough + neem formulation to achieve higher yields and net margins and reduce total dependence on synthetic insecticides against fall armyworm.

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