HAYATI
Journal of Biosciences

Vol. 32 No. 1, January 2025 70-79
DOI:10.4308/hjb.32.1.70-79
ISSN: 1978-3019
EISSN: 2086-4094

Research Article

The Effectiveness of Insectary Plant that Attracts and Sustains Beneficial Arthropods to Control *Spodoptera frugiperda* J.E Smith (Lepidoptera: Noctuidae) in Maize

Vien Sartika Dewi[1*], Sylvia Sjam[1], Sulaeha Sulaeha[1], Elsa Sulastri[2]

[1]Department of Plant and Disease, Faculty of Agriculture, Universitas Hasanuddin, Makassar 90245, Indonesia
[2]Department of Agroecotechnology, Faculty of Agriculture and Forestry, Universitas Sulawesi Barat, Majene 91412, Indonesia

ARTICLE INFO

Article history:
Received April 25, 2024
Received in revised form August 10, 2024
Accepted September 8, 2024

KEYWORDS:
Entomology,
Agroecosystem,
Plant Protection,
Agriculture

ABSTRACT

Spodoptera frugiperda J.E. Smith, or fall armyworm (FAW), is a significant pest in maize plants and can reduce crop yields. Synthetic insecticides are still used to control *S. frugiperda*, but their use harms the environment and non-target organisms and can cause pests to become resistant. For this reason, alternative environmentally friendly technologies are needed, such as habitat management by planting insectary plants. This research aims to evaluate the potential of insectary plants to attract beneficial arthropods to suppress the *S. frugiperda* population and minimize the damage caused. This research activity was carried out using field research. The treatment in this research was the type of insectary plant used, and as a comparison, observations were made on land managed by farmers. The research results show that habitat management by planting insectary plants can increase the population of beneficial arthropods such as Coccinellidae, Formicidae, Miridae, Staphylinidae, and Araneidae. Increasing the population of beneficial arthropods can suppress the population of *S. frugiperda* so that its damage decreases and yields increase. These results show that planting insectary plants has the potential to prevent outbreaks of *S. frugiperda*, which can be combined with the application of other environmentally friendly technologies.

1. Introduction

Maize (*Zea mays* L.) is a cereal plant from the grass family (Poaceae) and a grain that can be consumed (Bhan 2011). This native plant from Central America is the result of domestication of one of the world's food crops, which is widespread and cultivated worldwide because of its high adaptive capacity. It can be grown in various seasons and environmental conditions (Bennetzen & Hake 2009). Maize is widely used as animal feed, human food, biofuel, and an important industrial raw material and provides excellent opportunities for economic value (Erenstein *et al.* 2022). Maize is one of the most important food crops in the world and provides 40% of global food production annually (Kumar *et al.* 2012). Maize is a plant with many benefits. Apart from being used as food throughout the world, maize is also essential as a food crop, especially in Latin America and sub-Saharan Africa (Erenstein *et al.* 2022). Maize can grow in various climatic conditions and on all types of soil, from sandy to heavy clay, throughout the year, so it is easily cultivated by people (Roy *et al.* 2020).

One of the invasive pests in maize cultivation is *S. frugiperda*, or fall armyworm (FAW). *S. frugiperda* entered Indonesian territory in 2019 and spread quickly to various regions in Indonesia because of its capability to fly up to 500 km before starting oviposition (Nonci *et al.* 2019; Ganni *et al.* 2021). *S. frugiperda* has two genetic strains, the rice strain and the maize strain. The rice strain attacks rice plants and other grass species, and the maize strain attacks maize and sorghum plants (Abbas *et al.* 2022). *S. frugiperda*

* Corresponding Author
E-mail Address: fachrudinvien@yahoo.com

can cause yield loss at high pest investment (Asfiya *et al.* 2020). Control of *S. frugiperda* can be done by conservation and augmentation of its natural enemies rather than using synthetic insecticides, which have adverse effects (Altieri *et al.* 2005; Abbas *et al.* 2022). Because pesticides harm the environment and human health and cause insect pest resistance, there is a growing demand for an alternative approach that is low-risk, inexpensive, and target-specific (Abbas *et al.* 2022).

Conservation is an effort to preserve beneficial arthropods on agricultural land. Conservation is carried out by providing food like nectar and pollen (Bennett 2018) and providing a habitat for beneficial arthropods (Bennett 2018; Hajek & Eilenberg 2018). Meanwhile, augmentation is the multiplication of natural enemies released periodically on agricultural land to suppress pest populations (Hajek & Eilenberg 2018). Augmentations are generally developed in greenhouses and then released periodically to suppress pest populations (Altieri *et al.* 2005; Hajek & Eilenberg 2018). Conservation of beneficial arthropods in maize cultivation can be done through habitat management by planting insectary plants.

Insectary plants are flowering plants that have nectar and pollen (Armengot *et al.* 2020) as a source of energy for several living creatures, especially insect pollinators, and as a shelter for other beneficial arthropods (Bauddh *et al.* 2020). Pollinator insects are responsible for pollinating plants, thereby accelerating seed formation (Loy & Brosi 2022), and predator insects are responsible for suppressing pest populations in crops (Yurchak *et al.* 2023). Natural plant flora in the environment serves as a food source for predators, pollinators, and parasitoids that cannot access resources in agricultural fields (Dively *et al.* 2020). Because certain predators and parasitoids are only predaceous in one life stage, which means that life stages that are not predaceous rely on pollen and nectar, floral resources are crucial to maintaining beneficial insects (Bennett 2018). Insectaries are intended to attract and provide shelter for beneficial arthropods, which then predate or parasitize maize pests. The use of insecticide is decreasing due to the decreasing pest populations and improved plant health (Dewi *et al.* 2020).

Habitat management in maize plantations is an integrated pest management strategy with an efficient ecological approach to increase biodiversity and ecosystem balance, which has an impact on sustainable agricultural productivity (Altieri *et al.* 2005; Shrestha *et al.* 2019; Bauddh *et al.* 2020). The characteristics of plants that can be used as intercropping crops are that they are easy to obtain, easy to grow, and fast to flower (Bennett 2018; Retallack *et al.* 2019). Some flowering plants that fulfill this criteria include *Arachis pintoi, Portulaca oleracea*, and *Desmodium triflorum*. Some of these plants are legume plants, which can increase the nitrogen content in the soil. Leguminosae plants can symbiosis with *Rhizobium* sp. bacteria, thus increasing nitrogen levels in the soil and making plants more lush. (Roy *et al.* 2020; Ganni *et al.* 2021).

Based on preliminary survey results in Soppeng District, South Sulawesi, in general, damage to maize plants is caused by *S. frugiperda* larvae. This pest has a high-speed spreading ability, high reproduction speed, and destructive solid power, so if not controlled properly, it can cause yield loss.

This research aims to determine the potential of various insectary plants in the prevention of outbreaks of the *S. frugiperda* pest through field research. The success of this research provides an opportunity to develop the use of insectary plants to prevent the explosion of plant pests, especially *S. frugiperda* in maize plants, which can be combined with various other environmentally friendly technologies.

2. Materials and Methods

This research was conducted in Talepu Village, Soppeng District, South Sulawesi, Indonesia (Figure 1), and the Pest Science Laboratory, Department of Plant Pests and Diseases, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia, from October 2022 to February 2023.

The experiment was arranged in a complete randomized block design with four treatments. The maize crops experiment included insectary plants *Arachis pintoi, Portulaca oleracea*, and *Desmodium triflorum* as treatments and without insectary plants as controls (Figure 2). As a comparison, observations will be made on treating farmers with synthetic insecticides with the active ingredient deltamethrin and without insectary plants. Each treatment was repeated three times with one research plot consisting of 24 maize plants. In each replication, 16 sample plants were taken for observation of *S. frugiperda* and beneficial arthropods.

The treatment started in the early week of October 2022 until January 2023. Observation of the larval population of *S. frugiperda* pest and beneficial arthropods

Research Location Map

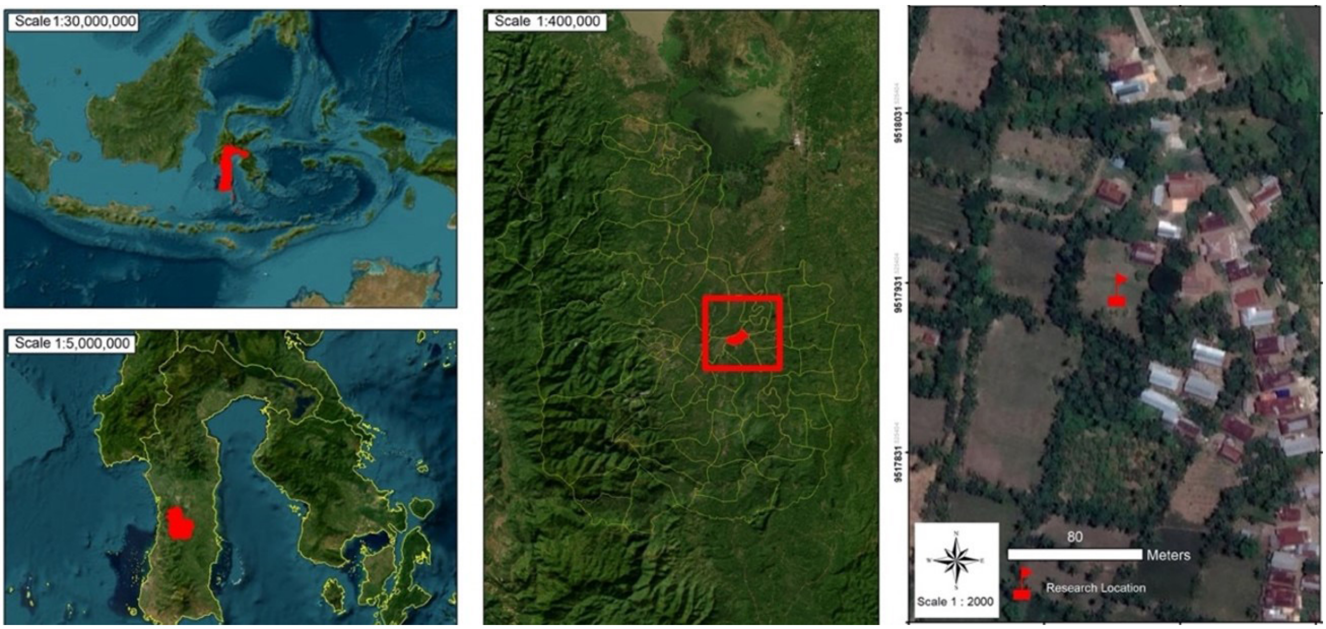

Figure 1. The research location is in Soppeng District, South Sulawesi, Indonesia (red color shows the research location)

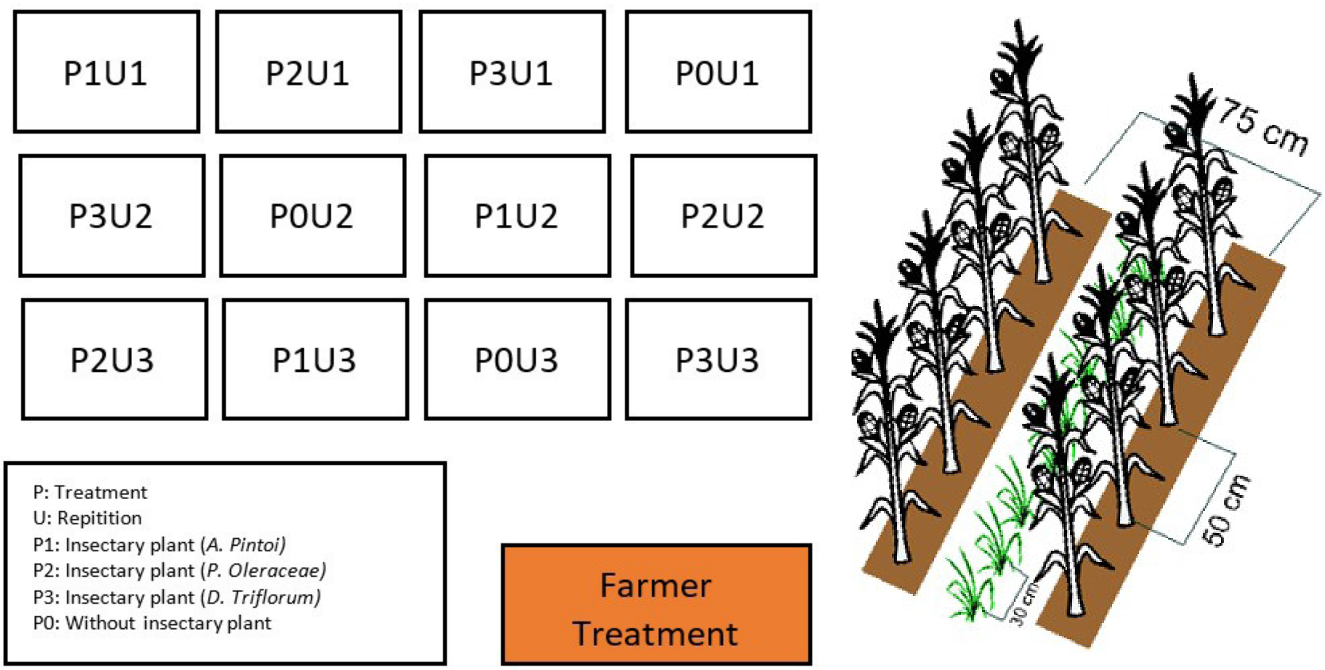

Figure 2. Experimental design, maize planting model, and insectary plant

was carried out every week from the plants that were 14 days old until 63 days old by counting the larval population and beneficial arthropods population on the sample plants. The number of beneficial arthropods seen directly and trapped in sweep nets and pitfall traps on the sample plants. Sweeping net observations were made by swinging the insect net three times in the direction of swinging left and right quickly. The pitfall trap is done by burying the container in the form of a plastic cup filled with soapy water until it is parallel to the ground surface. The insects obtained were put into a collection bottle that had been given 70% alcohol and then identified. Insects obtained in the field were photographed and put into bottles/jars and labeled by treatment type. Species-recognized insects were identified directly in the field, while unrecognized insects could be brought to the laboratory for identification using a lup and microscope. The damage of *S. frugiperda* was observed every week, from 14 days after sowing to 63 days after sowing, by calculating the damage on the sample plants. The parasitoid was observed by collecting eggs obtained from plants outside the sample for two weeks and then rearing them to observe the emergence of insects.

Arthropod population data were analyzed after transformation to Log x+1. Observation of *S. frugiperda* damage was carried out by assigning an attack score to the leaves from 1 to 9 on the sample plants (Davis scale), then calculated using the formula (Davis *et al.* 1992; Asfiya *et al.* 2020):

$$I = \frac{\sum_{i=0}^{z} (ni \times vi)}{z \times N} \times 100 \quad (1)$$

Where,
I : damage
Z : highest score (9)
N : number of leaves observed
ni : number of leaves attacked on the i-scale
vi : i-Damage scale

Duncan's multiple range test (DMRT) was then used to evaluate significant differences between the treatment means.

In addition to the above data, harvest data, and parasitization percentage data are also required. Yield data were obtained by weighing the dry weight of each treatment. Harvesting was done after the maize was 80 days after planting by taking each maize cob in each treatment. Each treatment and repetition were separated and then dried in the sun to reduce moisture content. After that, the maize was manually shelled and then dried in the sun again to get the dry weight. Data analysis for harvest data was as follows:

$$\text{Average of yields} = \frac{\Sigma P\ (U1 + U2 + U3)}{n} \quad (2)$$

Where,
P : treatment,
U : repetition,
n : number of repitition

Duncan's multiple range test (DMRT) was then used to evaluate significant differences between the treatment means.

Rearing groups of *S. frugiperda* eggs obtained parasitization percentage data from each treatment. *S. frugiperda* eggs were collected once a week for three weeks in each treatment. Each group of eggs taken was then reared until hatching. After hatching, the eggs were identified to determine whether they were *S. frugiperda* larvae or parasitoids. To calculate the percentage of parasitation using the formula:

$$P = \frac{N}{n} \times 100\% \quad (3)$$

Where,
P : parasitization percentage
N : number of eggs
n : number of parasitoids emergence

Duncan's multiple range test (DMRT) was then used to evaluate significant differences between the treatment means.

3. Results

The beneficial arthropods community is primarily composed of four orders (Araneidae, Hymenoptera, Coleoptera, Hemiptera) and six families (Lycosidae, Tetragnathidae, Staphylinidae, Coccinellidae, Miridae, Formicidae) (Figure 3). The most beneficial arthropods were found when treating the insectary plant *A. pintoi*, followed by *P. oleracea*, which was found the least the farmer's treatment. Meanwhile, the highest density of beneficial arthropods is in the Formicidae family, and the lowest is Staphylinidae. Coccinellidae and Staphylinidae insects were not found in farmer treatments. In the control treatment, no Staphylinidae insects were found either.

3.1. *Spodoptera frugiperda* Abundance and Damage

The total number of *S. frugiperda* individuals recorded in all treatments was 209 individuals. In the treatment of the insectary plant *Arachis pintoi*, 37 individuals were treated in *Portulaca. Oleracea* 37 individuals, *Desmodium tiflorum* 36 individuals, control 48 individuals, and farmer treatment 51 individuals (Figure 4). The damage caused by *S. frugiperda* attacks is directly proportional to the number of *S. frugiperda* individuals. The density of *S. frugiperda* and the damage caused were highest in the treatment without

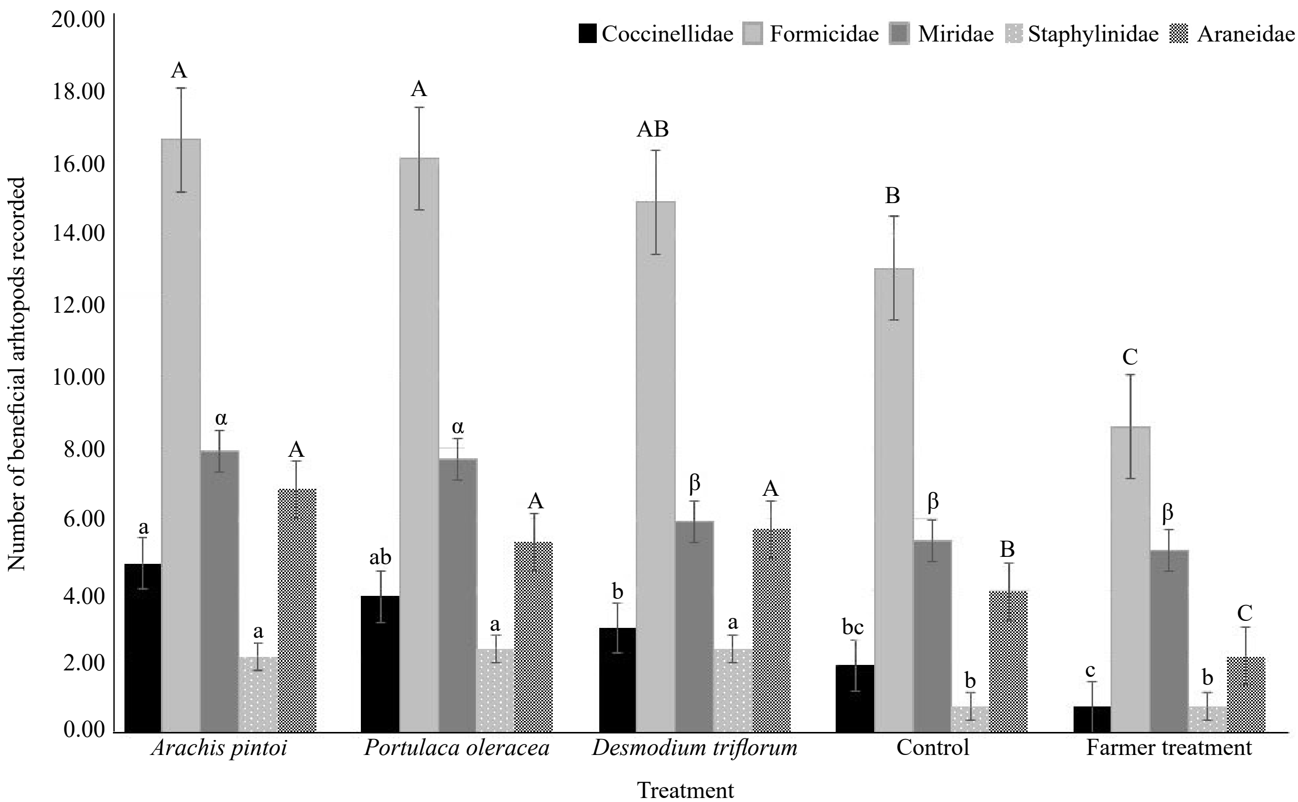

Figure 3. Population density of beneficial arthropods in each treatment. For each insect family, bars with different letters are significantly different (P<0.05)

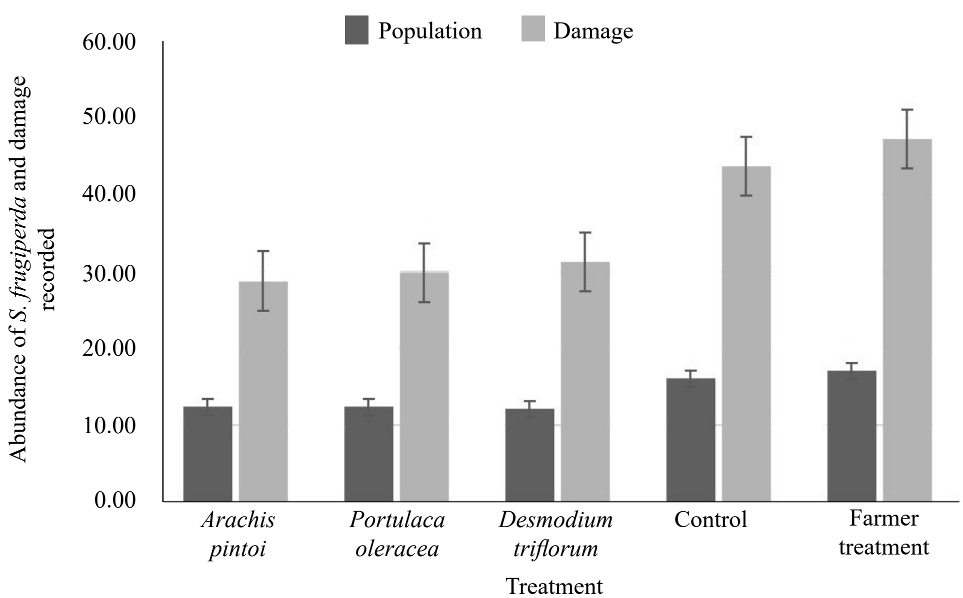

Figure 4. Abundance and damage of *S. frugiperda* in each treatment. Each bar with a different letter is significantly different (P<0.05)

insectary plants, control, and farmer treatments, which were significantly different from the treatment with insectary plants (Figure 3).

3.2. Maize Crop Yield

he production yield in the treatment with the insectary plant *A. pintoi* was the highest compared to the other treatments and was significantly different from the farmer's treatment. Production yields were lowest in the farmer treatment, followed by the control treatment (Table 1).

3.3. Percentage of Parasitization

S. frugiperda is an insect that lays eggs in large numbers on the surface of its host's leaves by forming egg clusters. The results of observations of *S. frugiperda* eggs obtained from the field showed that the percentage of parasitization was highest in treatments with the insectary plant *A. pintoi* (Figure 5).

3.4. Relationship between Beneficial Arthropods' Density and *S. frugiperda* Density

The relationship between beneficial arthropod density and *S. frugiperda* density is shown through a downward curve and is a negative linear graph with a regression of Y = -0.0435x + 18.429. This shows that the presence of beneficial arthropods has an essential effect on the density of *S. frugiperda*. The higher the population of beneficial arthropods, the lower the population of *S. frugiperda* (Figure 6).

3.5. Relationship between Beneficial Arthropod Populations and the Intensity of *S. frugiperda* Attacks

The relationship between beneficial arthropod density and the damage of *S. frugiperda* is shown through a downward curve and is a negative linear graph with a regression of Y = -0.166x + 53.397. This shows that the presence of beneficial arthropods has an essential effect on the intensity of *S. frugiperda*. The higher the population of beneficial arthropods, the lower the intensity of *S. frugiperda* (Figure 7).

Table 1. Maize yield according to treatment

Treatment	Yield (kg) means ± SEM
Arachis pintoi	3.93[a]±0.176
Portulaca oleracea	3.97[a]±0.448
Desmodium triflorum	3.80[ab]±0.577
Control (no insectary plant)	3.40[ab]±0.577
Farmer treatment (no insectary plant)	3.10[c]±0.577

3.6. Relationship between the Damage of *S. frugiperda* and Yields

The relationship between the damage of S. frugiperda and yields is shown through a downward curve and is a negative linear graph with a regression of Y= -0.0429x + 5.189. This shows that the damage caused by the *S. frugiperda* attack is very influential on yields. The higher the attack of *S. frugiperda*, the higher the yield loss caused (Figure 8).

4. Discussion

This research indicates the potential for utilizing insectary plants to enhance the population of beneficial arthropods, thereby reducing the population and damage caused by *S. frugiperda*. The presence of insectary plants significantly increases the abundance of beneficial insects and increases the percentage of parasitization. A planting system with a combination of plants will increase the biodiversity found in a garden ecosystem (Pickett *et al.* 2014; Roy *et al.* 2020; Ganni *et al.* 2021). The more diverse the plants, animals, and soil organisms that inhabit an agricultural land, the more diverse the community of beneficial organisms will be to support crops (Altieri 1999; Altieri *et al.* 2005). Therefore, to prevent outbreaks, proactive measures should be taken by managing agroecosystems, such as planting maize alongside a mix of insectary plants.

Insectary plants are effective in attracting natural enemies or beneficial arthropods due to the availability

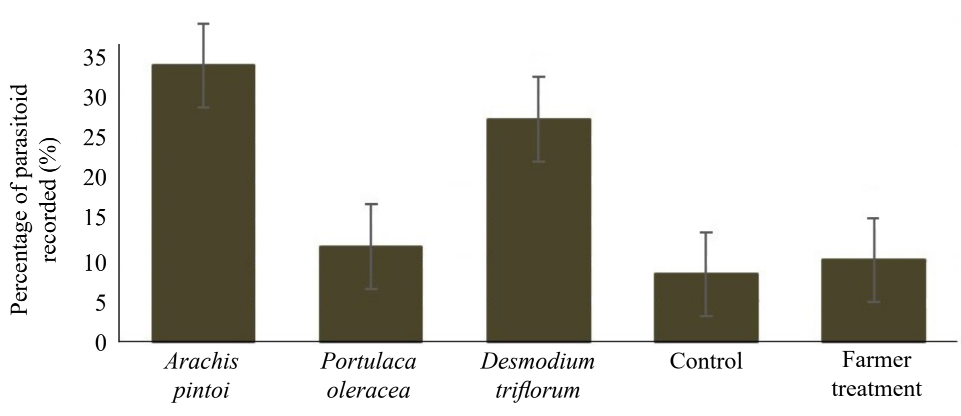

Figure 5. Percentage of parasitoids in each treatment. Bars with different letters are significantly different (P<0.05)

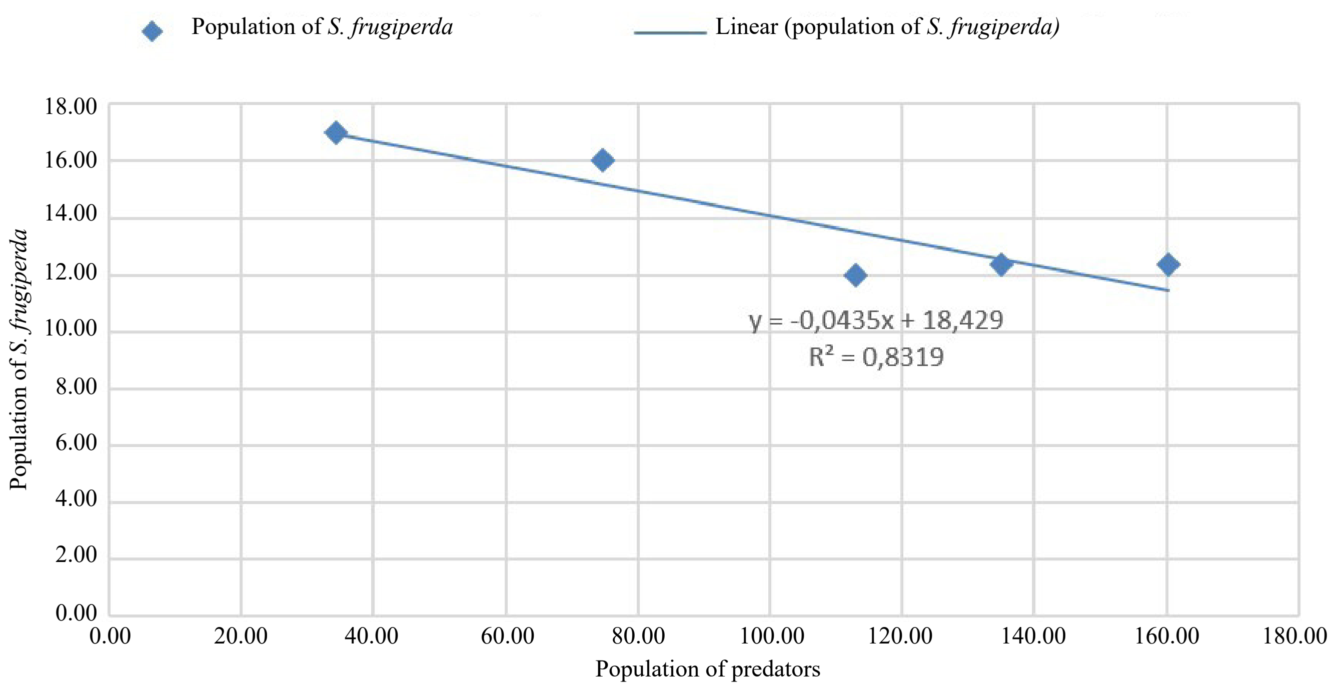

Figure 6. The relationship between beneficial arthropod density and *S. frugiperda* density

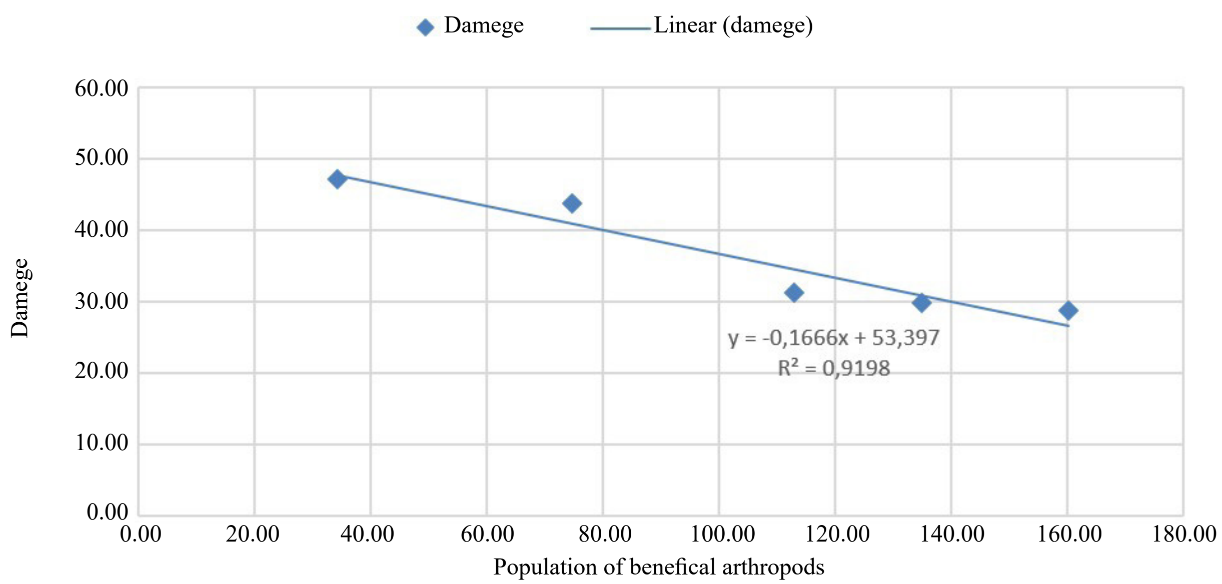

Figure 7. The relationship between beneficial arthropod density and the damage of *S. frugiperda*

of habitat and food sources such as nectar, pollen, and alternative hosts or prey. One of the insectary plants that attracts the most valuable insects is *A. pintoi. A. Pintoi* is a bright flowering legume plant that can attract beneficial arthropods and provide shelter. The 4-methyl -3,5-heptanedione content in legume plants functions as an aggregation pheromone to attract beneficial arthropods (Smart *et al.* 1994; Zhang *et al.* 2013). Plant diversity on agricultural land can facilitate beneficial arthropods such as predators and parasitoids to suppress *S. frugiperda* populations. The number of predators, parasitoids, and pathogens can increase along with the high diversity of surrounding plants (Magurran 1988; Bauddh *et al.* 2020). Several insect families that are natural enemies of *S. frugiperda* are Lycosidae, Tetragnathidae, Staphylinidae, Coccinellidae, Miridae, and Formicidae.

The population of beneficial arthropods in the farmer's treatment is lower than in other treatments because of the application of synthetic insecticide

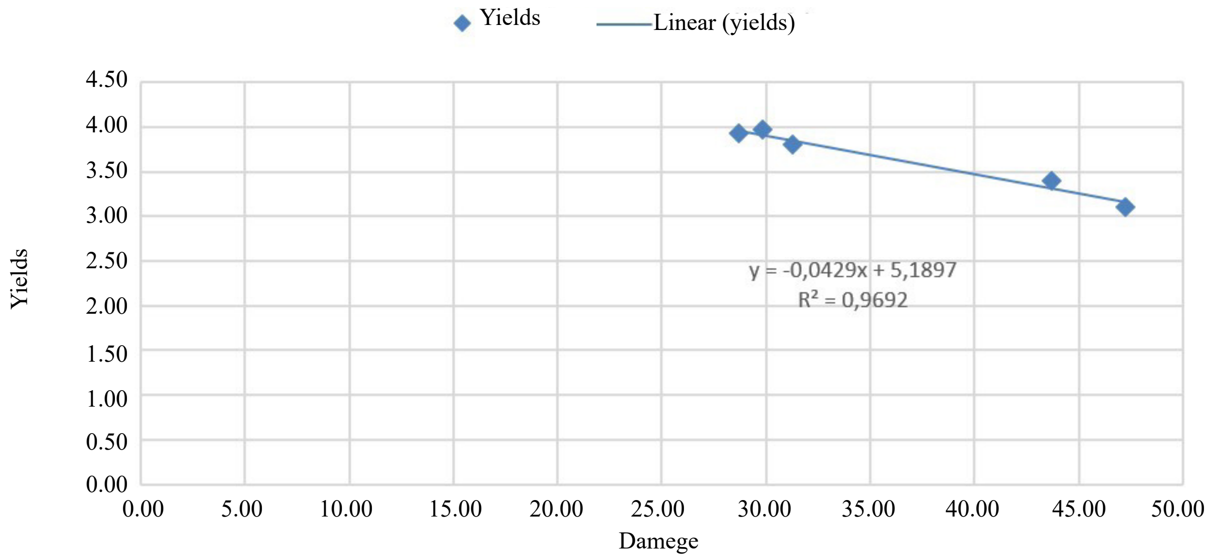

Figure 8. The relationship between the damage of *S. frugiperda* and yields

so that non-target organisms also die. Even though synthetic insecticide is used in farmers' treatments, the population of *S. frugiperda* is still higher than that of other treatments. This is because there has been an initial investment that resulted in a high population of larvae being discovered and being handled too late, causing damage to the maize plants. Therefore, preventive measures must be taken rather than control measures. The population of *S. frugiperda* is related to the damage caused, both from damage to the plant itself and the impact on loss of yields.

S. frugiperda larvae have potent jaws with serrated spear-like tips, which makes it easier to feed on plants with high silica content (Capinera 2017). *S. frugiperda* larvae damage maize plants by boring into the leaves at the growing point of the plant so that if they attack young plants, it can cause a decrease in production yields, and if the damage is extensive, it can cause yield loss. A larval population density of 0.2–0.8 per plant can cause yield losses of 5-20% (Makgoba *et al.* 2021). This is evident from the fact that production results in the farmer's treatment are lower than in other treatments due to the high population of *S. frugiperda*, even with the application of synthetic insecticide. In the control treatment without insectary plants, the population of *S. frugiperda* and the damage caused were still lower than in the farmer's treatment because the population of beneficial arthropods was still maintained. After all, synthetic insecticides were not used. The presence of beneficial arthropods in the control treatment can suppress the *S. frugiperda* population so that the damage is reduced. Apart from predators, beneficial arthropods that also play an essential role in suppressing the *S. frugiperda* population are parasitoid insects. Parasitoid insects can be used in agricultural systems as natural enemies to suppress pest populations (Smith *et al.* 2021).

Parasitoid insects are insects that were not found during observations because of their small size and agility. However, from the results of rearing groups of eggs, egg parasitoids *Telonomus* sp. and *Trichogramma* sp. were obtained (Figure 9). The highest percentage of parasitization was in the treatment with the insectary plant *A. pintoi*. Egg parasitoids are the most potential biological control agent for suppressing the population of pest *S. frugiperda*. Parasitoid insects that oviposition on egg groups will cause *S. frugiperda* larvae not to hatch. *Telenomus* sp. is the most common type of parasitoid that hatches from *S. frugiperda* eggs. This insect has a small size of 0.6 mm with a shiny black body, transparent wings, and reduced venation of the antennae. Male insects have 12 equally large segments, while female insects have 11 segments, and the last five segments are enlarged (Liao *et al.* 2019).

Based on the results of observations by rearing groups of *S. frugiperda* eggs to determine the percentage of parasitoids in Figure 5, it shows that the percentage of the appearance of egg parasitoids is found more in the treatment using insectary plants, especially in *A. pintoi* and *D. triflorum* plants. At the same time, the lowest percentage was in the control treatment and farmers' treatment. It can be concluded that the presence of insectary plants can increase the number of egg parasitoids and suppress the breeding

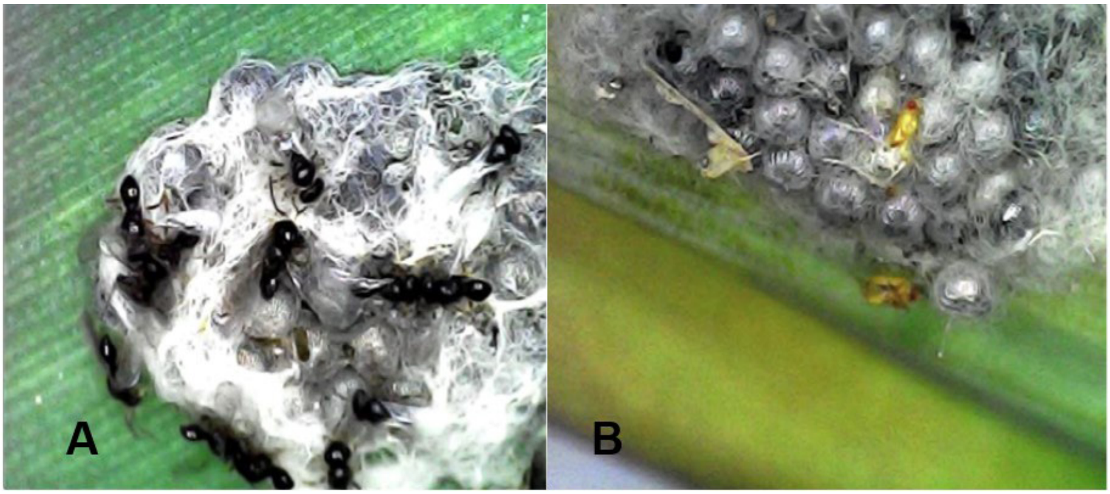

Figure 9. Arasitoids that hatch from the eggs of *S. Frugiperda*. (A) *Telonomus* sp. (B) *Trichogramma* sp.

of *S. frugiperda*. The presence of insectary plants can be a food source for parasitoids or other beneficial arthropods in the form of nectar as their energy source. Based on the results of linear regression analysis, the relationship between beneficial arthropod density and *S. frugiperda* density was in the robust category of 83%. Every 1% increase in beneficial insects will reduce the density of *S. frugiperda* by 0.43%. The decline in the *S. frugiperda* population has a direct impact on the damage caused. This is proven by the results of the regression analysis of the relationship between beneficial arthropod populations and the damage of *S. frugiperda* attacks, which are in the robust category (92%). Every 1% increase in beneficial arthropod populations can reduce the intensity of *S. frugiperda* attacks by 16%. Then, the results of the regression analysis of the relationship between the damage of *S. frugiperda* attacks and yield losses also showed a powerful category at 97%. Every 1% increase in the damage of *S. frugiperda* will reduce yields by 0.43%. Maize yield losses from 12 countries in Africa, based on studies in Ghana and Zambia, are estimated at between 8.3-20.5 million tons, valued at between US $2.5-$6.2 billion (Day *et al.* 2017). *S. frugiperda*, which attacks maize plants when the young leaves are still curled, causes yield losses of between 15-73% if the plant population is attacked up to 55-100% (Hruskal & Gould 1997).

In conclusion, the results showed that using insectary plants can suppress the population of *S. frugiperda* and the damage caused by them, so yields increase. In field conditions, the effect of habitat management by planting insectary plants can attract more beneficial arthropods such as predators and parasitoids, thereby suppressing pest populations and minimizing attacks. As a preventive measure, insectary plants can be combined with various other environmentally friendly technologies, such as botanical insecticide, to control remaining pests in the field.

Acknowledgements

The current study was supported by the Department of Plant Pest and Disease, Faculty of Agriculture, Hasanuddin University, Makassar, Indonesia. We thank our friends and all parties involved, from sampling to the process of publishing this article.

References

Abbas, A., Ullah, F., Hafeez, M., Han, X., Dara, M.Z.N., Gul, H., Zhao, C.R., 2022. Biological control of fall armyworm, *Spodoptera frugiperda. Agronomy,* 1-16. https://doi.org/10.3390/agronomy12112704

Altieri, M.A., 1999. The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems & Environment*. 74, 19-31.

Altieri, M.A., Nicholls, C.I., Fritz, M., 2005. *Manage Insects on Your Farm: a Guide to Ecological Strategies*. Sustainable Agriculture Network, Beltsville, MD.

Armengot, L., Ferrari, L., Milz, J., Velásquez, F., Hohmann, P., Schneider, M., 2020. Cacao agroforestry systems do not increase pest and disease incidence compared with monocultures under good cultural management practices. *Crop Protection.* 130, 1-9. https://doi.org/10.1016/j.cropro.2019.105047

Asfiya, W., Subagyo, V.N.O., Dharmayanthi, A.B., Fatimah, F., Rachmatiyah, R., 2020. Intensitas serangan *Spodoptera frugiperda* J.E. Smith (Lepidoptera: Noctuidae) pada pertanaman jagung di Kabupaten Garut dan Tasikmalaya, Jawa Barat. *J Entomol Indones.* 17, 163. https://doi.org/10.5994/jei.17.3.163

Bauddh, K., Kumar, S., Singh, R.P., Korstad, J., 2020. *Ecological and Practical Applications for Sustainable Agriculture, Ecological and Practical Applications for Sustainable Agriculture*. Springer, Singapore. https://doi.org/10.1007/978-981-15-3372-3

Bennett, A., 2018. *Using Insectary Plants to Attract and Sustain Beneficial Insects for Biological Pest Control*. State University Mexico, New Mexico.

Bennetzen, J., Hake, S., 2009. *Handbook of Maize: Its Biology*. Springer Science and Business Media, New York. https://doi.org/10.1007/978-0-387-79418-1

Bhan, M.K., 2011. *Biology of Maize*. Department of Biotechnology Ministry of Environment and Forest, New Delhi.

Capinera, J.L., 2017. *Fall Armyworm, Spodoptera frugiperda (J.E. Smith) (Insecta: Lepidoptera: Noctuidae)*. University of Florida. Gainesville. https://doi.org/doi.org/10.32473/edis-in255- 2000

Davis, F.M., Sen, SN, Wiliam, PW, 1992. *Visual Rating Scales for Screening Whorl-stage Corn for Resistance to Fall Armyworm*. Mississippi State University, USA.

Day, R., Abrahams, P., Bateman, M., Beale, T., Clottey, V., Cock, M., Colmenarez, Y., Corniani, N., Early, R., Godwin, J., Gomez, J., Moreno, P.G., Murphy, S.T., Oppong-Mensah, B., Phiri, N., Pratt, C., Silvestri, S., Witt, A., 2017. Fall armyworm: Impacts and implications for Africa. *Outlooks on Pest Management.* 28, 196–201. https://doi.org/10.1564/v28_oct_02

Dewi, V.S., Nurariaty, A.A., Sulastria, Tuwo, M., 2020. Arthropoda diversity in organic cocoa farming in Bantaeng District. *IOP Conf. Ser.: Earth Environ. Sci*. 486, 1-5. https://doi.org/10.1088/1755-1315/486/1/012164

Dively, G.P., Leslie, A.W., Hooks, C.R.R., 2020. Evaluating wildflowers for use in conservation grass buffers to augment natural enemies in neighboring cornfields. *Ecol Eng.* 144, 105703. https://doi.org/10.1016/j.ecoleng.2019.105703

Erenstein, O., Jaleta, M., Sonder, K., Mottaleb, K., Prasanna, B.M., 2022. Global maize production, consumption and trade: trends and R&D implications. *Food Secur*. 14, 1295–1319. https://doi.org/10.1007/s12571-022-01288-7

Ganni, O., Guera, M., Castrejón-Ayala, F., Robledo, N., Jiménez-Pérez, A., Sánchez-Rivera, G., Salazar-Marcial, L., Flores Moctezuma, H.E., 2021. Effectiveness of push-pull systems to fall armyworm (*Spodoptera frugiperda*) Management in Maize Crops in Morelos, Mexico. *Insects.* 12, 298. https://doi.org/10.3390/insects

Hajek, A.E., Eilenberg, J., 2018. Conservation and enhancement of natural enemies. *In: Natural Enemies: An Introduction to Biological Control*. Cambridge: Cambridge University Press. pp. 85–106. https://doi.org/10.1017/9781107280267.006

Hruskal, A.J., Gould, F., 1997. Fall armyworm (Lepidoptera: Noctuidae) and *Diatraea lineolata* (Lepidoptera: Pyralidae): impact of larval population level and temporal occurrence on maize yield in nicaragua. *Journal of Economic Entomology.* 90, 611–622.

Kumar, B., Karjagi, Chikkappa.G., Jat, S.L., Parihar, C.M., Yathish, K.R., Singh, V., Hooda, K.S., Dass, A.K., Mukri, G., Sekhar, J.C., Kumar, R., Kumar, R.S., 2012. *Maize Biology: An Introduction Directorate Of Maize Research*. Directorate of Maize Research, Pusa Campus, New Delhi.

Liao, Y.L., Yang, B., Xu, M.F., Lin, W., Wang, D. Sen, Chen, K.W., Chen, H.Y., 2019. First report of *Telenomus remus* parasitizing *Spodoptera frugiperda* and its field parasitism in southern China. *J Hymenopt Res* 93, 95–102. https://doi.org/10.3897/JHR.73.39136

Loy, X., Brosi, B.J., 2022. The effects of pollinator diversity on pollination function. *Ecology*. 103, e3631. https://doi.org/10.1002/ecy.3631

Magurran, A.E., 1988. *Ecological Diversity and Its Measurement*, first ed. Princeton University Press, New Jersey. https://doi.org/DOI 10.1007/978-94-015-7358-0

Makgoba, M.C., Tshikhudo, P.P., Nnzeru, L.R., Makhado, R.A., 2021. Impact of fall armyworm (*Spodoptera frugiperda* J.E. Smith) on small-scale maize farmers and its control strategies in the Limpopo province, South Africa. *Jamba: Journal of Disaster Risk Studies.* 13, 1–9. https://doi.org/10.4102/JAMBA.V13I1.1016

Nonci, N., Kalqutny, S.H., Mirsam, H., Muis, A., Azrai, M., Aqil, M., 2019. *Pengenalan Fall Armyworm (Spodoptera frugiperda J.E. Smith)*. Balai Penelitian Tanaman Serealia, Maros.

Pickett, J.A., Woodcock, C.M., Midega, C.A.O., Khan, Z.R., 2014. Push-pull farming systems. *Curr Opin Biotechnol*. 26, 125-132. https://doi.org/10.1016/j.copbio.2013.12.006

Retallack, M., Thomson, L., Keller, M., 2019. Native insectary plants support populations of predatory arthropods for Australian vineyards. *BIO Web Conf.* 15, 01004. https://doi.org/10.1051/bioconf/20191501004

Roy, K., Chandra, B., Viswavidyalaya, K., 2020. The Push Pull Strategy: An Eco-friendly Approach for Management of Fall Armyworm (*Spodoptera frugiperda*), Department of Agricultural Entomology. West Bengal, India. https://doi.org/10.13140/RG.2.2.19965.18403

Shrestha, B., Finke, D.L., Piñero, J.C., 2019. The 'botanical triad': The presence of insectary plants enhances natural enemy abundance on trap crop plants in an organic cabbage agroecosystem. *Insects.* 10, 181. https://doi.org/10.3390/insects10060181

Smart, L.E., Blight, M.M., Pickett, J.A., Pye, B.J., 1994. Development of field strategies incorporating semiochemicals for the control of the pea and bean weevil, *Sitona lineatus* L. *Crop Protection.* 13, 127-135. https://doi.org/https://doi.org/10.1016/0261-2194(94)90163-5

Smith, H.A., Capinera, J.L., Martini, X., 2021. *Natural Enemies and Biological Control*. University of Florida, Gainesville. https://doi.org/10.32473/edis- in1201-2018

Yurchak, V., Leslie, A.W., McCluen, S.R., Hooks, C.R.R., 2023. Evaluating French marigold as a border insectary plant for the enhancement of beneficial arthropods in sweet corn plantings. *Ecol Eng.* 190, 106928. https://doi.org/10.1016/J.ECOLENG.2023.106928

Zhang, Z., Sun, X., Luo, Z., Gao, Y., Chen, Z.,2013. The manipulation mechanism of "push–pull" habitat management strategy and advances in its application. *Acta Ecologica Sinica.* 33, 94–101. https://doi.org/10.1016/j.chnaes.2013.01.005