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Role of crop diversification on occurrence of sap-sucking insect pests and their associated natural enemies on tomato

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Tomato production is constrained by arthropod pests and diseases. Among the arthropod pests, sap-sucking insect pests such as whiteflies (*Bemisia tabaci* (Gennadius 1889)), aphids (*Aphis* spp.) and *Thrips* sp. are the insect pests of economic importance in the study area. The overall result indicated that intercropping significantly reduced the population of these insect pests compared to sole tomato. The most effective population reduction was recorded on tomato - onion (63.13, 56.46 and 25% in aphids, whiteflies and thrips, respectively) next to karate (83.51, 73.74 and 66.04%) and tobacco leaf extract (77.31, 71.51 and 69.34 in aphids, whiteflies and thrips, respectively). The companion crops harbored the predators and parasitoids of diverse species predominantly. Tomato onion intercropping led the best performances in guarding tomato crop from major insect pests compared to other companion crops. Therefore, tomato onion intercrops may be used as the first options in boosting tomato production as an alternative to karate and tobacco leaf extract in sap-sucking insect pests' management. Further study on the detailed morphological and molecular-based parasitoid species identification and their ecological host ranges are of utmost importance in the sustainable integrated pest management (IPM) strategies in tomatoes.

Key words: Companion crops, pest reduction, beneficial insects, repellence.

INTRODUCTION

One of the most extensively cultivated vegetable crops in Ethiopia is tomato (*Lycopersicon esculentum* Mill.), which is grown on small and big farms, privately owned or operated by enterprises, under both rain-fed and irrigated agriculture systems (Emana et al., 2014; Ireri et al., 2018). Tomato accounted for 2.51% of the total production area of vegetable crops in 2017/18, covering 5,235.19 ha (CSA, 2018). Although tomato production has economic advantages, it faces numerous challenges due to a variety of factors, including temperature,

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humidity, diseases and insect pests (Rwomushana et al., 2020; Tadele, 2016; Wang et al., 2021). These issues lead to decreased crop quantity and quality in a number of nations, including Ethiopia (Dube et al., 2020; Yankova, 2012). Among the insect pests, sucking insect pests are the major ones in tomato causing significant yield loss ranging from 20 to 100% (Papisarta and Garzia, 2002; Ram and Parihar, 2002; Jones, 2003). Whitefly, *Bemisia tabaci*, aphid, *Aphis* sp. and thrips, *Thrips* sp. (Dube et al., 2020; Tadele, 2020) are those causing the main challenges in the production potentials of tomatoes in Ethiopia.

Tomatoes were shown to have high levels of whiteflies, aphids and cotton thrips (*Frankliniella schultzei* (Gashawbeza and Abiy, 2013; Tadele, 2020). Each year, the combined effects of the whitefly attack whether direct or indirect causes substantial yield losses in tomatoes of up to 100%, amounting to over one hundred million dollars (Moodley et al., 2019). More plant stunting (8-15%) and a 60-83% decrease in yields were produced by early infestation (2-3 weeks after transplanting) (Bambhaniya et al., 2018). Throughout the year, sucking pests are polyphagous by nature. These insects can directly harm plants by excreting honeydew that builds up on various plant sections and by continuously sucking sap, which causes physiological abnormalities in plants. Furthermore, the production of tomatoes and the availability of alternate hosts promote the year-round increase of pest pressure. The sucking pests, such as aphids, whiteflies and thrips, in addition to directly feeding on crops, can spread viruses that injure crops severely (Azouz, 2016; Tadele, 2020).

Farmers rely entirely on pesticides which have been used in agriculture to secure food production and have demonstrated their potential to increase global food production, to combat the issues caused by these insect pests, despite the fact that they are known to pose risks to the environment and human health (Thomine et al., 2022). In addition to the development of pest resistance and the poisoning of beneficial insects, the indiscriminate use of chemical pesticides has been linked to established dangers to human health and the environment (Matthews, 2008; Thomine et al., 2022).

Additionally, the high costs of insecticides combined with their increasing application leads to a rise in cultivation costs, further rendering the crop unprofitable (Bambhaniya et al., 2018). This has created a demand for an intercropping method of pest control. Plant diversity in the same plot makes it harder for pests to find their hosts and encourages the presence of the pests' natural enemies (Parker et al., 2013). The plant volatiles, which disrupt the location of the pest host plant and react chemically and physiologically to render the host plant inhospitable to pests, are thought to be responsible for the ability of intercropping suitable plants to attract or repel insects from the target plants (Moreno and Racelis, 2015). Moreover, host-hiding and fostering natural enemies suppress pest population growth, decreasing the requirement for pesticide use and boosting crop yields (Parker et al., 2013). According to Moono et al., (2019), intercropping garlic rape reduced aphid populations on rape the most and increased rape production. The prevalence of whitefly-transmitted viruses and the quantity of whiteflies in tomato fields were effectively decreased by intercropping tomatoes with coriander (*Coriandrum sativum* L.) (Apiaceae) (Hilje and Stansly, 2008). Comparing tomato single cropping to tomato garlic intercropping, Azouz (2016) found that the latter greatly increased the population of thrips. Moreover, it is possible that the volatiles in aromatic plants deterred insect pests, causing their numbers to decline relative to the mono crop (Islam et al., 2011; Sujayanand et al., 2015; Moono et al., 2019).

Despite the fact that intercropping significantly reduced the number of tomato sucking insect pests, the research area's farmers were overshadowed by the use of pesticides, which are deadly to humans, animals, and the environment. Regarding managing insect pests, farmers are unaware of the practice of intercropping tomatoes with other crops. Hence, the objective of this research was to evaluate the effect of intercropping on occurrences of sap-sucking insect pests of tomato and their associated natural enemies on tomato.

MATERIALS AND METHODS

The experiment was conducted at Haramaya University, Ethiopia at Rare Research Station using irrigation (located at 42°3'E and 9°26'N and 2006 m.a.s.l) in 2021. It is situated in the semi-arid tropical belt of East Oromiya, Ethiopia and is characterized by a sub-humid type of climate. Improved tomato variety*, Geli-lema,* was used as the main crop intercropped with onion (*Nafis red* variety), beans (*Babile-1* variety), and cabbage (*Copenhagen market* variety) which was collected from Melkassa Agricultural Research Center (EIAR), Ethiopia and tobacco crude leaf extract (adjusted with the rate of 1 kg leaves per one litre of water for the stock solution) as well as lambda cyhalothrin (karate 5% EC) were used as checks. The experiment was laid out in Randomized Complete Block Design (RCBD) with four replications with the following list of treatments and their combination: Sole tomato (control), tomato + cabbage, tomato + common bean, tomato + onion, tomato + tobacco leaf extract (as botanical check) and tomato + karate 5% EC (as chemical check). A plot consisted of six rows of 3.6 m length and 2.4 m width and plot area (8.64 m^2) with the distance between blocks and plots 1.5 and 1 m, respectively. The spacing between rows and plants of tomato was 60 cm × 40 cm, respectively.

Field management

The companions, beans, cabbage and onions were planted between the rows of tomatoes as extra plant population (s). Seedlings of onion, cabbage and tomato were raised in the nursery at Rare Research Station. Tomato seeds were sown at the rate of 200 $gmha^{-1}$ (EIAR, 2007) on seedbeds of 1 × 5 m area. Seedlings were transplanted to the main experimental field when they attained 3 to 4 true leaves (40 days after sowing) by carefully uprooting them from nursery beds. Then the seedlings were transplanted to well prepared and irrigated experimental field. Beans were directly sown on the rows allotted to it in the main field.

Observation of insect pests and their natural enemies

Whitefly

Data collection was conducted from the middle four rows of tomato for the representative samples of each plot. Data on whiteflies were collected in the abaxial side of the leaflets, as the number of whitefly nymph and adults at each observation period starting from two weeks of transplanting, by slowly turning the leaflet upside down to prevent the escape of the insects. To proceed with the counting of nymphs, six plants were tagged and whiteflies were collected per plot from the leaves of the plants (Arnemann et al., 2019). The observations were made weekly and carried out during the early morning (between 6:00 am and 8:00 am) when whiteflies were particularly less active and easier to spot and count (Ofori et al., 2014).

Aphids

The population number of aphids was counted weekly after transplanting until physiological maturity. The same procedures were followed for aphid's inspection like whiteflies and thrips.

Thrips

The number of thrips per plant was recorded weekly after transplanting until physiological maturity. On each selected plant, three leaves each from the upper, middle and bottom portions were inspected from the lower side for the presence of thrips. Nymphs, as well as adults, were recorded by using the hand lenses of 10 times magnifications. Counting was done early in the morning (Gebretsadkan et al., 2019; Tadele, 2020).

Natural enemies

Natural enemies especially predators were visually observed in the experimental plots and for clear identification, the samples were brought to laboratory to see under the microscope whereas parasitoids on *Aphids* sp, were recorded on the insect (aphid) specimen/infested leave samples were taken from tomato plantations for laboratory rearing until the parasitoids or the adult of the specimens have emerged. In the lab, infested leaves were placed inside a rearing cage covered with a muslin cloth to allow ventilation and left up to the emergence of parasitoid adults (Mahmoud et al., 2020). Emerged parasitoids were preserved in 70% ethyl alcohol for identification. Taxonomic identification of the parasitoids was conducted using identification keys of the morphological characters by senior entomologists at genus level and referring to published articles, searching and matching with online insect specimen databases and also consulting various insect bloggers of public groups (for instance; Entomology Group, Insects (Entomology) worldwide and many other public groups) by posting a clear picture of the insect specimens we need for identification. For each parasitoid emerged, the parasitism rate was determined according to Russell (1987) as follows:

$$\text{Parasitism rate (\%)} = \frac{\text{Parasitoids emerged}}{\text{Host insect emerged + Parasitoids emerged}} x100$$

The percentage of reduction of insect pests was calculated according to Henderson and Tilton (1955) as follows:

$$\%\text{PR} = \frac{\text{C}-\text{T}}{\text{C}} X\ 100$$

Where c, control; t, treatment; and %PR, percent population reduction. Infestation levels or damages were recorded based on the work of Mackenzie et al. (1993) using a scale of 1 to 5 where, 0-1 = ≤10% no damage; 2 = ≤25% slight damage; 3 = (25-50% moderate); 4 = 50-75% severe); 5 = >75% very severe damage.

Statistical analysis

Data collected was performed as per the methods described by Gomez and Gomez (1984) using SAS computer software version 9.4. (SAS, 2013). Differences among treatment means were compared using Tukey's Studentized range test at 0.05 probability level.

RESULTS

Occurrences of insect pests

Whitefly

In this experiment three major sap-sucking insect pests were observed in the tomato plantations (Table 1). The population number of whiteflies and infestation ($F_{a,\ b}$ = 33.7, 3.3; *df* =15; $p < 0.001$, $F_{a,\ b}$ = 45.25, 3.3; *df* = 15; $p < 0.001$) were significantly affected by the applied treatments, indicating that the population of whiteflies were highly reduced on the intercropped treatments.

The result revealed that the lowest population of whiteflies from intercrops was recorded in tomato intercropped with onion (5.09), which resulted in lower percentage infestations (Table 2). Higher (2.95) infestations of whiteflies were recorded in the sole tomato plantations, indicating that intercropping of tomato with onion resulted in lower infestations of whiteflies in the current study.

Aphids

The number of aphid *spp.* and infestation ($F_{a,b}$ = 207.9, 3.3; *df* =15; $p < 0.001$, $F_{a,b}$ = 28.98, 3.31; *df* = 15; p < 0.001) were significantly affected by the applied treatments, indicating that the population of aphids were highly reduced on the intercropped treatments. Accordingly, the result on the population densities of *aphid spp*. revealed minimum populations and infestation were recorded from tomato intercropped with onion (28.67, 0.75) (Table 2) among intercrops.

Table 1. Seasonal incidence of whiteflies in the sole and intercropped tomato during 2021.

Treatment	Whiteflies		
	NWPP	Infestation (%)	PROC (%)
Sole tomato	11.69[a] ± 1.00	2.95[a] ± 0.10	-
Cabbage + tomato	10.48[a] ± 0.46	2.19[b] ± 0.07	10.35
Common bean + tomato	7.97[b] ± 0.99	1.90[c] ± 0.16	31.82
Onion + tomato	5.09[c] ± 0.31	1.30[d] ± 0.04	56.46
Tobacco + tomato	3.33[d] ± 0.54	1.20[d] ± 0.03	71.51
Karate + tomato	3.07[d] ± 0.65	1.13[d] ± 0.07	73.74
P-value	< 0.001	< 0.001	
LSD	1.56	0.25	
CV	14.96	9.49	

Value with the same letters assigned in the column is not significantly different at 0.05 level of significance. NWPP, Number of Whiteflies per plant; PROC (%), Population reduction over control.

Table 2. Seasonal incidence of *Aphids spp*. in the sole and intercropped tomato during 2021.

Treatment	*Aphids* spp.		
	NAPP	Infestn (%)	PROC (%)
Sole tomato	77.76[a] ± 2.65	1.95[a] ± 0.30	-
Cabbage + tomato	72.74[b] ± 2.03	1.82[a] ± 0.09	6.46
Common bean + tomato	58.01[c] ± 2.08	1.22[b] ± 0.07	25.40
Onion + tomato	28.67[d] ± 0.86	0.75[c] ± 0.54	63.13
Tobacco + tomato	17.64[e] ± 0.93	0.68[c] ± 0.57	77.31
Karate + tomato	12.82[f] ± 0.62	0.68[c] ± 0.56	83.51
P-value	< 0.001	< 0.001	
LSD	4.72	0.26	
CV	7.03	14.51	

Mean value with the same letters is not significantly different at 0.05 level of significance. NAPP, Number of Aphids per plant; Infestn (%), Infestation in percent; PROC (%), Population reduction over control.

Thrips

The number of *Thrips* spp. and infestation ($F_{a,b}$ = 47.46, 3.31; df = 15; p < 0.001; $F_{a,b}$ = 80.42, 3.31; df = 15; p < 0.001) were significantly affected by the applied treatments, indicating that the population of thrips were highly reduced on the intercropped treatments. Moreover, lower *Thrips* spp. populations (1.59) and infestations (1.09) were recorded from onion intercropping, which resulted in higher *Thrips spp.* reduction in comparison to control plots (Table 3).

Abundance of natural enemies

Intercropping is one of the mechanisms of sustaining natural enemies due to diversity and harboring various insects devastating the insects of economic importance. Predators and parasitoids are the main beneficial insects of an agricultural system.

Results of the study indicated that the treatments were highly significant in harboring various natural enemies except the synthetic insecticides, karate 5% EC. The result revealed that lady beetles or coccinelids (Coleoptera: Coccinellidae) are the most abundant beneficial insects associated with tomato insect pests recorded on common bean intercropping (1.25) whereas lowest population was recorded on karate 5%EC (Table 4). Lace wings, *Chrysoperla zastrowi* (Esben-Petersen) (Neuroptera: Chrysopidae) were another predators that were significantly harbored in the tomato fields. From the table results, the most population was abundantly found on the head cabbage (1.15) and common bean intercropping (1.00) but no population was found in the chemically treated plots. Spiders (Araneae: Araneidae) were significantly found in the study field more

Table 3. Seasonal incidence of thrips in the sole and intercropped tomato during 2021.

Treatment	Thrips sp.		
	NTPP	**Infestn (%)**	**PROC (%)**
Sole Tomato	$2.12^{a} \pm 0.05$	$2.04^{a} \pm 0.06$	-
Cabbage + tomato	$1.81^{bc} \pm 0.04$	$1.39^{b} \pm 0.04$	14.62
Common bean + tomato	$1.99^{ab} \pm 0.05$	$1.46^{b} \pm 0.03$	6.13
Onion + tomato	$1.59^{c} \pm 0.04$	$1.09^{c} \pm 0.04$	25.00
Tobacco + tomato	$0.65^{d} \pm 0.04$	$0.68^{d} \pm 0.07$	69.34
Karate + tomato	$0.72^{d} \pm 0.04$	$0.68^{d} \pm 0.05$	66.04
P-value	< 0.0001	< 0.001	
LSD	0.22	0.14	
CV	10.04	7.55	

Mean value with the same letters is not significantly different at 0.05 level of significance. NTPP, Number of Thrips per plant; PROC (%), Population reduction over control**;** Infestn (%), Infestation in percent.

Table 4. Population abundance of predators in tomato during January to May in 2021.

Treatment	Lady beetles	Lace wings	Spiders	Pray mantis	Hover flies	Mirid predators	Pirate bugs
Sole tomato	0.98^{bc}	0.45^{bc}	0.71^{a}	0.75^{b}	0.88^{b}	0.4^{bc}	0.48^{a}
Cabbage + tomato	1.15^{ab}	1.15^{a}	0.82^{a}	0.79^{b}	1.10^{a}	0.70^{a}	0.43^{a}
Bean + tomato	1.25^{a}	1.00^{a}	0.93^{a}	1.08^{a}	0.98^{ab}	0.60^{ab}	0.43^{a}
Onion+ tomato	0.96^{bc}	0.65^{b}	0.71^{a}	0.96^{a}	0.94^{ab}	0.73^{a}	0.29^{b}
Tobacco+ tomato	0.90^{c}	0.30^{c}	0.79^{a}	0.79^{b}	0.85^{b}	0.33^{cd}	0.20^{b}
Karate + tomato	0.19^{d}	0.00^{d}	0.12^{b}	0.17^{c}	0.58^{c}	0.13^{d}	0.00^{c}
LSD	0.24	0.26	0.22	0.16	0.21	0.24	0.12
CV	17.37	29.54	21.78	14.44	15.75	32.68	23.75

Mean value with the same letters is not significantly different at 0.05 level of significance.

abundantly mainly in the intercrops whereas the lowest population was seen in karate 5% EC. The praying mantis (Dictyoptera: Mantidae) was highest in the common bean intercropping (1.08) which is statistically similar to onion intercropping (0.96). The least number of populations was obtained on karate 5%EC (0.17). Hover fly (Diptera: Syrphidae) was the most abundant on tomato cabbage intercropping (1.10) but the lowest population (0.58) was recorded in karate. Predators, namely *Nesidiocoris tenuis* (Reuter), were also carefully observed in the tomato field. The highest population was obtained in the onion intercrop (0.73), which is similar to the cabbage intercrop (0.70), while the least population was in karate (0.13). Pirate bugs or *Orius* spp. (Hemiptera: Anthocoridae) populations were significantly different in tomato fields with different treatments, with a relatively higher population recorded in sole tomatoes (0.48) similar to common bean (0.43) and cabbage (0.43) intercrops, while no on karate (0.00).

Aphelinus spp. (Hymenoptera: Aphelinidae) and *Aphididius* spp. (Hymenoptera: Braconidae) arthropod parasitoids were obtained from the aphid sample collected from the cabbage intercrops, common bean intercrops and sole crops after being tested in the laboratory (Table 5).

DISCUSSION

The number of insect pests and their infection of host crops are positively impacted by crop variety. This study shows that whereas sap-sucking insect pests decimated monocropped plants, they had no effect at on intercropped plants. Lower densities of *Bemitsia tabaci* populations were also reported on tomatoes grown in intercrops with garlic (*Allium sativum* L.), onions (*Allium cepa* L.), and common beans (*Phaseolus vulgaris* L.) (Li et al., 2021; Verma et al., 2011). This indicates that the quantity of whiteflies on tomato plants was greatly impacted by the presence of companion plants, such as onions and common beans. In the open-field experiment, tomatoes interplanted with basil and coriander decreased

Table 5. The occurrences of parasitoids and their parasitism rate on tomato collected in 2021.

Treatments	Host insect	Order: Family: Parasitoids	Parasitism rate (%)
Tomato sole	Aphids	Hymenoptera: Aphelinidae: *Aphelinus* sp.	0.67
Tomato + cabbage	Aphids	Hymenoptera: Aphelinidae: *Aphelinus* sp.	1.33
		Hymenoptera: Braconidae: *Aphidius* sp.	1.33
Tomato + bean	Aphids	Hymenoptera: Aphelinidae: *Aphelinus* sp.	0.67
		Hymenoptera: Braconidae: *Aphidius* sp	0.67
Tomato + onion	-	-	-
Tomato + tobacco	-	-	-
Tomato + karate	-	-	-

the whitefly population by 37.7% mean reduction (Carvalho et al., 2017). Coriander intercropping decreased the number of whitefly nymphs in irrigation systems in a similar pattern (Togni et al., 2018). According to Islam et al. (2011), aromatic plants, such as onions, produce large amounts of volatile secondary metabolites that are intended to disguise or repel scents in order to disrupt insect pests' host selection. This could explain why whiteflies have a negative effect on onion intercrops. *Aphid spp.* infestations and population densities in tomato plantations were probably reduced by intercropping tomatoes with onions. In line with these findings, Moono et al. (2019) found that intercropping tomatoes and onions had a substantial impact on aphid populations, with fewer numbers observed in the intercropping than in monoculture tomato farms. According to Afifi et al. (1990), nymph populations of *M. persicae* (Sulzer) reduced by 86 to 87% when grown on tomato alone as opposed to when cultivated with either onion or garlic. The same is true with Abigail and Danny (2019) who reported the population reduction of aphids in tomato garlic intercropping. Monika et al. (2005) reported a similar outcome, indicating that intercropping mustard with coriander (*Coriandrum sativum*) led to a reduced aphid population when compared to control plots. The best control strategy was to intercrop tomatoes and onions. According to Azouz (2016), tomato garlic intercropping considerably decreased the population of thrips as compared to tomato single cropping, which is consistent with these findings. Since tomato and onion intercropping decreased the population of onion thrips compared to onion sole crops, onions can also be employed as trap crops for onion thrips in other situations (Habib et al., 2019). According to Mohamed et al. (2021), when garlic and peas were interplanted, there was a reduction in the amount of pods infected with the pulse pod borer moth, *Etiella zinckenella* (Treitschke, 1832) as compared to when peas were planted alone.

The companion crops more effectively harbored the natural enemies in the open field. The results are consistent with those of Sujayanand et al. (2015), who observed that maize interplanted with eggplants harbored a significant population of coccinellids and syrphids, which may have contributed to a decrease in leafhopper nymphs on eggplants as well as the harboring of lace wings (*Chrysoperla zastrowi*). The intercropping of cabbage onions was shown to have the highest density of ladybird beetles by Fening et al. (2013), while the populations of hoverflies (*Paragus borbonicus*) and spiders (Araneae) did not change substantially from solitary cabbage. According to Rahman et al. (2018), arthropod predators were classified into five taxonomic orders based on how frequently they were found in intercropping tomato, onion, garlic, lettuce, and brinjal. Of these orders, Acari had the highest abundance (31.4%), followed by Hymenoptera (24.6%), Coleoptera (17.4%), Diptera (15.0%), and Neuropteran (11.5%). The findings from Mochiah et al. (2011)'s study on the relationship between cabbage and tomatoes showed that the number of ladybird beetles, spiders and black ants was higher on the solo crop of cabbage, which was in contrast to the data showing a much higher number of predators on the intercropped plots compared to the sole tomato. Son et al. (2018) reported that in tomato plots with aromatic plants, the auxiliaries' families (predators and parasitoids) were more prevalent than in tomato plots without relationship. Moreover, Parthiban et al. (2018) revealed that when groundnuts and onions were interplanted, more lace wings and coccinellids were discovered to be harbored in the intercrops than in the solo crops. Several helpful insects were discovered on the companion crops in addition to the previously stated predators of tomato insect pests. Aeolothrips Spp., a predatory thrip, was identified in tomato fields and was widely distributed on onion intercrops. According to Fok et al. (2014), plant-feeding thrips can be effectively controlled by using natural enemies such mites, minute pirate bugs, predatory thrips, and specific parasitic wasps. Additionally, according to Gebretsadkan et al. (2019), there were considerably more predatory thrips (*Aeolothrips* spp.) in onion intercropped with cabbage and carrot than in plots treated with karate. In addition, Nesidiocoris tenuis was

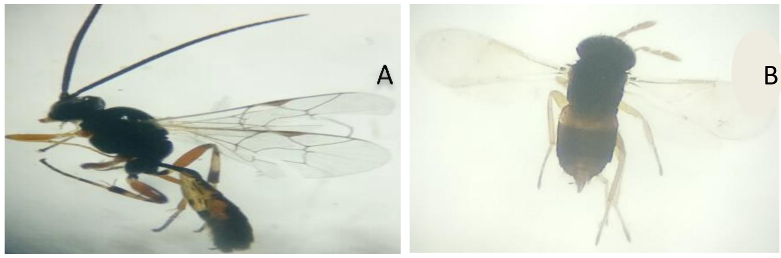

Figure 1. Parasitoids of aphids (A-*Aphidius* sp; B- *Aphelinus* sp.) recorded from tomato experimental farm, Haramaya University, Rare Research Farm, in 2021 and identified in the Haramaya University Protection laboratory by Senior Entomologists.

observed in abundance feeding on soft-bodied insects like whitefly, jassid, and aphids in the tomato fields (Haldhar et al., 2021).

More arthropod parasitoids were significantly recorded in tomato intercropping with other crops. The result provoked the positive impact of crop diversification in beneficial insect's ecology. This finding was similar to Perdikis et al. (2008) who reported natural enemies commonly used in greenhouse tomato crops to include the parasitoids, *Aphidius* spp. and *Aphelinus* spp. on aphids. Junhe et al. (2017) reported that the abundance levels of natural enemies and the control rates of parasitoids were maximum in the intercropping and minimum in monoculture in wheat maize intercropping. Canola (*Brassica napus* L) as an intercrop with common bean used as aphidid parasitoid promotion which was stated by Sarwar (2012). The maximum parasitism rate was recorded in head cabbage intercrops on the host aphids, respectively. The parasitoids were identified as *Aphidiius* spp. and *Aphelinus* sp. (Figure 1) up on the taxonomic identification keys. In the other studies, Fening et al. (2013) stated intercropping promoted the natural enemy abundance.

Furthermore, compared to farmers' fields (monoculture), Son et al. (2018) found that the tomato-onion combination had the fewest tomato insect pests. Companion plant volatiles, which disrupt the host plant's location and react chemically and physiologically to render it unsuitable for the insect, are thought to be the cause of the attraction or draw of insects away from the target plant when compatible plants are interplanted (Moreno and Racelis, 2015). Certain compounds produced by onions resist a variety of insect pests, including sucking insect pests (Islam et al., 2011). In general, intercropping prevents the growth of insect pests and promotes the spread of natural enemies by offering additional food and shelter. Furthermore, it is possible that the volatiles in aromatic plants deterred insect pests, lowering their populations (Sujayanand et al., 2015). Alternative hosts for sap-sucking insects include head cabbages and common beans. However, a population decline in the primary crop was noted in this study; possible causes include the presence of physically prohibitive barriers to movement, confounding masking chemical stimuli, and companion plants that serve as natural enemies' havens (Zhou et al., 2013).

Conclusion

While intercropping increased the occurrence of some natural enemies, it had a negative effect on sap-sucking insect pests. Even though the number of insect pests was decreased by the intercrops, tomato onion intercropping, after synthetic chemicals and botanical extract, had the greatest impact on the population decline of tomato insect pests when compared to other intercropping. The intercropping treatments with relatively high parasitism rates have largely natural enemies, a few predators, and parasitoids; this illustrates the harboring impact of diverse crops as opposed to monocropping. Consequently, intercropping tomatoes and onions is a valuable alternative management strategy for reducing insect pests of tomato crops and establishing sustainable habitats for beneficial organisms.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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