American Journal of Agricultural and Biological Sciences

Original Research Paper

Ecofriendly Management of Two Spotted Spider Mites on Tomato (*Solanum lycopersicum* (Mill.) in Eastern Ethiopia

[1,2]Belachew Dabalo

[1]*Bore Agricultural Research Center, Oromia Agricultural Research Institute, Addis Abeba, Ethiopia*
[2]*School of Plant Science, College of Agriculture and Environmental Science, Haramaya University, Ethiopia*

Article history
Received: 19-04-2024
Revised: 13-06-2024
Accepted: 18-07-2024

Email: dabalobelachew@gmail.com

Abstract: One of the most widely grown vegetable crops in Ethiopia is the tomato (*Solanum lycopersicon*). Two Spotted Spider Mites (TSSM) are the primary pests that pose a threat to tomato production in Eastern Ethiopia. Synthetic pesticides remain the primary method of controlling TSSM, but because of the pest's high fecundity, inbreeding, arrhenotokous reproduction, high mutation rate, and short life cycle, TSSM develops extensive and intense resistance to nearly all classes of pesticides. To address these issues, the study was started with the aim of assessing the effectiveness of tobacco leaf extract and the feasibility of intercropping on TSSM in Eastern Ethiopia. The experiment was set out in a randomized complete block design with four replications at the Hara Maya University Rare research location. The trial's treatments included tomatoes, tomatoes + cabbage, tomatoes + common beans, tomatoes + onions, tomatoes + tobacco leaf extract, and tomatoes + karate 5% EC. When compared to solitary tomatoes, the overall result showed that intercropping and tobacco leaf extract considerably reduced the population of these mite pests. The karate intercropping population had the lowest population with infestation (14.65, 0.79), followed by the tomato-tobacco leaf extract (16.50, 0.92) and the tomato onion (36.53, 1.74). The control group had the highest population with maximal infestation (94.10, and 2.88, respectively). When compared to an untreated plot, tobacco leaf extract showed the greatest population reduction with infestation, followed by tomato-onion intercropping. The tomato-onion intercrops produced the maximum yield (50.73tha-1), which was followed by the tobacco extract (43.65tha-1) and karate 5% EC (43.96tha-1). The head cabbage intercrops produced the lowest yield (30.10tha-1). Tomato-onion intercrops yielded the highest net benefit (688653.45 ETB), while common bean intercrops (354176.60 ETB) showed the lowest net benefit. Consequently, as an alternative to using karate 5% EC and as anticipated as a common integrated management of TSSM on tomato, tomato onion intercrops, and tobacco leaf extract may be regarded as the primary choices in increasing tomato output.

Keywords: Botanical Extract, Intercropping, Population Reduction, Infestation, Yield

Introduction

One of the most extensively planted vegetable crops in Ethiopia is the tomato (*Solanum lycopersicum* Mill.), which is grown on both small and big farms at the private or commercial levels using both rainfed and irrigated systems (Gemechis *et al*., 2012; Emana *et al*., 2014). In Ethiopia, smallholder farmers cultivate it extensively as a high-value horticultural crop for processing and domestic use (Hunde, 2017; Kanna, 2016).

Even if there are financial benefits, growing tomatoes in the tropics in an open-field setting presents a number of challenges because of many elements like temperature, humidity, diseases, and insect pests (Rwomushana *et al*., 2023; Tadele and Emana 2017; Wang *et al*., 2021). In some places, these issues also lead to lower yields and quality (Dube *et al*., 2020; Murúa *et al*., 2014). The primary causes of problems with tomato production in Ethiopia are arthropod pests, specifically the tomato leaf miner (Tuta absoluta), tomato fruit worm (Helicoverpa armigera),

whitefly (Bemisia tabaci), leafhopper (Amrasca sp), aphid, serpentine leaf miner, thrips and mites (*Tetranichus urticae*) (Ayele *et al*., 2020; Dube *et al*., 2020; Tadele and Emana 2017). Ethiopia has reported having a high mite infestation of tomatoes (Yigezu *et al*., 2022). *Tetranychus urticae* (Trombidiformes: Tetranychidae), commonly referred to as the two-spotted spider mite, is a significant worldwide agricultural crop pest (Migeon *et al*., 2010; Boubou *et al*., 2012) state that the spider mite is regarded as an aggressive invasive species globally. The world is becoming more vulnerable to invasive red spider mites due to rising temperatures and greater aridity (Navajas *et al*., 2010).

The crop most severely impacted by mite infestation is the tomato, but many other crops are also significantly impacted, including sweet corn, pepper, eggplant, tomato, and cucurbits (Meck *et al*., 2009). Synthetic pesticides remain the cornerstone for controlling *T. urticae*. Several studies have shown that red tomato mites can be successfully eliminated with chemical and natural pesticides (Muzemu *et al*., 2011). However, because of its short life cycle, high fecundity, inbreeding, arrhenotokous reproduction, and high mutation rate, *T. urticae* develops an exceptional resistance to practically all pesticides. Furthermore, synthetic pesticides have the potential to damage the environment, public health, and animals, which are not their intended targets. The development of alternative pest management techniques is currently receiving a great deal more attention due to the unfavorable side effects of synthetic pesticides. Two non-chemical alternative management options are crop diversity and plant extracts.

Plant extracts and intercropping systems are two cultural solutions to pesticide concerns (Zhou *et al*., 2019; Mulugeta *et al*., 2020). According to Son *et al*. (2018), the tomato-onion (*Allium cepa*) combination provided the greatest fruit protection against arthropods and the greatest productivity benefits of tomatoes. Hussein (2019) discovered that intercropping tomatoes with coriander was the most successful treatment for reducing the population of two-spotted spider mites on tomatoes, yielding a 91.2% reduction in the pest population. Similar to this, using garlic as an intercrop reduced the number of Two-Spotted Spider Mites (TSSM) in strawberry fields by as much as 52% (Hata *et al*., 2016).

Additionally, when (Rocha *et al*., 2020) investigated the use of plant extracts to control leaf miners, they discovered that extracts from pepper and tobacco leaves were more successful in lowering the larval mortality of *Liriomyza* species by 70%. Tests on the acaricidal and sub-lethal effects of tobacco leaves were carried out by Akyazi *et al*. (2018), who found that applying tobacco greatly decreased *T. urticae* fertility and inhibited its eggs. The current approaches to managing pests provide special attention to alternative control methods that are user- and consumer-safe, reasonably priced, flexible, and efficient. This implies that intercropping schemes and plant extracts are sensible substitutes for insecticides in pest management. In Ethiopia, especially in western Hararghe, tobacco leaf extract was widely used to fight pest insects that feed on maize and tomatoes (Negeri *et al*., 2019). Farmers in Eastern Hararghe do not yet employ tobacco leaf extracts or knowledge of the assessment of tomato intercropping with other crops to battle arthropod pests on tomatoes. In order to obtain an additional yield by sowing in the interval between the main crops, they instead mainly concentrate on cereal-legume and less cereal-vegetable intercropping. This study was conducted in order to evaluate the effect of intercropping and the efficacy of tobacco leaf extract on the management of TSSM in Eastern Ethiopia.

Materials and Methods

Irrigation was used in the experiment, which was carried out in 2021 at the Haramaya University research site. The experiment's principal crop was the tomato (Geli-lema variety), which was transplanted at 40 days and interplanted with beans (Babile 1), cabbage (Copenhagen market type), onion (Nafis red variety), and a single tomato. With the exception of cabbage and beans, all of these crops were acquired from the Melkassa Agricultural Research Center (EIAR). Furthermore, a treatment of 5% EC karate and crude leaf extract from tobacco was sprayed at 320 mL/ha (Standard check). Generally speaking, the trial employed six treatments: Tomato sole, tomato + cabbage, tomato + common bean, tomato + onion, tomato + tobacco leaf extract, and tomato + karate. Freshly gathered leaf materials were mashed with a mortar and pestle to make tobacco leaf extracts. The resulting leaf juice was filtered through muslin cloth in accordance with (Magsi *et al*., 2017) work for the stock solution and it was then adjusted to have an extract that could be sprayed on tomato crops at a rate of 1 kg of leaves per one liter of water. After diluting the solution with one (1) Liter of water, it was sprayed onto the target plot. A Randomized Complete Block Design (RCBD) with four replications was used to set up the experiment.

Field Management

There were six rows in a plot with a 3.6 m length, 2.4 m breadth, and 8.64 m plot area. Plots and blocks were divided by 1.5-1 m, respectively. 40 cm made up the intraspace and 60 cm made up the interspace. The vegetables, onions, cabbage, and beans were sown in between the tomato rows as an extra plant population. Tomato seedlings were moved to the main experimental field 40 days after sowing when they had three to four true leaves. Beans were sown straight into the allotted rows in the main field. All recommended management techniques were applied. Using a Nap-sack sprayer, tobacco leaf extract and

Karate 5 % EC were applied eight times weekly and six times every ten days, respectively beginning on day twenty-one (21) after transplanting and ending with the first fruit harvesting (Tadele, 2016).

Data Collection

Six (6) Plants were chosen and tagged from the middle four rows of tomatoes in each plot prior to data collection. Every week, three leaves from each plant were evaluated to examine the abundance of insects. Following (Tadele, 2016) research, data were gathered on the number of insects per leaf, per plant, and the number of infested or damaged leaves weekly Eight (8) times. After two weeks of transplantation, population counts of two-spotted spider mites using hand lenses with ten times magnification started. Early in the morning, observations were taken on the abaxial surface of the chosen plant leaves (Hata *et al*., 2016). Levels of infestation or damages noted according to Mackenzie *et al*. (1993). The amount of damage or infestation level was determined by counting the number of areas that were yellowing, crumbling, and bronzing caused by mites. The areas were then scored on a scale of 1-5, with 0 representing no damage, 2 representing little damage, 3 representing (25-50%), 4 representing serious damage (50-75%) and 5 representing extremely severe damage (>75%). The percentage of decrease of insect pests was computed as follows in order to assess the effectiveness of the tested materials: % PR = (C-T)/C X 100 where c, control; t, treatment; and % PR, percent population reduction (Henderson and Tilton, 1955).

Data Analysis

All the collected data were analyzed using SAS software version 9.4 (SAS Institute, 2013), and Analysis of Variance (ANOVA) on the obtained parameters was carried out in accordance with the procedures outlined by Gomez and Gomez (1984). Tukey's Studentized range test was used to test treatment mean differences at a 5% significance level. The percent population reduction (% PR) was calculated as follows (Henderson and Tilton, 1955).

Results and Discussion

Seasonal Abundance of Two-Spotted Spider Mite, Tetranychus urticae

The result revealed that botanical extract and intercrops showed highly significant differences in the populations ($F_{a,b}$ = 91.22, 3.31; df = 15; p<0.0001) and infestation ($F_{a,b}$ = 73.06, 3.31; df = 15; p<0.0001) of TSSM. The tomato sole had the highest mite population and infestation (94.10 and 2.88, respectively) (Table 1) Fig (1), followed by the common bean (80.06 and 2.22, respectively). Following tobacco crude leaf extracts (16.5 and 0.92), the tomato treated with karate had the lowest population number and infestation (14.65 and 0.79). Intercropping tomatoes and onions dramatically decreased the number of mites and their infection (36.53 and 1.74). Additionally, as compared to the control, all treatments significantly decreased the mite population (Table 1). Effective population reduction by onion intercrops was also demonstrated and the largest decrease from tobacco leaf extracts was comparable to 5% karate. Fig. (2) illustrates that the intercrops of tomato common beans exhibited the least decline, at 14.92%. In line with this finding, (Mtambo and Hoeschle-Zeledom, 2000) found that applying soap, ash, and tobacco extract significantly reduced the amount of TSSM in tomatoes. (Akyazi *et al*., 2018) conducted tests on the acaricidal and sub-lethal effects of soft soap, garlic bulbs, and tobacco leaves. They discovered that applying tobacco at the tested dose significantly reduced *T. urticae* fecundity. The same author also found that *T. urticae* eggs might be suppressed by using extracts from tobacco leaves and garlic bulbs. Similar studies on the lethal effects of plant extracts on potato TSSM in a lab setting were carried out by Wakgari and Yigezu (2018). They discovered that Amitraz 20 EC and A. indica seed oil managed TSSM just as well. According to this finding, tobacco leaf extracts may be utilized as a substitute for Karate 5% EC, which continues to cause ecological issues for both people and other beneficial organisms. In this investigation, tobacco leaf extracts showed a good acaricidal effect in reducing the population and infestation of TSSM.

Table 1: Effect of Intercropping and tobacco leaf extract on population abundance and infestation of two-spotted spider mites

Treatments	Nomites/plant	Infestation
Control (Tomato sole)	94.10[a]	2.88[a]
Tomato + cabbage	77.27[b]	2.19[b]
Tomato + common bean	80.06[b]	2.22[b]
Tomato + onion	36.53[c]	1.74[c]
Tomato + tobacco extract	16.50[d]	0. 92[d]
Tomato + karate	14.65[d]	0.79[d]
LSD (0.05)	8.74	0.23
CV (%)	10.90	8.43

Means assigned with the same letter are not significantly different at a 5% level of significance

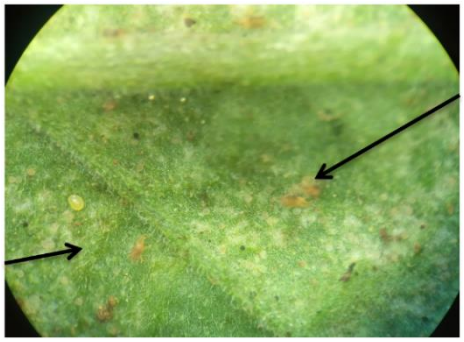

Fig. 1: Picture of Two-Spotted Spider Mites assessed during January to May in 2021

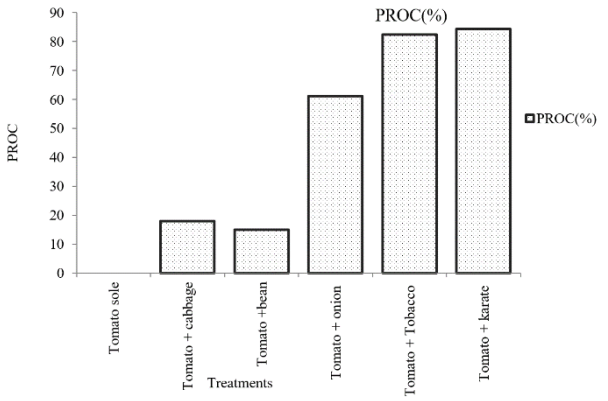

Fig. 2: Population reduction of TSSM assessed during January to May in 2021

where, PROC = Population reduction over control.

Because aromatic plants naturally contain volatile compounds and emit a strong scent, they can deter pests from eating their host when grown as an intercrop. This result was in line with the study of Abo-Shanab *et al*. (2019), who found that intercropping tomatoes with coriander was the most effective way to reduce the number of two-spotted spider mites on tomatoes. By using this technique, the pest's population was 91.2% lower. Similar to this, (Hata *et al*., 2016) discovered that garlic intercropping decreased the number of Two-Spotted Spider Mites (TSSM) in strawberry fields by as much as 52%. (Hata *et al*., 2019) examined the impact of aromatic plants on *T. urticae* on strawberry leaves in a lab and greenhouse environment. They discovered that the fragrant plants affected the biological characteristics of the mite. For instance, garlic reduced the number of eggs by 25.65%, while Chinese chives dropped the number of eggs by 34.79%. Moreover, (Mtambo and Hoeschle-Zeledom, 2000) found that intercropping onions with tomatoes reduced the TSSM infestation on tomatoes. According to Hata *et al*. (2016), aromatic plants in intercropping are often said to lower insect numbers and plant damage. The key finding of the study, in addition to a decrease in TSSM populations and infestations, was an increase in beneficial insects as a result of the aromatic crops' attraction effects (Karuppaiah *et al*., 2018).

Impact of Tobacco Extract and Intercropping on Tomato Yields

Among the treatments, there were significant differences in the marketable yield ($F_{a,b}$ = 38.07, 3.31, df = 15, p<0.0001), non-marketable yield ($F_{a,b}$ = 21.75, 3.31; df = 15; p = <0001) and overall yield ($F_{a,b}$ = 29.46, 3.31; df = 15; p = <0001) (Table 2). In contrast to solitary tomatoes (19.58tha-1 and 38.96tha-1), tobacco leaf extracts (marketable yield = 33.65tha-1 and total yield = 43.65tha-1) produced the highest marketable yield (39.37tha-1) and total yield (50.73tha-1) from the tomato-onion intercrops (Table 2). (Rahman *et al*., 2014) found that neem and tobacco leaf extract sprayed plots produced the maximum yield, which was in line with this conclusion. The current result is also consistent with the findings of Hussein *et al*. (2015), who found that adding eucalyptus oil and garlic extract to tomatoes enhanced their overall output when compared to the control. According to Muhammad *et al*. (2018), neem and turmeric extracts had a favorable effect on the yield and growth of okra crops. According to Hossain *et al*. (2013), the lower frequency of pest infestations can be ascribed to the increased gross yield produced by these extracts. In a similar vein, (Son *et al*., 2018) found that growing tomatoes with aromatic plants doubled their output compared to growing tomatoes alone. According to Zhou *et al*. (2013), one possible explanation for the increase in crop yield linked to aromatic crops is the release of chemicals that can either have an indirect effect, like encouraging natural enemies and creating resistance in the host plant, or a direct effect, like repellent, toxic, masking host plant odors and masking visual orientation. Because legumes fix nitrogen from the air, increasing soil fertility and reducing moisture stress on the plant's broad leaves or canopy, legume-tomato intercropping is a compatible cropping practice that, according to this study, also increased tomato yields when compared to sole cropping.

Alemayew *et al*., (2016) discovered maize legume intercropping was fruitful and increased yield by 18% compared to maize single crops. This finding is comparable to the current one. According to Gertrude *et al*. (2018), maize interplanted with all legumes yielded a larger yield advantage than solitary maize in the same tests. According to De Carvalho *et al*. (2012), who researched tomato peppermint and fennel intercropping, head cabbage rivalry for the greater area and its canopy as well as fighting for abiotic resources like sunlight, nutrients, and water may affect the output of tomatoes in head cabbage intercrops. In contrast to this outcome, (Asare-Bedi *et al*., 2010) reported that intercropping cabbage tomatoes was compatible in terms of yield and pest infestation reduction. Tomatoes can replace chlorpyrifos spray for the Diamondback Moth (Plutella xylostella), leading to better production results than 8cabbage mono-crop. Although there is no academic evidence to demonstrate the economic benefits of head cabbage for tomatoes, head cabbage productivity rose wherever tomatoes intercropped (Parra Almonacid, 2020). All intercrops did, however, provide an increase in land utilization, which raised the total yield attained per unit area. In addition to lowering TSSM populations, it's possible that aromatic plants boost growers' income and productivity without expanding their production area (Zito *et al*., 2019)

Table 2: Impact of intercropping and tobacco leaf extract on tomato yields in 2021 (January to May)

Treatments	MYtha^{-1}	NMYtha^{-1}	TYtha^{-1}	%Yield increase
control	19.58^{d}	19.38^{a}	38.96^{c}	
Tomato + cabbage	17.19^{d}	12.92^{c}	30.10^{d}	-12.21
Tomato + bean	25.52^{c}	17.19^{b}	42.71^{b}	30.34
Tomato + onion	39.37^{a}	11.35^{cd}	50.73^{a}	103.15
Tomato + Tobacco	33.65^{b}	10.00^{d}	43.65^{b}	71.86
Tomato + karate	33.85^{b}	10.01^{d}	43.96^{b}	72.88
LSD (0.05)	3.46	2.05	3.16	
CV (%)	8.14	10.09	5.02	

The means with the same letters assigned have no significance difference at a 5% level of significance.
NMYtha^{-1}= Nonmarketable yield in tone per hectare
MYtha^{-1}= Marketable yield in tone per hectare
TYtha^{-1} = Total yield in tone per hectare

Financial Advantages of Intercrops and Tobacco Leaf Extract

The economics of production were calculated for each treatment. The net gross is the total amount of money received from tomatoes and intercrops. The costs of labor and fertilizer used for each treatment made up the total cost of the study. Apart from the principal crop in tobacco extracts and karate, the cost of seed also differed between the treatments. The costs and earnings were computed using Bate and Haramaya town's local market pricing Table (3) presented the benefit-cost ratios, costs related to each treatment, and net gross generated from each treatment. Table (3) displays differences in net returns between the treatments. The most lucrative tomato plots were those that interplanted with onion crops, as shown by their highest net return and B: C ratios (12520.97 and 7.191, respectively). The second most profitable were tobacco extracts (7926.91 and 6.340) and tomato crops treated with 5% karate (7981.09 and 6.381). The least profitable crop to grow alone was tomatoes since it yielded the lowest net returns and B: C ratio (4290.4 and 4.088, respectively). As an example of the current result, consider the research by Son *et al*. (2018), which discovered that the tomato-onion association recorded the highest net advantages compared to solitary tomatoes, and the gained benefit was five times that of tomato without association. Sharma *et al*. (2018) reported that the benefit-cost ratio rose to 3.00 when coriander and okra were interplanted. When compared to sole crops and other spice intercrops, (Sarker *et al*., 2007) found that mustard interplanted with onion and garlic yielded the best cost-benefit ratios. In place of the 5 % EC in the research area, tobacco leaf extracts appeared to be a promising botanical extract for TSSM reduction in tomatoes. In order to increase tomato output and obtain high net benefits while producing tomatoes with fewer afflicted fruits, the first approach is to intercrop tomato and onion.

Table 3: Yield, economic benefits, and cost analysis of treatments in 2021 cropping Season.

Treatments	Yields (kg/ha)	NG ($)	TC ($)	NB ($)	B: C ratio
Sole	19580.00	5340.00	1049.60	4290.40	4.088
Cabbage	73486.29	12876.73	2016.80	10859.93	5.385
Cbean	27603.33	7717.57	1278.00	6439.57	5.039
Onion	47124.63	14262.10	1741.13	12520.97	7.191
Tobacco	33650.00	9177.27	1250.36	7926.91	6.340
Karate	33850.00	9231.82	1250.73	7981.09	6.381

NG ($), Net gross in American Dollar, B: C ratio, Benefit to cost ratio
TC ($), Total cost in American dollars, NB (ETB), Net benefits in American dollar
Sole, Tomato sole, Onion, Tomato + onion
Cabbage,Tomato + cabbage, Tobacco, Tomato + tobacco extract
Cbean, Tomato + common bean, Karate, Tomato + karate 5% EC

Conclusion

Tomatoes are the most commonly consumed healthy vegetable globally. In the research region, tomatoes are the horticultural crop that is most negatively impacted by arthropod pests. The primary sucking pests that eat tomatoes are red spider mites. This study discovered that tobacco leaf extract and tomato-onion intercropping decreased tomato infestation and the number of Two Spotted Spider Mites (TSSM). As a result, the yields of the tobacco leaf extract treatment and tomato-onion intercropping were maximized in comparison to other treatments and the untreated control. The greatest net benefit and maximum production advantage were also obtained by intercropping tomatoes and onions. Two-spotted spider mite populations in the research area were generally negatively impacted by crop diversification and botanical extract. Tobacco leaf extract and tomato-onion intercropping are two eco-friendly management options for controlling Two Spotted Spider Mites in the research area and the same ago ecologies, as opposed to applying with 5 % EC. Thus, the two most promising management strategies for the integrated control of two-spotted spider mites on tomatoes are tobacco leaf extract and tomato onion intercropping.

Acknowledgment

I am grateful to Haramaya University for giving me research materials, particularly the research site that allowed me to take my work to this level, and to Oromia Agricultural Research Institute for sponsoring this research.

Funding Information

I would like to thank Oromia Agricultural Research Institute Bore Agricultural Research Center for the provision of research budget. Also I would like to acknowledge Haramaya University for provision of research materials especially experimental site and laboratory facilities.

Ethics

There is no any conflict of interest considered to this article.

References

Abo-Shanab, A. S. H., Moursi, Khadiga. S., Hussein, Hanaa, S. (2019). Effect of intercropping of coriander (*Coriandrum sativum* L) with tomato (*Solanum lycopersicum*) on sucking pest management infesting tomato in Nubariya, El-Bheira Governorate, Egypt. https://www.researchgate.net/publication/331811722

Alwmayew, A., Tana, T., Dechassa, N., Dessalgn, Y., Tesfaye, K., & Wortmann, C. S. (2016). Maize-Common Bean/Lupine Intercrop Productivity and Profitability in Maize-Based Cropping System of Northwestern Ethiopia. *Ethiopian Journal of Science and Technology*, *9*(2), 69–85. https://doi.org/10.4314/ejst.v9i2.1

Asare-Bedi, E., Addo-Quaye, A. A., & Mohammed, A. (2010). Control of Diamondback Moth (Plutella Xylostella) on Cabbage (Brassica Oleracea Var Capitata) Using Intercropping with Non-Host Crops. *American Journal of Food Technology*, *5*(4), 269–274. https://doi.org/10.3923/ajft.2010.269.274

Ayele, B. A., Muleta, D., Venegas, J., & Assefa, F. (2020). Morphological, Molecular and Pathogenicity Characteristics of the Native Isolates of Metarhizium Anisopliae against the Tomato Leafminer, Tuta Absoluta (Meyrick 1917) (Lepidoptera: Gelechiidae) in Ethiopia. *Egyptian Journal of Biological Pest Control*, *30*, 1–11. https://doi.org/10.1186/s41938-020-00261-w

Boubou, A., Migeon, A., Roderick, G. K., Auger, P., Cornuet, J.-M., Magalhães, S., & Navajas, M. (2012). Test of Colonisation Scenarios Reveals Complex Invasion History of the Red Tomato Spider Mite Tetranychus Evansi. *PLoS ONE*, *7*(4), e35601. https://doi.org/10.1371/journal.pone.0035601

De Carvalho, L. M., de Oliveira, I. R., Almeida, N. A., & Andrade, K. R. (2012). The effects of biotic interaction between tomato and companion plants on yield. *Acta Horticulturae*, *45*(933), 347–354. https://doi.org/10.17660/actahortic.2012.933.45

Dube J, D., G, D., & M, M. (2020). Tomato Breeding in Sub-Saharan Africa-Challenges and Opportunities: A Review. *African Crop Science Journal*, *28*(1), 131–140. https://doi.org/10.4314/acsj.v28i1.10

Emana, B., Ayana, A., Balemi, T., & Temesgen, M. (2014). Scoping Study on Vegetables Seed Systems and Policy in Ethiopia. *Asian Vegetable Research and Development Center.*

Gemechis, A. O., Struik, P. C., & Emana, B. (2012). Tomato Production in Ethiopia: Constraints and Opportunities. In *International Research on Food Security, Natural Resource Management and Rural Development. Resilience of Agricultural Systems against Crises: Book of Abstracts*.

Gertrude, P. K., Kabongo, J. P. T., Kankolongo, M., Hauser, S., Djamba, M., Vumilia Roger, K., & Nkongolo, K. K. (2018). Evaluation of Yield and Competition Indices for Intercropped Eight Maize Varieties, Soybean and Cowpea in the Zone of Savanna of South-West RD Congo. *OALib*, *5*(1), 1–18. https://doi.org/10.4236/oalib.1103746

Gomez, K. A., & Gomez, A. A. (1984). *Statistical Procedures for Agricultural Research* (2nd, illustrated Eds.). John Wiley and Sons Ine. ISBN-10: 9780471870920.

Hata, F. T., Ventura, M. U., Carvalho, M. G., Miguel, A. L. A., Souza, M. S. J., Paula, M. T., & Zawadneak, M. A. C. (2016). Intercropping Garlic Plants Reduces *Tetranychus Urticae* in Strawberry Crop. *Experimental and Applied Acarology*, *69*(3), 311–321. https://doi.org/10.1007/s10493-016-0044-3

Hata, F. T., Ventura, M. U., Béga, V. L., Camacho, I. M., & de Paula, M. T. (2019). Chinese Chives and Garlic in Intercropping in Strawberry High Tunnels for Neopamera Bilobata Say (Hemiptera: Rhyparochromidae) Control. *Bulletin of Entomological Research*, *109*(4), 419–425. https://doi.org/10.1017/s0007485318000299

Henderson, C. F., & Tilton, E. W. (1955). Tests with Acaricides against the Brown Wheat Mite12. *Journal of Economic Entomology*, *48*(2), 157–161. https://doi.org/10.1093/jee/48.2.157

Hossain, S., Baque, M., & Amin, M. (2013). Comparative Effectiveness of Seed Treating and Foliar Insecticides against Sucking Pests of Cotton and Impact on Their Natural Enemies. *Bangladesh Journal of Agricultural Research*, *38*(1), 61–70. https://doi.org/10.3329/bjar.v38i1.15190

Hunde, N. F. (2017). Opportunity, Problems and Production Status of Vegetables in Ethiopia. *Journal of Plant Science and Research*, *4*(2), 172.

Hussein, N. M., Hussein, M. I., Gadel Hak, S. H., Shaalan, H. S., & Hammad, M. A. (2015). Effect of Two Plant Extracts and Four Aromatic Oils on Tuta Absoluta Population and Productivity of Tomato Cultivar Gold Stone. *Journal of Plant Protection and Pathology*, *6*(6), 969–985. https://doi.org/10.21608/jppp.2015.74529

Hussein, H. (2019). Effect of intercropping of Coriander (*Coriandrum sativum* L.) with Tomato (*Solanum lycopersicum*) on sucking pest management infesting tomato in Nubariya, El-Bheira Governorate, Egypt.

Kanna, Pcr. (2016). Value Chain and Market Analysis of Vegetables in Ethiopia–A Review. *International Journal of Economics and Business Management*, *2*(1), 90–99.

Karuppaiah, V., Soumia, P. S., & Wagh, P. D. (2018). Diversity and Foraging Behaviour of Insect Pollinators in Onion. *Indian Journal of Entomology*, *80*(4), 1366–1369. https://doi.org/10.5958/0974-8172.2018.00312.7

Magsi, F. H., Syed, T. S., Memon, A.-U.-R., Bhutto, Z. A., Chang, B. H., Chandio, M. A., Soomro, A. A., & Channa, N. A. (2017). Effect of Different Tobacco Extracts on the Population Buildup of Sucking Complex in Okra Crop. *International Journal of Fauna and Biological Studies*, *4*(2), 120–123.

MacKenzie, C. L., Cartwright, B., Miller, M. E., & Edelson, J. V. (1993). Injury to Onion by Thrips Tabaci (*Thysanoptera: Thripidae*) and Its Role in the Development of Purple Blotch. *Environmental Entomology*, *22*(6), 1266–1277. https://doi.org/10.1093/ee/22.6.1266

Meck, E. D., Walgenbach, J. F., & Kennedy, G. G. (2009). Effect of Vegetation Management on Autumn Dispersal of *Tetranychus urticae* (*Acari: Tetranychidae*) from Tomato. *Journal of Applied Entomology*, *133*(9–10), 742–748. https://doi.org/10.1111/j.1439-0418.2009.01413.x

Migeon, A., Nouguier, E., & Dorkeld, F. (2010). Spider Mites Web: A comprehensive database for the Tetranychidae. In *Trends in Acarology* (pp. 557–560). Springer Netherlands. https://doi.org/10.1007/978-90-481-9837-5_96

Mtambo, C. C., & Hoeschle-Zeledom, I. (2011). The Development of Integrated Control Methods for the Tomato Bed Spider Mite (Tetranychus Evansi) in Malawi. *Malawi. Malawi- Germany Plant Protection Project*, 139–147.

Muhammad, U., Khattak, T. N., Hazir, R., M.K., D., Waheed, M., & Azizullah, A. (2018). Effects of Neem (Azadirachta Indica) Seed and Turmeric (Curcuma Longa) Rhizome Extracts on Aphids' Control, Plant Growth and Yield in Okra. *Journal of Applied Botany and Food Quality*, *91*(1), 194–201. https://doi.org/10.5073/JABFQ.2018.091.026

Mulugeta, T., Muhinyuza, J.-B., Gouws-Meyer, R., Matsaunyane, L. Andreasson, E., & Alexandersson, E. (2020). Botanicals and Plant Strengtheners for Potato and Tomato Cultivation in Africa. *Journal of Integrative Agriculture*, *19*(2), 406–427. https://doi.org/10.1016/s2095-3119(19)62703-6

Murúa, M. G., Scalora, F. S., Navarro, F. R., Cazado, L. E., Casmuz, A., Villagrán, M. E., Lobos, E., & Gastaminza, G. (2014). First Record of Helicoverpa Armigera (Lepidoptera: Noctuidae) in Argentina. *Florida Entomologist*, *97*(2), 854–856. https://doi.org/10.1653/024.097.0279

Muzemu, S., Mvumi, B. M., Nyirenda, S. P. M., Sileshi, G. W., Sola, P., Chikukura, L., ... & Stevenson, P. (2011). Pesticidal effects of indigenous plants extracts against rape aphids and tomato red spider mites. In *African Crop Science Conference Proceedings* (Vol. 10, pp. 169-171). https://apps.worldagroforestry.org/downloads/Publications/PDFS/PP12057.pdf

Navajas, M., Migeon, A., Estrada-Peña, A., Mailleux, A.-C., Servigne, P., & Petanović, R. (2010). Mites and Ticks (Acari). Chapter 7.4. *BioRisk*, *4*, 149–192. https://doi.org/10.3897/biorisk.4.58

Negeri, M., Urge, M., & Selvaraj, T. (2019). Farmers' Indigenous Knowledge and Management of Insect Pests in Maize and Tomato Crops at West Hararghe Zone, Oromia Region, Ethiopia. *Annals of Plant Protection Sciences*, *27*(3), 358–362. https://doi.org/10.5958/0974-0163.2019.00078.8

Parra Almonacid, L. P. N. (2020). Assessment of Improvements of Polyculture against Monoculture in an Urban Farming Hydroponic System. *Journal of the Agriculture, Food and Human Values Society*.

Rahman, A. K. M. Z., Haque, M. H., Alam, S. N., Mahmudunnabi, M., & Dutta, N. K. (2014). Efficacy of Botanicals against Helicoverpa Armigera (Hubner) in Tomato. *The Agriculturists*, *12*(1), 131–139. https://doi.org/10.3329/agric.v12i1.19868

Rocha, L. I. R., Pratissoli, D., Damascena, A. P., Araujo Júnior, L. M. de, Carvalho, J. R. de, Tamashiro, L. A. G., & Bueno, R. C. O. de F. (2020). Plant Extracts and Pesticides for the Management of the American Serpentine Leafminer (*Liriomyza Trifolii*). *International Journal of Advanced Engineering Research and Science*, *7*(2), 144–147. https://doi.org/10.22161/ijaers.72.20

Rwomushana, I., Beale, T., Chipabika, G., Day, R., Gonzalez-Moreno, P., Lamontagne-Godwin, J., Makale, F., Pratt, C., & Tambo, J. (2023). Strategies for Sustainable Management of the Tomato Leafminer (*Tuta absoluta*) in Africa. *Plant Health Cases*, phcs20230021. https://doi.org/10.1079/planthealthcases.2023.0021

Sarker, P. K., Rahman, M. M., & Das, B. C. (2007). Effect of Intercropping with Mustard with Onion and Garlic on Aphid Population and Yield. *Journal of Bio-Science*, *15*, 35–40. https://doi.org/10.3329/jbs.v15i0.2200

SAS Institute. (2013). Base SAS 9.4 procedures guide: Statistical procedures, 40

Sharma, A., Neupane, K. R., Regmi, R., & Neupane, R. C. (2018). Effect of Intercropping on the Incidence of Jassid (Amrasca Biguttula Biguttula Ish.) and Whitefly (*Bemesia Tabaci Guen*.) in Okra (*Abelmoschus Esculentus* L. *Moench*). *Journal of Agriculture and Natural Resources*, *1*(1), 179–188. https://doi.org/10.3126/janr.v1i1.22233

Son, D., Somda, I., Legreve, A., & Schiffers, B. (2018). Effect of Plant Diversification on Pest Abundance and Tomato Yields in Two Cropping Systems in Burkina Faso: Farmer Practices and Integrated Pest Management. *International Journal of Biological and Chemical Sciences*, *12*(1), 101–119. https://doi.org/10.4314/ijbcs.v12i1.8

Tadele, S., & Emana, G. D. (2017). Effects of Crude Extracts of Medicinal Plants in the Management of Tuta Absoluta (Meyrick) (*Lepidoptera: Gelechiidae*) Under Laboratory and Glasshouse Conditions in Ethiopia. *Journal of Entomology and Nematology*, *9*(2), 9–13. https://doi.org/10.5897/jen2017.0169

Tadele, S. (2016). Evaluation of Improved Tomato Varieties (Lycopersicon Esculentum Mill.) Performance against Major Insect Pests Under Open Field and Glasshouse Conditions. *International Journal of Research Studies in Agricultural Sciences*, *2*(3), 1–7. https://doi.org/10.20431/2454-6224.0203001

Wakgari, M., & Yigezu, G. (2018). Evaluation of Some Botanical Extracts Against Two-Spotted Spider Mite (Tetranychidae: Tetranychus Urticae Koch) Under Laboratory Condition. *Ethiopian Journal of Science*, *41*(1), 1–7

Wang, X., Liu, J., & Zhu, X. (2021). Early Real-Time Detection Algorithm of Tomato Diseases and Pests in the Natural Environment. *Plant Methods*, *17*(1), 43. https://doi.org/10.1186/s13007-021-00745-2

Yigezu, G., Wakgari, M., & Goftishu, M. (2022). Management of Two-Spotted Spider Mite (Tetranychidae: *Tetranychus urticae* Koch) on Potato (*Solanum tuberosum* L.) in Eastern Hararghe, Ethiopia. *Cogent Food and Agriculture*, *8*(1), 2141237. https://doi.org/10.1080/23311932.2022.2141237

Zhou, Y., Cen, H., Tian, D., Wang, C., & Zhang, Y. (2019). A Tomato and Tall Fescue Intercropping System Controls Tomato Stem Rot. *Journal of Plant Interactions*, *14*(1), 637–647. https://doi.org/10.1080/17429145.2019.1689582

Zhou, H., Chen, J., Liu, Y., Francis, F., Haubruge, E., Bragard, C., Sun, J., & Cheng, D. (2013). Influence of Garlic Intercropping or Active Emitted Volatiles in Releasers on Aphid and Related Beneficial in Wheat Fields in China. *Journal of Integrative Agriculture*, *12*(3), 467–473. https://doi.org/10.1016/s2095-3119(13)60247-6

Zito, P., Tavella, F., Pacifico, D., Campanella, V., Sajeva, M., Carimi, F., Ebmer, A. W., & Dötterl, S. (2019). Interspecific Variation of Inflorescence Scents and Insect Visitors in Allium (Amaryllidaceae: Allioideae). *Plant Systematics and Evolution*, *305*(9), 727–741. https://doi.org/10.1007/s00606-019-01601-6