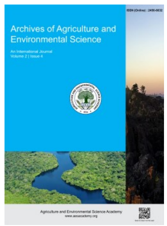
Archives of Agriculture and Environmental Science 9(2): 317-323 (2024)
https://doi.org/10.26832/24566632.2024.0902016

e-ISSN: 2456-6632

This content is available online at AESA

Archives of Agriculture and Environmental Science

Journal homepage: journals.aesacademy.org/index.php/aaes



ORIGINAL RESEARCH ARTICLE

Farmers' perception and adoption of management practices against tomato damage by tomato leaf miner (*Tuta absoluta*) in Pokhara, Nepal

Santosh Kafle[1,2*], Aashish Karki[3] and Prayan Pokharel[4*]

[1]Faculty of Agriculture, Agriculture and Forestry University (AFU), Rampur, Chitwan, NEPAL
[2]Center for Environmental and Sustainable Agricultural Research (CESAR), Pokhara, NEPAL
[3]Department of Agricultural Sciences, Clemson University, Clemson, South Carolina, USA
[4]Gandaki Province Academy of Science and Technology (GPAST), Pokhara, NEPAL
[*]Corresponding author's E-mail: sntshkafle@gmail.com

ARTICLE HISTORY

Received: 03 April 2024
Revised received: 20 May 2024
Accepted: 07 June 2024

Keywords

Farmers' perception
Pest management and adoption
Pest problems in tomato

ABSTRACT

The tomato leaf miner, *Tuta absoluta*, poses a significant threat to tomato cultivation globally, with a notable impact on yields. This study investigates the perceptions and practices of farmers in Pokhara, Nepal, regarding *T. absoluta* management. We aimed to assess the current adoption of management strategies, identify influencing factors, and uncover knowledge gaps among farmers. We surveyed 69 randomly selected households involved in tomato cultivation using a semi-structured questionnaire. The survey collected data on observations of *T. absoluta* damage, management practices (chemical, physical, pheromone-based), and awareness of integrated pest management (IPM) and ecosystem services. Our findings reveal that 94% of farmers observed *T. absoluta* damage in their fields, with a predominant reliance on chemical pesticides (86.96%). Awareness and adoption of environmentally friendly practices, such as IPM, were notably lacking. Factors such as the age of the household head, crop rotation, cropping systems, and family type significantly influenced the adoption of various management practices. While 44.93% of farmers used pheromones, 31% recognized them as effective. This study highlights the severe threat *T. absoluta* poses to tomato cultivation in Pokhara and the insufficiency of current management practices. Bridging knowledge gaps regarding eco-friendly approaches, such as pheromones and biological controls, is crucial. We emphasize the need to tailor extension services by considering sociodemographic factors and promoting awareness of ecosystem services. Ultimately, our study will contribute to more sustainable pest management practices in agricultural settings.

©2024 Agriculture and Environmental Science Academy

Citation of this article: Kafle, S., Karki, A., & Pokharel, P. (2024). Farmers' perception and adoption of management practices against tomato damage by tomato leaf miner (*Tuta absoluta*) in Pokhara, Nepal. *Archives of Agriculture and Environmental Science*, *9*(2), 317-323, https://dx.doi.org/10.26832/24566632.2024.0902016

INTRODUCTION

Tomato, *Lycopersicum esculentum*, is a solanaceous herbaceous crop grown for its edible fruit/berry. Tomato is a popular and high-value vegetable crop common in most farming communities of Nepal (Bhandari *et al.*, 2016). The area under tomato cultivation in Nepal for the FY 2021/22 was 22,911 ha, with a production of 4,22,703 mt. Likewise, the area under tomato cultivation in Kaski district for the FY 2021/22 was 406 ha, with a production of 6,469 mt. The productivity of tomatoes in the Kaski district was 15.93 mt/ha, which is much lower than the national productivity of 18.45 mt/ha and also lower than the productivity of tomatoes in Gandaki province (16.23 mt/ha) (MoALD, 2023). Research has shown many different reasons behind the lower productivity of tomatoes. However, increasing infestation of new pests has also caused immense damage in production, one of which is Tomato Leaf Miner(TLM). The tomato leaf miner (TLM, *Tuta absoluta* (Lepidoptera: Gelechiidae) (Meyrick, 1917), is an oligophagous pest and can cause damage to several species of solanaceous crops (Bajracharya *et al.*, 2016). In studying the biology of TLM, tomatoes were found to be the primary host among many solanaceous crops (Pandey *et al.*, 2023). In tomatoes, larvae mine through the mesophyll layer of the leaf, thus reducing the photosynthetic capacity and subsequent yield, while damage to the fruit causes direct losses in yield (Pereyra & Sánchez, 2006). TLM can infest and reproduce in other solanaceous crops such as eggplant (*Solanum melongena*), potato (*Solanum tuberosum*), and wild host plants such as *Solanum nigrum*, *S. eleagnifolium*, *S. bonariense* L., *S. sisymbriifolium* Lam., *S. saponaceum*, *Lycopersicum puberulum* Ph., *Datura ferox* L., *D. stramonium* L. (Desneux *et al.*, 2010). In addition, broad bean, cowpea, and wild radish have been identified as new alternative hosts (Abdul-Ridha *et al.*, 2012). The damage of TLM has also been observed in weed species. *Chenopodium album* shows conspicuous mines with black larval frass on the leaf (Ogur *et al.*, 2014). The adult *T. absoluta* lays creamy white eggs on the ventral side of the leaves, which later turn to white yellow before hatching. The larva, on hatching, penetrates leaves on which they feed and develop, creating mines and tunnels (Desneux *et al.*, 2010).

The TLM was reported for the first time in Nepal in May 2016 from a commercial farm in Kathmandu. Open borders, weak quarantine, and the import of tomatoes from India are possible reasons for pest invasion (Bajracharya *et al.*, 2016). It has been reported in 23 districts, mainly in the mid-hills and plain areas of Nepal (Bajracharya & Bhat, 2018). The pest can establish itself and spread quickly in newly introduced areas (Bajracharya *et al.*, 2016). The damage of TLM can be observed throughout the year under appropriate conditions and threatens tomato production under greenhouse and open field conditions. Despite being a new pest, it can result in massive potential yield loss and financial loss of as high as 80-100% and $50 million per year, respectively (Lamsal *et al.*, 2022). Different management practices against it include cultural, physical, chemical attractants (such as pheromone), botanicals (such as neem-based products, jholmol- a homemade biopesticide and biofertilizer), and chemical pesticides. Although the use of chemical pesticides is the most commonly used control measure against TLM, the development of resistance against common pesticides can be a limiting factor to its effectiveness (Upreti *et al.*, 2020; Wangari Nderitu *et al.*, 2020). Cultural methods, including proper greenhouse structures, removing infected organs, and avoiding alternate host plants, may be necessary for managing TLM (Desneux *et al.*, 2010). Low-cost pest exclusion nets (PEN) help control TLM (Bhusal *et al.*, 2019). Different pheromone-baited traps can be used for monitoring and controlling (Kadel *et al.*, 2018). In IPM, integrating agronomic and cultural controls with pheromones and biological methods proves practical and environmentally conscious (Desneux *et al.*, 2022).

Even though the infestation of TLM in the mid-hills of the country and information relating to its occurrence in different places, no proactive plans have been made to date from the stakeholder's side to face its severe infestation in Nepal. It has also been seen in many news and magazines about the problems faced by farmers due to the damage caused by this new pest. Further, most of the farmers are not fully aware of its management practices if shown in the tomato field and have to bear a lot of loss due to lack of knowledge. Similar cases are seen in many parts of the Kaski district and specifically within the Pokhara Metropolitan City, where commercial cultivation of tomatoes has flourished for a long time. However, no studies have been done to portray the real scenario of what is going on and suggestions for what should be done to manage this devastating pest in tomatoes to date by far. Thus, there needs a detailed study regarding the status of management practices and preliminary knowledge that farmers need to manage the TLM in tomatoes to prevent further reduction of productivity in the Pokhara area. Therefore, our study will be the first to assess the farmers' perception of damage caused by the TLM and the management practices they have adopted to date against it in tomatoes of Pokhara. It will also show the real scenario of the actual damage and economic loss caused solely due to TLM in tomatoes and the effectiveness of different management practices they are using. We believe this study would prove to be a milestone in planning any strategy to manage the TLM in tomatoes of the Pokhara area and would help many private and government organizations in allocating budgets and effective resources to keep TLM below the threshold level.

MATERIALS AND METHODS

Research site

We conducted our research in August 2022 in Pokhara, Kaski district. Our research area, including all wards of Pokhara Metropolitan City, is a part of the command area of the vegetable superzone, Kaski. The vegetable superzone Kaski is under the jurisdiction of the Project Implementation Unit (PIU), Prime Minister Agriculture Modernization Project (PMAMP), and Kaski district. Pokhara is located in the western hills of Nepal at 28.26°N latitude and 84.96°E longitude.

Sample and sampling method

A simple random sampling procedure was employed to collect the representative sample. For the total available population of registered commercial tomato-growing farmers in the Pokhara Metropolitan City, we consulted the Vegetable Superzone, Kaski, which declared it to be 83 to date. The sample size was calculated using a Raosoft Sample Size Calculator (Raosoft, 2022), with a margin of error of 5%, a confidence level of 95%, and a population portion of 50%. In our research conducted in the Pokhara Valley, 69 commercial tomato farmers participated through a household survey as suggested by Raosoft Software. We employed a semi-structured questionnaire, pre-tested before implementation, to collect firsthand information from these farmers. All 69 selected farmers responded, forming the primary dataset.

Data and data types

Our study utilized both primary and secondary sources of data.

Primary data

The preliminary data predominantly stemmed from the administered semi-structured questionnaire, designed to gather specific insights from tomato-growing farmers in their work environments. This allowed us to systematically organize and analyze pertinent information aligning with our study objectives.

Secondary data

The secondary sources encompassed a diverse array of openly accessible online journals, books, reports, articles, and websites dedicated to tomato production. Additionally, esteemed institutions like the Ministry of Agriculture and Livestock Development (MoALD), Food and Agriculture Organization (FAO), Nepal Agricultural Research Council (NARC), Vegetable Superzone Kaski, and the Central Bureau of Statistics (CBS) contributed valuable secondary data. This amalgamation of data from existing literature and authoritative sources enabled a comprehensive and structured analysis of information relevant to tomato growers.

Data analysis

The data gathered from the household survey was coded and compiled using Microsoft Excel. For the statistical analysis, we used STATA (version 16). Calculations were made using descriptive statistics like percentages and frequencies.

Logistic model and indexing

There might be many factors that affect the chance of adoption of various management practices against TLM in tomatoes. Thus, to understand the relation of the adoption of management practices with other parameters, we carry out several regression analyses where the dependent variable i.e. adoption of management practices was regressed with seven independent variables, namely the age of household head, religion, family type, affiliation with co-operatives, cropping system, and crop planted in a year. Here, the dependent variable, i.e., adoption of physical management practices, adoption of chemical management practices, adoption of pheromone lure, and adoption of mulching were individually regressed with seven independent variablesas in Table S_1, Table S_2, Table S_3, and Table S_4, respectively.

RESULTS AND DISCUSSION

Socio-demographics

The study involved 26.09% female and 73.91% male respondents of the total population. We found the average age of the household head was 41.06 years, with an average family size of 5.29. The majority, 57.97%, of the households were joint, while the remaining 42.03% were nuclear.

Tomato cultivation system

Most farmers (91.30%) only cultivated tomatoes in plastic houses, while the remaining (8.7%) cultivated tomatoes in both plastic houses and open field conditions (Figure 1). 72.36% of the farmers used a simple plastic house for tomato cultivation, 17.39% had simple plastic houses with netting along the sides, 4.90% of the respondents had a semi-high-tech tunnel, 2.90% used tunnels with plastic long down structures, and 2.90% cultivated tomatoes under high-tech tunnels. Bhandari *et al.* (2016) reported that the trend of using plastic houses for tomato production has been increasing in Nepal with increased consumption and demand. A study of the comparative economics of tomato cultivation has also shown a good return in plastic houses over open field conditions in the long run in Dhading, Nepal (Khadka & Adhikari, 2021). Increasing knowledge levels and off-season farming techniques are also driving Nepalese farmers' positive attitudes toward plastic houses rather than open fields (Maharjan, 2019). Plastic houses and tunnels are also very effective for maintaining the temperature and preventing the entry of pests being a physical barrier (Kandel *et al.*, 2020). 'Srijana F1' (developed by the Nepal Agricultural Research Council) was the most popular variety in cultivation. Its high yield, greater adaptability, tolerance to bacterial wilt, longer shelf-life, and excellent taste make it a popular variety in Nepal (Magar et al., 2016). Also, 'Srijana F1' was found to be superior in terms of yield-attributing characters and qualitative parameters among studied indeterminate tomato varieties in Bara, Nepal (Gurung *et al.*, 2020). Likewise, studies conducted by Tiwari *et al.* (2020) in Kathmandu, and by Ghimire & Chhetri (2023) in four districts also concluded the popularity of 'Srijana F1' in the region. Therefore, it has been seen to be the recommended variety in various agroecological regions of Nepal. The majority of the respondents, 62.32%, grew tomatoes in a single season in a year. 60.87% of the respondents cultivated tomato as the sole crop, whereas 39.13% of the respondents practiced mixed cropping and cultivated tomato with other crops such as spinach and beans (Figure 1).

Major pests occurring in tomato fields

The results illustrate that 94.20% of farmers observed *T. absoluta* damage in their fields, making it a significant pest in the region. Apart from this, the farmers also reported the occurrence of fruit borer, white flies, aphids, and nematodes (Figure 1). Lamsal *et al.* (2022) and Rijal *et al.* (2018) reported

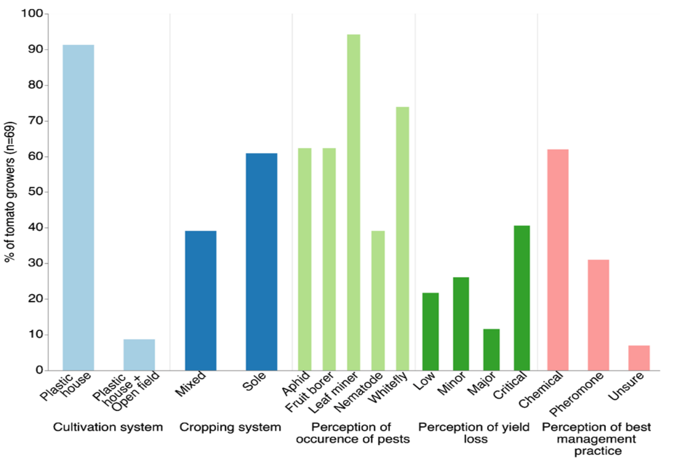


Figure 1. *Different aspects of tomato cultivation, and perception of pests & management practices.*

TLM as a significant pest of tomato production in Surkhet and Nuwakot respectively. The primary diseases associated with tomato production in Pokhara were blight, bacterial wilt, stem rot, and viral diseases. Symptoms of damage were observed in leaves, stems, and fruits. 89.71% of the farmers reported observing damage symptoms such as tunneling and mapping in the leaves of tomatoes. We found the damage symptoms on the stem to be less severe, with 50.72% reporting the occurrence of symptoms and 49.28% reporting the absence of damage symptoms in the stem. Farmers (84.06%) also observed damage symptoms on fruits. Similar damage symptoms were recorded by Ghimire & Chhetri. (2023) while studying in different districts of Nepal. Farmers (40.58%) perceived the damage from TLM in the tomato yield to be critical (between 75-100%), 11.59% perceived the damage to be primary (between 50-75%), 26.09 % perceived the damage to be minor (between 25-50%), and only 21.74% perceived the damage to be low (between 0-25%) (Figure 1). A study of overall damage by TLM on tomatoes in different countries have shown variable losses from 11-100% (Pandey *et al*., 2023). TLM can cause a yield loss of up to 80-100% if no control measures are adopted (Bajracharya & Bhat, 2018). Farmers of Lalitpur, Nepal did experience a loss of about 72% solely due to TLM in their tomato fields after the incidence of this pest (Lamsal *et al*., 2018).

Adoption of management practices against *T. absoluta*

Tomato farmers adopted various management practices such as monitoring the pest, using pheromones, crop rotation, mulching, physical management practices, botanicals, and chemicals. Biological control measures such as natural enemies (use of hemipteran predators and parasitic hymenopterans) were not followed by any farmers. Chemical management practice (Nuvan (dichlorvos), roger (dimethoate), chloropyriphos, cypermethrin, imidacloprid, chlorantraniliprole, emamectin benzoate, Spinosad) was adopted by 86.96% of the farmers. In addition to this, farmers also adopted the use of botanicals, such as neem-based products, jholmol (46.38%), and the use of pheromone (44.93%) (Table 1). 91.67% (55) of the farmers used precautionary tools such as masks and gloves while using chemical management practices. Fewer than half of the surveyed farmers practiced all management practices besides chemicals. The management of TLM could be more effective if the farmers adopted other management practices. Farmers were unaware of integrated pest management practices (IPM) and insect pollination services. Tomato flowers, though self-fertile, depend on vibration to release anthers and require wind and wild insects for a better fruit set and quality (Zhang *et al*., 2022). As such, farmers' lack of awareness of pollination services is severe and requires attention. The majority of the farmers, 62%, considered chemical management of TLM to be the best management practice, followed by 31% of the farmers referring to the use of pheromone as the best management practice, whereas the remaining 7% of the respondents were unsure about the best management practice (Figure 1). Joshi *et al*. (2017) reported that 89% of farmers in Kavre used chemical pesticides against TLM. Similarly, farmers of Palpa have a predilection towards chemical pesticides to control TLM over other measures (Bastola *et al*., 2020). The effectiveness and ease of use may be the potential reason for the increased use of chemical pesticides (Adhikari *et al*., 2019; Ghimire & Chhetri, 2023). Lamsal *et al*. (2022) in their study of Surkhet road corridors reported that the farmers considered chemical means the most effective, followed by pheromone traps. The use of pheromone was a widespread management practice against *T. absoluta*, and among 31 farmers who adopted the use of pheromone lure, 61.29% (19) considered it highly effective, 32.26% (10) thought it to be moderately effective, and only 6.25% (2) considered it to be ineffective. Farmers from Kavre, Nepal responded to the high effectiveness of pheromone lures over other management practices though a majority of them relied on chemical pesticides (Gautam *et al*., 2018). Similarly, Ghimire & Chhetri (2023) concluded the TLM lure as the best measure to manage TLM while studying four different regions of Nepal. The farmers did not use any sort of biological control measures. More research and integration of biological strategies are necessary to treat TLM successfully (Adhikari *et al*., 2019).

Factors affecting the adoption of physical management practices against TLM

The age of the household head was positively correlated with

Table 1. Adoption of management practices by tomato growing farmers.

Management practices against *T. absoluta*	Adoption by households
Monitoring and visual inspection of the field using light, sticky traps	17 (24.64%)
Use of sex pheromones and lures	31 (44.93%)
Physical management practices	14 (20.29%)
Use of botanicals such as Jholmol, cow urine, neem cake, oil	32 (46.38%)
Chemical control	60 (86.96%)
Biological Control	0 (0%)
Good agricultural practices	
Crop rotation with non-solanaceous crop	2 (2.90%)
Proper planting distance	38 (55.07%)
Mulching to identify & control infestation	17 (24.64%)
Adequate irrigation and fertilization and removal of post-harvest debris	32 (46.38%)

Table 2. Factors affecting the adoption of physical management practices.

Physical	Coefficient	Std. Error	Z	p>|z|	dy/dx
Age	0.06*	0.04	1.78	0.08	0.01*
Gender	0.57	0.92	0.62	0.53	0.07
Religion	2.20	1.61	1.37	0.17	0.30
Family	-0.04	0.69	-0.07	0.95	-0.01
Affiliation with co-operatives	-0.06	0.72	-0.09	0.93	-0.01
Cropping System	0.78	0.68	1.14	0.25	0.11
Crop planted in a year	1.55**	0.74	2.09	0.04	0.23**
Number of observations			= 69		
LR chi2(7)			= 10.04		
Prob > chi2			= 0.19		
Pseudo R2			= 0.14		
Log Likelihood			= -29.78		

** Significant at 5%, *Significant at 10%.

Table 3. Factors affecting the adoption of chemical management practices.

Chemical	Coefficient	Std. Error	Z	p>|z|	dy/dx
Age	0.00	0.40	0.20	0.84	0.00
Gender	0.55	0.85	0.65	0.51	0.54
Family	-0.37	0.83	-0.44	0.66	-0.03
Affiliation with co-operatives	0.44	0.83	0.54	0.60	0.04
Cropping System	1.90*	1.11	1.71	0.09	0.15*
Crop planted in a year	1.69	0.81	0.21	0.84	0.01
Number of observations			= 69		
LR chi2(6)			= 5.40		
Prob > chi2			= 0.49		
Pseudo R2			= 0.10		
Log Likelihood			= -24.02		

*Significant at 10%.

the adoption of physical management practices at a 10% significance level (Table 2). With each year of increase in the respondent's age, the adoption of physical management practices increased by 1% (0.83%). This might be because older farmers have been adopting physical management practices since before and prefer to continue and also lack of capacity to bear risk with new technologies with growing ages. The number of tomato crops grown in a year was positively correlated with the adoption of physical management practices at a 5% significance level (Table 2). With each unit change in tomato grown from once a year to more than once, we found the adoption of physical management practices to increase by 23.4%. As the number of crops grown in a year increases, the need for pest management also arises. Increasing crop abundance could substantially increase absolute pest density (John & Barlow, 2001). When tomatoes are planted more than once in the same field, the abundance of TLM would be greater and may find some resistance with the previously effective pesticides or other measures. This might be the reason behind the adoption of physical measures to cultivate tomatoes more than once a year.

Factors affecting the adoption of chemical management practices against TLM

The cropping system adopted by the farmer was positively correlated with the adoption of chemical management practices at a 10% significance level (Table 3). With each unit change in the cultivation practice from sole cropping to mixed cropping, we found that the adoption of chemical management practices increased by 15.17%. Mixing two or more crops can improve the overall abundance of the pest, as a more favorable environment can be created depending on the food, shelter, and oviposition requirements (Perrin, 1976). Moreover, intercropping leads to the unsuitability of using other management practices due to encroachment and complexity leaving behind the only choice of chemical management against TLM in tomatoes.

Factors affecting the adoption of pheromone against TLM

The type of family was positively correlated with the pheromone lure at a 10% significance level (Table 4). With each unit change in family type from nuclear to joint, the adoption of pheromone lures increased by 25.56%. This may be because the joint family has more labor to spare for monitoring the pest using pheromone traps. Large family size is typically associated with more labor resources, allowing them to adopt a laborious agricultural practice (Saha *et al.*, 2019).

Factors affecting the adoption of mulching against TLM

The age of the household head was observed to be positively

Table 4. Factors affecting the adoption of pheromone.

Pheromone Lure	Coefficient	Std. Error	Z	p>|z|	dy/dx
Age	0.03	0.03	1.16	0.25	0.01
Gender	-0.07	0.62	-0.11	0.91	-0.02
Religion	0.01	1.58	0.01	0.99	0.00
Family	1.03*	0.56	1.86	0.06	0.26*
Affiliation with co-operatives	0.25	0.56	0.44	0.66	0.06
Cropping System	-0.28	0.55	-0.52	0.61	-0.07
Crop planted in a year	-0.54	0.56	-0.96	0.34	-0.13
Number of observations			= 69		
LR chi2(7)			= 8.15		
Prob > chi2			= 0.32		
Pseudo R2			= 0.09		
Log Likelihood			= -43.40		

*significant at 10%.

Table 5. Factors affecting the adoption of mulching.

Mulching	Coefficient	Std. Error	Z	p>|z|	dy/dx
Age	0.09**	0.05	2.09	0.04	0.01**
Gender	0.48	0.84	0.57	0.57	0.07
Occupation	-0.24	1.51	-0.16	0.87	-0.04
Family	-0.04	0.70	-0.06	0.95	-0.01
Education Status	0.13	1.65	0.08	0.94	0.02
Affiliation with co-operatives	-2.13**	0.85	-2.52	0.01	-0.31**
Cropping System	-0.11	0.71	-0.16	0.87	-0.02
Crop planted in a year	1.45**	0.71	2.04	0.04	0.24**
Number of observations			= 69		
LR chi2(8)			= 15.28		
Prob > chi2			= 0.05		
Pseudo R2			= 0.20		
Log Likelihood			= -43.40		

** Significant at 5%.

associated with the adoption of mulching at a 5% significance level (Table 5). With each year's increase in the respondents' age, the adoption of mulching was found to increase by 1.3%. A possible reason for this could be that older farmers possess more farming experience and thus can assess the merits/ demerits of an agricultural practice. However, we found that the affiliation of farmers with co-operatives negatively correlated with the adoption of mulching at a 5% significance level (Table 5). With every unit change in the respondents from non-affiliated to affiliated with co-operatives, the adoption of mulching decreased by 30.78%. The number of tomato crops grown in a year was positively correlated with the adoption of mulching at a 5% significance level (Table 5). With every unit change in tomatoes grown once a year to more than once, the adoption of mulching was found to increase by 24.12%. This can be attributed to the increased pest abundance accompanying the intensified pest cycle.

Conclusion

Tuta absoluta significantly threatens tomato cultivation in Pokhara, Nepal. Our survey of 69 households found that 94% of farmers observed damage, with 86.96% relying on chemical pesticides. Awareness and adoption of eco-friendly practices like integrated pest management (IPM) were low, influenced by factors such as the age of the household head, crop rotation, cropping systems, and family type. Although 44.93% of farmers used pheromones, only 31% found them effective. Bridging knowledge gaps and tailoring extension services to promote sustainable practices are essential for better pest management.

DECLARATIONS

Author contribution statement

Conceptualization, S.K. and P.P.; Methodology, S.K. and P.P.; Software and validation: N/A; Formal analysis and investigation, S.K., A.K. and P.P.; Resources, N/A; Data curation, A.K., S.K. and P.P.; Writing—original draft preparation, A.K. and S.K.; Writing—review and editing, P.P. and S.K.; Visualization, P.P.; Supervision, P.P.; Project administration, S.K. and P.P.; Funding acquisition: N/A. All authors have read and agreed to the published version of the manuscript.

Conflicts of interest: The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Ethics approval: Not applicable.

Consent for publication: All authors have given their consent for the publication.

Data availability: Data will be made available on request.

Supplementary data: Table S_1, Table S_2, Table S_3, and Table S_4.

Funding statement: The research received no external funding.

Additional information: No additional information is available for this paper.

ACKNOWLEDGMENTS

We would like to express our sincere gratitude to the vegetable superzone, Kaski for providing information related to the farmers in tomato production. Lastly, we are very grateful to all the farmers in the study area for their valuable time and useful data.

Open Access: This is an open access article distributed under the terms of the Creative Commons Attribution Non-Commercial 4.0 International License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) or sources are credited.

REFERENCES

Abdul-Ridha, M., Alwan, S. L., Helal, S. M., & Aziz, K. A. (2012). Alternative hosts of South American tomato moth Tuta absoluta (Gelechiidae: Lepidoptera) in some tomato farms of Najaf Province. Euphrates *Journal of Agriculture Science*, *4*(4), 130–137.

Adhikari, D., Subedi, R., Gautam, S., Pandit, D. P., & Sharma, D. R. (2019). Monitoring and management of tomato leaf miner, (Tuta absoluta, Meyrick) in Kavrepalanchowk, Nepal. *Journal of Agriculture and Environment*, *20*, 1–9.

Bajracharya, A. S. R., & Bhat, B. (2018). Life cycle of South American tomato leaf miner, Tuta absoluta (Meyrick, 1917) in Nepal. *Journal of Entomology and Zoology Studies*, 6(1), 287–290.

Bajracharya, A. S. R., Mainali, R. P., Bhat, B., Bista, S., Shashank, P. R., & Meshram, N. M. (2016). The first record of South American Tomato Leaf Miner, Tuta absoluta (Meyrick 1917) (Lepidoptera: Gelechiidae) in Nepal. Journal *of Entomology and Zoology Studies*, 4(4), 1359–1363.

Bastola, A., Pandey, S. R., Khadka, A., & Regmi, R. (2020). Efficacy of commercial insecticides against Tomato Leaf Miner Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) in Palpa, Nepal. *Turkish Journal of Agriculture - Food Science and Technology*, *8*(11), 2388–2396. https://doi.org/10.24925/turjaf.v8i11.2388-2396.3680

Bhandari, N. B., Bhattarai, D., & Aryal, M. (2016). Demand and supply situation of tomato in Nepal, 2015/16. Agribusiness Promotion & Market Development Directorate, Ministry of Agriculture Development, Department of Agriculture, Government of Nepal, Lalitpur, Nepal.

Bhusal, K., GC, S., & Bhattarai, K. (2019). Use of low-cost pest exclusion net to control Tuta absoluta infestation and boost the yield of tomatoes in Surkhet and Dang districts of Nepal. World Research Journal *of Agricultural Sciences*, *6*(2), 162–166.

Desneux, N., Han, P., Mansour, R., Arnó, J., Brévault, T., Campos, M. R., Chailleux, A., Guedes, R. N. C., Karimi, J., Konan, K. A. J., Lavoir, A., Luna, M. G., Perez-Hedo, M., Urbaneja, A., Verheggen, F. J., Zappalà, L., Abbes, K., Ali, A., Bayram, Y., Biondi, A. (2022). Integrated pest management of Tuta absoluta: Practical implementations across different world regions. Journal *of Pest Science*, *95*(1), 17–39. https://doi.org/10.1007/s10340-021-01442-8

Desneux, N., Wajnberg, E., Wyckhuys, K. A. G., Burgio, G., Arpaia, S., Narváez-Vasquez, C. A., González-Cabrera, J., Catalán Ruescas, D., Tabone, E., Frandon, J., Pizzol, J., Poncet, C., Cabello, T., & Urbaneja, A. (2010). Biological invasion of European tomato crops by Tuta absoluta: Ecology, geographic expansion and prospects for biological control. *Journal of Pest Science*, *83*(3), 197–215. https://doi.org/10.1007/s10340-010-0321-6

Gautam, S., Adhikari, D., Sapkota, B. R., & Shrestha, A. K. (2018). Monitoring South American Tomato Leaf Miner, Tuta absoluta (Meyrick), and assessment of management practices adopted in Kavre, Nepal. *Journal of the Plant Protection Society*, *5*, 129–138.

Ghimire, S., & Chhetri, B. P. (2023). Menace of Tomato Leaf Miner (*Tuta absoluta* [Meyrick, 1917]): Its impacts and control measures by Nepalese farmers. *AgroEnvironmental Sustainability*, *1*(1), 37–47.

Gurung, S., Adhikari, P., Giri, K., Gotame, T. P., & Shrestha, S. L. (2020). Growth and yield performance of hybrid tomato (*Solanum lycopersicum* L.) lines at Parwanipur, Bara, Nepal. *Journal of Agriculture and Natural Resources*, *3*(1), 180–189. https://doi.org/10.3126/janr.v3i1.27166

John M., K., & Barlow, N. D. (2001). A spatial model for the successful biological control of Sitona discoideus by Microctonus aethiopoides. Journal *of Applied Ecology*, 38 (1), 162–169. https://doi.org/10.1046/j.1365-2664.2001.00579.x

Joshi, D., Rajbhandari, B. P., & Sah, L. (2017). Management practices adopted by commercial tomato growers against Tuta absoluta. Nepalese *Journal of Agricultural Sciences*, 15.

Kadel, J., Sah, L. P., Devkota, M., Colavito, L. A., Norton, G., Rajotte, E. G., & Muniappan, R. (2018). Effectiveness of different types of traps for management of Tuta absoluta in Nepal. *Journal of the Plant Protection Society*, 5, 166–174.

Kandel, D. R., Marconi, T. G., Badillo-Vargas, I. E., Enciso, J., Zapata, S. D., Lazcano, C. A., Crosby, K., & Avila, C. A. (2020). Yield and fruit quality of high-tunnel tomato cultivars produced during the off-season in South Texas. *Scientia Horticulturae*, *272*, 109582. https://doi.org/https://doi.org/10.1016/j.scienta.2020.109582

Khadka, S., & Adhikari, R. K. (2021). Comparative economics of tomato production under polyhouse and open field condition in Dhading district of Nepal. *Nepalese Journal of Agricultural Sciences*, *20*, 100–107.

Lamsal, A., Sah, L. P., Giri, A. P., Devkota, M., Colavito, L. A., Norton, G., Rajotte, E. G., & Muniappan, R. (2018). Occurrence of South American Tomato Leaf Miner (*Tuta absoluta*) and current management practices adopted by farmers in Lalitpur district, Nepal. *Journal of the Plant Protection Society*, *12*(11), 155–165.

Lamsal, K., Sapkota, R., Dahal, K. C., Upadhyaya, N., & Khanal, D. (2022). Farmers' management practices against Tomato Leaf Miner Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae) in Surkhet, Nepal. *Journal of the Plant Protection Society*, 7, 53–65.

Magar, D. B., Gauchan, D., Timsina, K. P., & Ghimire, Y. N. (2016). Srijana hybrid tomato: A potential technology for enterprise development in Nepal. Khumaltar, Lalitpur, Nepal: Socioeconomics & Agricultural Research Policy Division, Nepal Agricultural Research Council (NARC).

Maharjan, S. K. (2019). Off seasonal tomato production practices in Nepal. *International Journal of Agrochemistry*, *5*(2), 13–18.

Ministry of Agriculture and Livestock Development (MoALD). (2023). Statistical Information on Nepalese Agriculture 2078/79 (2021/2022)).

Ogur, E., Unlu, L., & Karaca, M. (2014). Chenopodium album L.: A new host plant of Tuta absoluta Povolny (Lepidoptera: Gelechiidae). Turkish *Bulletin of Entomology*, *4*(1), 61–65.

Pandey, M., Bhattarai, N., Pandey, P., Chaudhary, P., Katuwal, D. R., & Khanal, D. (2023). A review on biology and possible management strategies of tomato leaf miner, Tuta absoluta (Meyrick), Lepidoptera: Gelechiidae in Nepal. *Heliyon*, 9(6), 1–12. https://doi.org/10.1016/j.heliyon.2023.e16474

Pereyra, P. C., & Sánchez, N. E. (2006). Effect of two solanaceous plants on developmental and population parameters of the tomato leaf miner, Tuta absoluta (Meyrick) (Lepidoptera: Gelechiidae). Neotropical *Entomology*, 35(5), 671–676. https://doi.org/10.1590/S1519-566X2006000500016

Perrin, R. M. (1976). Pest management in multiple cropping systems. Agro-Ecosystems, 3, 93–118. https://doi.org/10.1016/0304-3746(76)90110-4

Raosoft Sample Size Calculator. (2022). Retrieved July 10, 2022, from http://www.raosoft.com/samplesize.html.

Rijal, R. K., Poudel, D., Lamichhane, P., & Gaire, K. R. (2018). Effect and control measures adopted for Tomato Leaf Miner (Tuta absoluta) in Nuwakot, Nepal. *International Journal of Research*, *5*(23), 644–656.

Saha, M. K., Biswas, A. A. A., Faisal, M., Meandad, J., Ahmed, R., Prokash, J., & Sakib, F. M. (2019). Factors affecting to adoption of climate-smart agriculture practices by coastal farmers in Bangladesh. *American Journal of Environment and Sustainable Development*, *4*(4), 113–121.

Tiwari, I., Shah, K. K., Tripathi, S., Modi, B., Shrestha, J., Pandey, H. P., Bhattarai, B. P., & Rajbhandari, B. P. (2020). Post-harvest practices and loss assessment in tomato (*Solanum lycopersicum* L.) in Kathmandu, Nepal. Journal *of Agriculture and Natural Resources*, *3*(2), 335–352. https://doi.org/10.3126/janr.v3i2.32545

Upreti, E., Rajbhandari, B. P., Devkota, M., Colavito, L. A., & Sah, L. P. (2020). Evaluation of the impact and adoption of IPM against Tuta absoluta in Kavre and Lalitpur districts. *Nepalese Journal of Agricultural Sciences*, *19*, 200–209.

Wangari Nderitu, P., Jonsson, M., Arunga, E., Otieno, M., Jamleck Muturi, J., & Wafula, G. O. (2020). Combining host plant resistance, selective insecticides, and biological control agents for integrated management of *Tuta absoluta*. *Advances in Agriculture*, 2020, 1–8. https://doi.org/10.1155/2020/6239491

Zhang, H., Han, C., Breeze, T. D., Li, M., Mashilingi, S. K., Hua, J., Zhang, W., Zhang, X., Zhang, S., & An, J. (2022). Bumblebee pollination enhances yield and flavor of tomato in Gobi desert greenhouses. *Agriculture*, 12(6), 795. https://doi.org/10.3390/agriculture12060795