

**EVALUATION OF INDIGENOUS TOMATO VARIETIES FOR RESISTANCE
TO *Tuta absoluta* (MEYRICK) (LEPIDOPTERA: GELECHIIDAE)
IN SURKHET, NEPAL**

Chitra Bahadur Rokaya, Sundar Tiwari, Resham Bahadur Thapa and Min Raj Pokhrel

Department of Entomology, Faculty of Agriculture,
Agriculture and Forestry University, Chitwan, Nepal
Correspondence: chitarokaya@gmail.com

ABSTRACT

The South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), is an invasive pest threatening tomato production in Nepal. This study evaluated sixteen indigenous tomato varieties (*Solanum lycopersicum* L.) for growth, yield, and resistance to *T. absoluta* under field conditions in Surkhet, Nepal, during summer 2025. The experiment used a randomized complete block design with three replications. Data on growth parameters, yield attributes, and leaf and fruit damage were subjected to analysis of variance. Significant genetic variability ($p < 0.001$) was observed among varieties for all traits. Plant height ranged from 57.5 to 116.0 cm, and total fruits per plant varied from 12.5 to 239.5. Leaf damage ranged from 5.5% (NGRCO 9571) to 24.3% (NGRCO 9575), while fruit damage ranged from 0.0% (NGRCO 9572) to 18.2% (NGRCO 9570). Notably, NGRCO 9572 showed no fruit damage, while NGRCO 9573 and NGRCO 9581 exhibited minimal fruit damage (0.6% each). High-yielding cultivars (NGRCO 9579, NGRCO 9568) were moderately to heavily damaged, suggesting trade-offs between productivity and resistance. The resistant genotypes identified, particularly NGRCO 9572, NGRCO 9573, and NGRCO 9581, represent valuable genetic resources for integrated pest management and resistance breeding programmes against *T. absoluta* in Nepal.

Keywords: antixenosis, genetic variability, host plant resistance, indigenous germplasm, *Tuta absoluta*

INTRODUCTION

Tomato (*Solanum lycopersicum* L.) is one of the most important vegetable crops worldwide, cultivated across diverse agro-ecological zones. In Nepal, tomato is grown on approximately 26,791 hectares, with an annual production of 552,607 metric tons and a national average productivity of 20.53 mt/ha (Ministry of Agriculture and Livestock Development, 2025). The crop contributes significantly to household nutrition, food security, and income generation for smallholder farmers.

Tomato production faces numerous constraints, with insect pest infestation being a major limiting factor. Among these, the South American tomato leaf miner, *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae), has emerged as a devastating invasive pest threatening tomato production globally (Desneux et al., 2010). Originating from South America, *T. absoluta* has rapidly spread across Europe, Africa, and Asia, causing substantial economic losses. Yield losses of 50-100% have been

reported in severely infested fields (Bajracharya et al., 2016). The pest primarily damages tomato plants by mining leaves, stems, and fruits, as well as feeding on flower buds and young shoots (Poudel & Kafle, 2021).

In Nepal, *T. absoluta* was first detected in May 2016 in Kathmandu during a plant clinic session and subsequently confirmed through morphological and genitalia studies (Bajracharya et al., 2016). The pest quickly proliferated across major tomato-growing areas, including the Kathmandu Valley and surrounding districts. The rapid spread of *T. absoluta* in Nepal has been attributed to favorable climatic conditions, lack of natural enemies, and increased trade of infested plant materials (Venkatramanan et al., 2020).

Current management of *T. absoluta* relies heavily on synthetic insecticides. However, the pest's cryptic feeding behavior and rapid development of insecticide resistance compromise the efficacy of chemical control (Guedes et al., 2019). Moreover, indiscriminate insecticide use poses risks to human health, non-target organisms, and the environment. Host plant resistance offers a sustainable and ecologically sound alternative for managing *T. absoluta*.

Indigenous tomato varieties, adapted to local conditions over generations, represent a potential reservoir of resistance traits against both native and invasive pests. These landraces may harbor unique resistance mechanisms developed through co-evolution with local pest complexes. However, systematic evaluation of indigenous Nepalese tomato germplasm for resistance to *T. absoluta* is lacking. Therefore, this study evaluated the resistance levels of indigenous tomato varieties collected by the National Agriculture Genetic Resource Centre (Genebank), Khumaltar, Nepal, from diverse geographic regions against *T. absoluta* under field conditions in Surkhet district, Nepal.

MATERIALS AND METHODS

Study site

The field experiment was conducted at Birendranagar-9, Surkhet, Nepal (28°33'53"N, 81°35'56"E; 630 m above sea level) during the summer season of 2025 (Fig. 1). The site has a subtropical climate with an altitude of 630 meter above sea level, mean maximum and minimum temperatures of 30.27 °C and 16.41 °C, respectively, average humidity of 72.13%, and total precipitation of 4.55 mm during the study period. These dry conditions required frequent irrigation (twice weekly) and increased the risk of *T. absoluta* infestation.

Experimental design and treatments

Sixteen indigenous tomato varieties were evaluated, comprising fifteen accessions from the National Agriculture Genetic Resource Centre (NAGRC), Khumaltar, Nepal (NGRCO 9567, 9568, 9569, 9570, 9571, 9572, 9573, 9574, 9575, 9576, 9577, 9578, 9579, 9580, and 9581) and one local landrace 'Dullu' from Dailekh district. Seedlings were raised in a nursery bed (5 m × 1 m) and transplanted on March 30, 2025.

The experiment was arranged in a randomized complete block design with three replications. Each plot measured 3.0 m × 1.8 m, with 0.5 m gaps between plots and 1.0 m pathways between blocks. A

1.0 m border surrounded the experimental area. Plant spacing was 0.75 m between rows and 0.45 m between plants, with eight plants per plot. Farmyard manure (20 mt ha⁻¹) and inorganic fertilizers (150:120:100 kg NPK ha⁻¹) were applied uniformly. Recommended agronomic practices, including irrigation, weeding, and staking, were followed. No insecticides were applied to allow natural pest infestation.

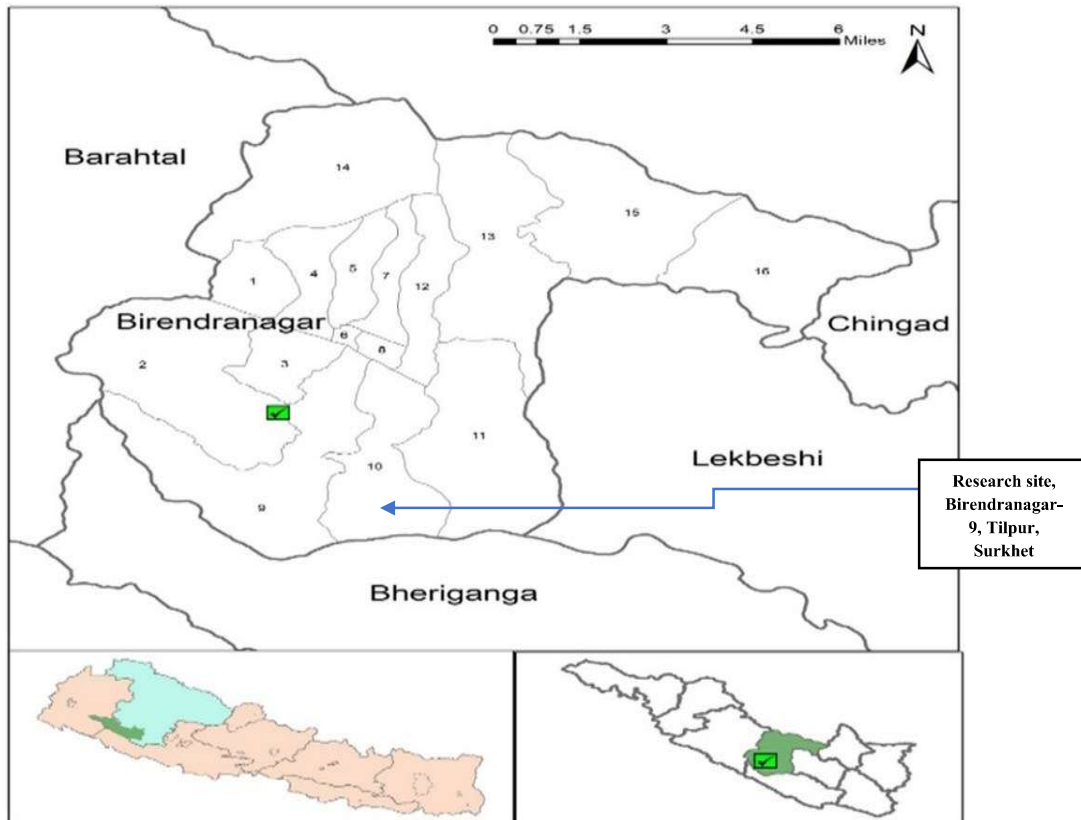


Fig. 1. Map of research location (Birendranagar-9, Tilpur, Surkhet, Nepal)

Data collection

Five randomly selected plants from the central rows of each plot (excluding border plants) were used for data collection. Growth parameters (plant height, canopy width, number of branches, and flowers) were recorded at 7-day intervals from 13 May to 10 June, 2025. Plant height was measured from the base to the shoot apex. Canopy width was calculated as the average of east-west and north-south spread. Data presented in Table 1 represent observations at 120 days after transplanting (final harvest stage).

Table 1. Growth parameters of indigenous tomato varieties under field conditions in Surkhet, Nepal

Variety	Plant Height (cm)	Plant Canopy (cm)	Number of Branches	Number of Flowers
NGRCO 9570	62.5 ^{cd}	62.5 ^{ab}	25.5 ^e	6.0 ^{de}
NGRCO 9576	79.0 ^{bc}	46.0 ^{cde}	28.5 ^{de}	5.5 ^e
NGRCO 9573	64.0 ^{cd}	59.5 ^{abc}	46.5 ^{bcd}	7.5 ^{cde}
NGRCO 9572	70.0 ^{cd}	52.5 ^{bcd}	31.0 ^{cde}	19.5 ^{ab}
NGRCO 9581	72.5 ^{cd}	59.5 ^{abc}	42.5 ^{bcd}	15.0 ^{bc}
NGRCO 9580	72.5 ^{cd}	39.5 ^{de}	34.5 ^{cde}	11.5 ^{bcd}
Dullu Landrace	94.5 ^{ab}	60.0 ^{abc}	55.5 ^b	5.5 ^e
NGRCO 9571	57.5 ^d	48.5 ^{cd}	27.0 ^e	6.0 ^{de}
NGRCO 9577	87.5 ^{ab}	69.0 ^a	45.5 ^{bcd}	14.0 ^{bc}
NGRCO 9567	81.0 ^{bc}	24.5 ^f	41.0 ^{bcd}	10.0 ^{cde}
NGRCO 9574	88.0 ^{ab}	60.0 ^{abc}	62.0 ^b	21.5 ^{ab}
NGRCO 9579	92.5 ^{ab}	70.0 ^a	126.5 ^a	21.0 ^{ab}
NGRCO 9578	77.5 ^{bc}	45.0 ^{cde}	74.5 ^b	44.5 ^a
NGRCO 9568	116.0 ^a	74.0 ^a	120.5 ^a	23.5 ^{ab}
NGRCO 9569	70.0 ^{cd}	45.0 ^{cde}	36.0 ^{cde}	13.0 ^{bcd}
NGRCO 9575	62.5 ^{cd}	40.0 ^{de}	36.0 ^{cde}	10.0 ^{cde}
Mean	77.3	53.2	51.6	14.7
SEM (±)	(3.8)	(3.1)	(6.9)	(2.3)
CV%	15.2	18.0	41.6	48.3
P-value	<0.001*	<0.001*	<0.001*	<0.001*

Note: Means followed by the same superscript letter within a column are not significantly different at $P = 0.05$ according to Duncan's Multiple Range Test (DMRT). SEM = standard error of the mean; CV = coefficient of variation; *Significant at $P < 0.05$.

Yield and pest-damage parameters were recorded at the final harvest. Total fruits per plant, total leaves, damaged leaves, and damaged fruits per plant were counted. Leaf damage was assessed by counting mines and larvae on all leaves. Fruit damage was quantified at each harvest (weekly from 90-120 DAT, i.e., 20 May to 10 June 2025) as fruits with larval entry and exit holes. Percentage damage was calculated as:

$$\text{Leaf damage (\%)} = (\text{Total damaged leaves} / \text{Total leaves}) \times 100$$

$$\text{Fruit damage (\%)} = (\text{Total damaged fruits} / \text{Total fruits}) \times 100$$

Statistical analysis

Data were analyzed using one-way analysis of variance (ANOVA) with R version 4.2.1. Percentage data were arcsine-transformed before analysis. Means were separated using Duncan's Multiple Range Test at $p=0.05$.

RESULTS

Growth parameters

Significant differences ($p < 0.001$) were observed among tomato varieties for all growth parameters evaluated (Table 1). The number of leaves per plant varied from 152.0 (NGRCO 9575) to 608.0 (NGRCO 9568). NGRCO 9568 produced the highest number of leaves (608.0), followed by NGRCO 9578 (484.0) and NGRCO 9579 (478.0). The lowest leaf production was observed in NGRCO 9575 (152.0) and NGRCO 9569 (158.5).

Plant height ranged from 57.5 cm (NGRCO 9571) to 116.0 cm (NGRCO 9568), with an overall mean of 77.3 cm. The tallest plants were recorded in NGRCO 9568 (116.0 cm), which were statistically similar to NGRCO 9579 (92.5 cm), NGRCO 9574 (88.0 cm), NGRCO 9577 (87.5 cm), and Dullu landrace (94.5 cm). The shortest plants were observed in NGRCO 9571 (57.5 cm) and NGRCO 9570 (62.5 cm).

Plant canopy width varied from 24.5 cm (NGRCO 9567) to 74.0 cm (NGRCO 9568), with a mean value of 53.2 cm. The number of branches per plant showed wide variation, ranging from 25.5 (NGRCO 9570) to 126.5 (NGRCO 9579). NGRCO 9579 (126.5 branches) and NGRCO 9568 (120.5 branches) produced the highest number of branches, while NGRCO 9570 (25.5 branches) and NGRCO 9576 (28.5 branches) produced the fewest.

Flower production also differed significantly among varieties. NGRCO 9578 produced the highest number of flowers (44.5 flowers plant⁻¹), followed by NGRCO 9568 (23.5 flowers plant⁻¹) and NGRCO 9574 (21.5 flowers plant⁻¹). The lowest flower production was recorded in NGRCO 9576 (5.5 flowers plant⁻¹) and Dullu landrace (5.5 flowers plant⁻¹).

The overall means for growth parameters were 77.3 cm (plant height), 53.2 cm (plant canopy), 51.6 branches plant⁻¹, and 14.7 flowers plant⁻¹. The coefficients of variation (CV) ranged from 15.2% (plant height) to 48.3% (flower number), indicating moderate to high variability among the indigenous genotypes.

Pest damage and infestation parameters

Analysis of pest damage parameters revealed significant differences among the evaluated genotypes ($p < 0.001$; Tables 2, 3).

Table 2. Yield and *Tuta absoluta* (Meyrick) damage parameters of indigenous tomato varieties under field conditions

Variety	Total Fruits (No.)	Total Leaves (No.)	Damaged Leaves (No.)	Damaged Fruits (No.)
NGRCO 9570	22.0 ^{de}	239.0 ^{de}	32.0 ^{bcd}	4.0 ^b
NGRCO 9576	19.5 ^{de}	218.5 ^{de}	38.5 ^{ab}	0.5 ^c
NGRCO 9573	80.5 ^{bc}	340.5 ^{bc}	27.5 ^{cde}	0.5 ^c
NGRCO 9572	13.5 ^e	253.0 ^{cde}	39.5 ^{ab}	0.0 ^c
NGRCO 9581	81.5 ^{bc}	329.0 ^{bcd}	41.0 ^{ab}	0.5 ^c
NGRCO 9580	26.5 ^{cde}	349.0 ^{bc}	31.0 ^{bcd}	1.0 ^c
Dullu Landrace	15.5 ^{de}	366.0 ^b	37.5 ^{ab}	0.5 ^c
NGRCO 9571	12.5 ^e	365.0 ^b	20.0 ^e	0.5 ^c
NGRCO 9577	35.0 ^{cde}	416.0 ^{ab}	33.5 ^{bc}	4.5 ^{ab}
NGRCO 9567	29.0 ^{cde}	360.0 ^b	28.0 ^{cde}	1.5 ^{bc}
NGRCO 9574	95.5 ^b	355.0 ^{bc}	40.0 ^{ab}	3.0 ^b
NGRCO 9579	239.5 ^a	478.0 ^a	37.5 ^{ab}	9.5 ^a
NGRCO 9578	167.0 ^a	484.0 ^a	57.0 ^a	4.0 ^b
NGRCO 9568	161.5 ^a	608.0 ^a	55.5 ^a	6.5 ^{ab}
NGRCO 9569	78.0 ^{bcd}	158.5 ^e	27.0 ^{de}	2.0 ^{bc}
NGRCO 9575	29.0 ^{cde}	152.0 ^e	37.0 ^{ab}	0.5 ^c
Mean	69.1	340.2	36.6	2.4
SEM (±)	13.2	28.5	2.5	0.6
CV (%)	59.2	26.0	21.2	77.5
P-value	<0.001*	<0.001*	<0.001*	<0.001*

Note: Means followed by the same superscript letter within a column are not significantly different at $P = 0.05$ according to Duncan's Multiple Range Test (DMRT). SEM = standard error of the mean; CV = coefficient of variation; *Significant at $P < 0.05$.

Table 3. Percentage of *Tuta absoluta* (Meyrick) infestation in indigenous tomato varieties under field conditions

Variety	Leaf Damage %	Fruit Damage %
NGRCO 9570	13.4	18.2
NGRCO 9576	17.6	2.6
NGRCO 9573	8.1	0.6
NGRCO 9572	15.6	0.0
NGRCO 9581	12.5	0.6
NGRCO 9580	8.9	3.8
Dullu Landrace	10.2	3.2
NGRCO 9571	5.5	4.0
NGRCO 9577	8.1	12.9
NGRCO 9567	7.8	5.2
NGRCO 9574	11.3	3.1
NGRCO 9579	7.8	4.0
NGRCO 9578	11.8	2.4
NGRCO 9568	9.1	4.0
NGRCO 9569	17.0	2.6
NGRCO 9575	24.3	1.7
Mean	11.8	3.8

¹Leaf damage % = (Total damaged leaves/Total leaves) × 100

²Fruit damage % = (Total damaged fruits/Total fruits) × 100

Foliar damage

The overall means for foliar damage were 36.6 damaged leaves and 11.8% leaf damage. Leaf damage percentage across varieties ranged from 5.5% to 24.3%. The minimum foliar damage was recorded in NGRCO 9571 (20.0 leaves; 5.5%), followed by NGRCO 9569 (27.0 leaves; 17.0%) and NGRCO 9573 (27.5 leaves; 8.1%). Other genotypes exhibiting low leaf-damage percentages included NGRCO 9567 (7.8%) and NGRCO 9579 (7.8%). The highest number of damaged leaves was observed in NGRCO 9578 (57.0 leaves) and NGRCO 9568 (55.5 leaves), while the highest percentage of leaf damage occurred in NGRCO 9575 (24.3%), followed by NGRCO 9569 (17.0%) and NGRCO 9570 (13.4%).

Fruit damage

For fruit damage, the overall means were 2.4 damaged fruits and 3.8%, with variety-specific values ranging from 0.0% to 18.2%. NGRCO 9572 demonstrated complete immunity to fruit damage (0.0%), whereas NGRCO 9573 (0.6%), NGRCO 9581 (0.6%), and the Dullu landrace exhibited only negligible damage (≤ 0.5 fruits). At the other extreme, the highest damage counts were recorded in NGRCO 9579 (9.5 fruits) and NGRCO 9568 (6.5 fruits), while the maximum percentage of fruit

damage was observed in NGRCO 9570 (18.2%), followed by NGRCO 9577 (12.9%). It is noteworthy that the high-yielding genotypes NGRCO 9579 and NGRCO 9568 experienced moderate to severe fruit damage, with counts ranging from 4.0 to 9.5 damaged fruits per plant.

Yield parameters

Analysis of yield parameters revealed highly significant differences among the indigenous genotypes ($p < 0.001$). Total fruit number per plant varied widely, ranging from 12.5 (NGRCO 9571) to 239.5 (NGRCO 9579), with an overall mean of 69.1. The highest-yielding genotype, NGRCO 9579 (239.5 fruits), was statistically comparable to NGRCO 9578 (167.0) and NGRCO 9568 (161.5). Conversely, the lowest fruit production was recorded in NGRCO 9571 (12.5) and NGRCO 9572 (13.5), which were significantly inferior to the top performers.

DISCUSSION

Genetic diversity in indigenous tomato varieties

The significant variability observed among indigenous tomato varieties for growth, yield, and resistance traits reflects the genetic diversity present in Nepalese tomato germplasm. This diversity provides opportunities for selecting genotypes with desirable traits for pest management and breeding programs. Similar variability in morphological traits has been reported in tomato landraces from diverse geographic regions (Schouten et al., 2019).

The wide range in plant height (57.5-116.0 cm) and branching pattern (25.5-126.5 branches) suggests adaptation to diverse agroecological conditions and varying pest pressures. Varieties with robust growth (NGRCO 9568, NGRCO 9579, Dullu landrace) may have potential for high biomass production under local conditions. The high fruit production in NGRCO 9579, NGRCO 9578, and NGRCO 9568 (161.5-239.5 fruits per plant) indicates their suitability for cultivation under low to moderate pest pressure.

Resistance to *Tuta absoluta*

The differential response of tomato varieties to *T. absoluta* infestation demonstrates the existence of genetic resistance within indigenous germplasm. The wide range of leaf damage (5.5-24.3%) and fruit damage (0.0-18.2%) confirms that some varieties possess effective resistance mechanisms.

NGRCO 9571 exhibited the lowest leaf damage (5.5%) and moderate fruit damage (4.0%), suggesting antixenosis or antibiosis mechanisms at the foliar level. This variety produced fewer leaves and fruits but maintained low damage levels, possibly due to morphological or biochemical traits that deter oviposition or larval feeding (Ataide et al., 2017). Trichome density, leaf toughness, and secondary metabolites have been implicated in resistance to *T. absoluta* (Khederi et al., 2014).

NGRCO 9572 demonstrated remarkable resistance with a complete absence of fruit damage (0.0%) despite moderate leaf damage (15.6%). This suggests mechanisms that protect reproductive structures from larval infestation, possibly through differential allocation of defensive compounds and temporal asynchrony between fruit development and peak pest activity (Miano, 2017). Similarly, NGRCO

9573 and NGRCO 9581 showed minimal fruit damage (0.6% each), confirming their potential as resistance sources.

The low fruit damage in these varieties is economically significant, as fruit damage directly affects marketable yield and farmer income (Ghaderi et al., 2019). Varieties with fruit damage below 1% under natural infestation could be promoted for cultivation in *T. absoluta*-prone areas and used as donor parents in resistance breeding (Mahmoud et al., 2024).

Relationship between growth traits and resistance

The relationship between plant growth traits and pest resistance was not linear. High-yielding genotypes NGRCO 9579 and NGRCO 9568, despite abundant fruit production, experienced moderate to severe fruit damage (4.0-9.5%), indicating that higher yield potential does not confer resistance and may even increase vulnerability by providing more oviposition sites and larval food resources (Han et al., 2024).

In contrast, certain low-yielding genotypes, including NGRCO 9571 and NGRCO 9572, demonstrated superior resistance, implying a possible antagonism between resource allocation to growth, reproduction, and defensive metabolism, a phenomenon widely documented in plant-pest interactions, wherein constitutive and induced defenses compete for limited plant resources (Karasov et al., 2017). Importantly, however, NGRCO 9578 deviated from this pattern, combining high yield (167 fruits) with moderate resistance (2.4% fruit damage), thereby suggesting that compatibility between high productivity and resistance is achievable.

Study limitations

While this study provides valuable insights into resistance sources among indigenous tomato varieties, certain limitations should be acknowledged. First, the experiment was conducted during a single season under specific environmental conditions; multi-season evaluations are needed to confirm the stability of resistance traits. Second, the study did not investigate the underlying mechanisms of resistance (e.g., biochemical, morphological, or molecular factors). Third, the natural pest infestation levels varied across the experimental period, which may have influenced damage assessments. Future research should include controlled infestation studies, biochemical analyses, and molecular characterization to elucidate resistance mechanisms.

CONCLUSIONS

This study confirmed the existence of substantial genetic variability among indigenous Nepalese tomato varieties for growth, yield, and resistance to *T. absoluta*. Several genotypes demonstrated effective resistance mechanisms, with some exhibiting complete protection of reproductive structures despite foliar damage, while others showed minimal fruit damage, confirming their potential as valuable resistance sources. Certain genotypes also displayed strong foliar resistance, suggesting the presence of antixenotic or antibiotic mechanisms at the vegetative level. However, high-yielding varieties tended to experience moderate to severe fruit damage, indicating a possible antagonism between resource allocation for productivity and defensive metabolism.

Nevertheless, genotypes combining high yield with moderate resistance were identified, demonstrating that compatibility between productivity and pest resistance is achievable. The resistant genotypes identified in this study, particularly those with low fruit damage and acceptable yield, can be promoted for direct cultivation in *T. absoluta*-prone areas and utilized as donor parents in resistance breeding programs. Their integration into breeding strategies will contribute to the development of improved varieties with durable pest resistance, thereby reducing reliance on synthetic insecticides and supporting integrated pest management initiatives in Nepal.

ACKNOWLEDGEMENTS

We thank the Faculty of Agriculture and the Department of Entomology at Agriculture and Forestry University (AFU), Rampur, Chitwan, for institutional support and laboratory facilities. We are grateful to the National Agriculture Genetic Resources Center (NAGRC), Khumaltar, for providing tomato germplasm. Special thanks to Mr. Tej Bahadur Khanal for providing the field land and assistance.

We acknowledge the Integrated Agriculture Laboratory (IAL), Karnali team, Mr. Chandra Singh, Ms. Usha Adhikari, Mr. Dhan Bahadur Oli, and Ms. Ganga Bhurung for technical support, and Mr. Mohan Acharya for expert advice. We also thank Mr. Chakra Rai for sharing the 'Dullu' landrace. Finally, we appreciate the research assistance of B.Sc.Ag. Interns Mr. Suman Pun, Mr. Bipin KC, and Mr. Binod Bist, along with OJT students.

REFERENCES

- Amin, E. K., Hassan, G. M., Emara, T. E., & H. H., S. (2021). Role of plant enzymes and phytochemical components on the susceptibility of some tomato varieties to the tomato borer, *Tuta absoluta* infestation in Egypt. *International Journal of Pharmaceutical Research (09752366)*, 13(2), 3869.
- Ataide, L. M. S., Arce, C. C. M., Curtinhas, J. N., da Silva, D. J. H., DeSouza, O., & Lima, E. (2017). Flight behavior and oviposition of *Tuta absoluta* on susceptible and resistant genotypes of *Solanum lycopersicum*. *Arthropod-Plant Interactions*, 11(4), 567-575.
- Bajracharya, A. S. R., Mainali, R. P., Bhat, B., Bista, S., Shashank, P. R., & Meshram, N. M. (2016). The first record of the South American tomato leaf miner, *Tuta absoluta* (Meyrick 1917) (Lepidoptera: Gelechiidae) in Nepal. *Journal of Entomology and Zoology Studies*, 4(4), 1359-1363.
- Bitew, M. K. (2018). Significant role of wild genotypes of tomato trichomes for *Tuta absoluta* resistance. *Journal of Plant Genetics and Breeding*, 2(1), 1-12.
- Desneux, N., Wajnberg, E., Wyckhuys, K. A. G., Burgio, G., Arpaia, S., Narváez-Vasquez, C. A., González-Cabrera, J., Ruescas, D. C., Tabone, E., Frandon, J., Pizzol, J., Poncet, C., Cabello, T., & Urbaneja, A. (2010). Biological invasion of European tomato crops by *Tuta absoluta* (Meyrick): Ecology, geographic expansion and prospects for biological control. *Journal of Pest Science*, 83(3), 197-215.

- Ghaderi, S., Fathipour, Y., Asgari, S., & Reddy, G. V. (2019). Economic injury level and crop loss assessment for *Tuta absoluta* (Lepidoptera: Gelechiidae) on different tomato cultivars. *Journal of Applied Entomology*, 143(5), 493-507.
- Guedes, R. N. C., Roditakis, E., Campos, M. R., Haddi, K., Bielza, P., Siqueira, H. A. A., & Nauen, R. (2019). Insecticide resistance in the tomato pinworm *Tuta absoluta*: Patterns, spread, mechanisms, management and outlook. *Journal of Pest Science*, 92(4), 1329-1342.
- Han, P., Zhang, Y., Arnó, J., & Mansour, R. (2024). Research toward enhancing integrated management of *Tuta absoluta*, an ongoing invasive threat in Afro-Eurasia. *Entomologia Generalis*, 44(2), 263–267. <https://doi.org/10.1127/entomologia/2024/2647>.
- Karasov, T. L., Chae, E., Herman, J. J., & Bergelson, J. (2017). Mechanisms to mitigate the trade-off between growth and defense. *The Plant Cell*, 29(4), 666-680.
- Khederi, S. J., Khanjani, M., Hosseini, M. A., Leite, G. L. D., & Jafari, M. (2014). Role of different trichome styles in the resistance of *Lycopersicon hirsutum* genotypes to *Tuta absoluta* (Meyrick) (Lepidoptera: Gelechiidae). *Ecologica Montenegrina*, 1(1), 55-63.
- Kumar, A., Kumar, V., Gull, A., & Nayik, G. A. (2020). Tomato (*Solanum Lycopersicon*). In *Antioxidants in vegetables and nuts-Properties and health benefits* (pp. 191-207). Singapore: Springer Singapore.
- Mahmoud, A. M., Ebadah, I. M., Moawad, S. S., Mahmoud, Y. A., Abd El-Hameid, A. R., & Sadek, H. E. (2024). *Tuta absoluta* (Meyrick) resistance in tomato (*Solanum lycopersicum* L.) accessions and species. *International Journal of Pest Management*, 70(4), 937-949.
- Mata-Nicolás, E., Montero-Pau, J., Gimeno-Paez, E., García-Pérez, A., Ziarsolo, P., Blanca, J., & Cañizares, J. (2021). Discovery of a major QTL controlling trichome IV density in tomato using K-seq genotyping. *Genes*, 12(2), 243.
- Miano, R. N. (2017). *Behavioral responses of Tuta absoluta to wild and cultivated tomato plants and characterization of the mediating semiochemical blends* [Master's thesis, Kenyatta University]. Kenyatta University Institutional Repository. <https://ir-library.ku.ac.ke/items/dc7cb0c5-3ced-45cf-b063-15dcc4d4c5f9>.
- Ministry of Agriculture and Livestock Development. (2025). *Statistical information on Nepalese agriculture, 2080/81 (2023/24)*. Government of Nepal. <https://www.moald.gov.np/>
- Poudel, A., & Kafle, K. (2021). *Tuta absoluta* (Meyrick): A devastating pest of tomato: A review. *International Journal for Research in Applied Sciences and Biotechnology*, 8(5), 193-197.
- Rakha, M., Zekeya, N., Sevgan, S., Musembi, M., Ramasamy, S., & Hanson, P. (2017). Screening recently identified whitefly/spider mite-resistant wild tomato accessions for resistance to *Tuta absoluta*. *Plant Breeding*, 136(4), 562-568.
- Schouten, H. J., Tikunov, Y., Verkerke, W., Finkers, R., Bovy, A., Bai, Y., & Visser, R. G. (2019). Breeding has increased the diversity of cultivated tomato in the Netherlands. *Frontiers in Plant Science*, 10, 1606.

Venkatramanan, S., Wu, S., Shi, B., Marathe, A., Marathe, M., Eubank, S., & Adiga, A. (2020). Modeling commodity flow in the context of invasive species spread: Study of *Tuta absoluta* in Nepal. *Crop Protection*, 135, 104736.