**Original Research Article**

**Optimizing crop geometry and intercropping for management of Tomato leaf curl disease**

ABSTRACT

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| --- |
| **Aims:** The aim of the study was to evaluate the efficacy of various treatments of crop geometry and intercropping strategies in managing tomato leaf curl virus (ToLCV) disease on tomatoes (*Lycopersicon esculentum* Mill.) and promote sustainable farming through eco-friendly management approach.  **Study design: Factorial** Randomised Block Design with nine treatments with three replications including control.  **Place and Duration of Study:** Biswanath Chariali, Assam, India (2022-2023).  **Methodology:** Hybrid tomato variety “Swaraksha” was used to evaluate the treatments, including raising of seedling in insect-proof condition, intercropping and crop geometry. Disease incidence and vector population were recorded at intervals of 15 days from 30 to 75 days after transplanting. Statistical tests; *viz.,* t-tests, ANOVA, correlation analysis between disease incidence and yield were performed to analyse the treatment effects.  **Results:** Treatment T7 (wider spacing with garlic as an intercrop) showed no disease symptoms and had low vector population averaged to 0-1.50 numbers per leaf followed by treatment T8 (wider spacing with marigold) with mild disease symptoms and low vector populations of 0-2.33 numbers per leaf. The regression analysis revealed a coefficient of 0.83 between whitefly population and ToLCV disease incidence. Correlation analysis demonstrated a strong positive relationship between disease incidence and whitefly population, with a correlation coefficient of 0.96.  **Conclusion:** Based on the findings, intercropping with garlic could be an efficient strategy for tomato growers. Garlic intercropping effectively reduced whitefly populations reducing transmission of tomato leaf curl virus, resulting in no disease incidence. This practice could be an efficient strategy for disease management with increased productivity. Future studies could explore the long-term impacts of these practices on soil health and sustainability. Additionally, evaluating other potential intercrops and their effects on disease and vector management might provide further insights. |

*Keywords: Crop geometry; intercropping; ToLCV;* ***whitefly***

1. INTRODUCTION

Tomato (*Lycopersicon esculentum* Mill.) is an herbaceous fruiting plant of Solanaceae family. It is an important source of umami flavour “fifth taste” (Fleming 2013). Origination of tomato is believed to be in Mexican and Peruvian region. Tomato is a widely cultivated vegetable crop and is a significant part of different cuisines around the world. Tomatoes, which are classified as vegetables for nutritional reasons, are a good source of vitamin C and phytochemical lycopene. It is treated as “protective food” universally and it provides almost all the vitamins and 22 minerals in quite a fair amount. It is a good source of income for small and marginal farmers (Parmar et al. 2019). India is the second largest producer of tomato accounting for 10.51% of total production after China followed by Turkey and United States. According to data from FAOSTAT, Tomatoes ranked as the most produced vegetable with 189 million tonnes on 5,167,388 hectares in 2021, achieving an average yield of 37.1 metric tonnes per hectare (Anon 2021a).In India, it occupies an area of about 854 thousand ha producing over 21,181,000 tonnes in 2021 and an estimated 20.34 million metric tonnes in 2022 with the productivity of 25.0 MT per hectare (Anon 2022a). Tomatoes are a vital crop with significant economic value; however, their production faces numerous constraints. Approximately 200 diseases; *viz.,* bacterial, fungal, viral, nematodal, and physiological; etc., affect tomato crops, leading to severe yield losses. Viral infections alone can cause crop losses ranging from 20- 90 per cent worldwide due to over 20 different viruses (Mubeen et al. 2020). The Tomato Yellow Leaf Curl Virus (TYLCV), also known as Tomato Leaf Curl Virus (ToLCV), is among the most destructive of these diseases. Found in tropical and subtropical regions, TYLCV causes substantial economic losses. This DNA virus belongs to the genus Begomovirus and the family Geminiviridae (Subhasmita et al. 2021). The prevalence of TYLCV has been closely linked to the population of its vector, *Bemisia tabaci*, which can lead to crop failure (Das et al. 2017). Besides being a damaging sucking pest, *Bemisia tabaci* also transmits TYLCV, causing extensive damage to tomato crops throughout tropical and subtropical regions year-round (Mandali et al. 2020). The impact of Tomato Leaf Curl Virus can result in up to 100% yield loss (Singh et al. 2019). Given these challenges, managing the virus is crucial for tomato growers. Today, issues such as climate change, environmental pollution, and their management are major global concerns. To maintain sustainability in crop production, eco-friendly organic and natural farming practices are being encouraged. In India, NITI Aayog has promoted such practices through the Bharatiya Prakritik Krishi Paddhati Programme (BPKP), an initiative under the centrally sponsored scheme Paramparagat Krishi Vikas Yojana (PKVY) (Anon 2021b). Optimization of intercropping strategies and the arrangement of crop geometry are key interventions aimed at reducing vector populations for the eco-friendly management of viral diseases. There are three ways in which intercropping can lead to pest and disease escape, each contributing to a slower rate of population expansion for the pest or pathogen; *viz.,* reduced host suitability as the presence of intercrop plants makes the main crop less suitable as a host for the pest or pathogen; direct interference with the pest or pathogen to directly obstruct their activities and environmental modification through which intercropping can alter the environment to favour natural enemies of the pests or pathogens (Trenbath 1993). Intercropping offers various additional benefits, including improved soil fertility, natural pest control, efficient resource utilization, and the ability to grow multiple crops simultaneously in the same space. This practice ensures optimal use of soil nutrients (Anon 2023). Crop geometry also plays a crucial role in enhancing yield by improving resource utilization, which leads to increased photosynthetic activity. With optimal crop geometry, a higher yield and a healthy, uniform stand can be achieved in the main field (Kumar 2019).

2. material and methods

A tomato hybrid variety “Swaraksha” was selected for the field experiment. The tomato seedlings were raised in nursery bed with in an insect-proof net house equipped with a 40-mesh net for protection. The study utilized nine (9) treatments in a Factorial Randomized Block Design (RBD) with three replications to evaluate the effect of crop geometry and intercropping strategies in managing tomato leaf curl disease incidence and vector population.

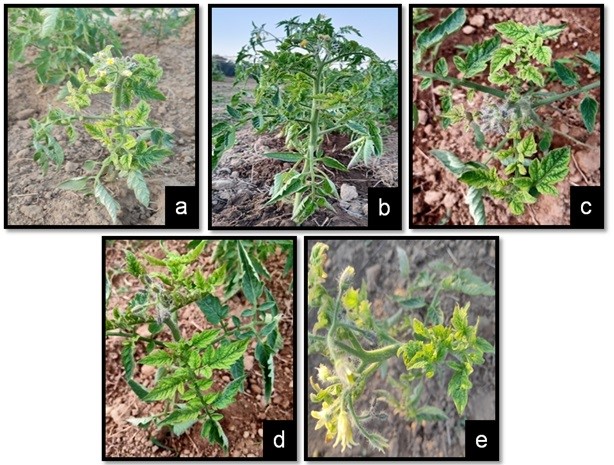
The field experiment was comprised of the following treatment combinations:

1. T0 = Recommended Spacing (50 cm X 30 cm) (Control)
2. T1 = Wide Spacing (70 cm X 40 cm)
3. T2 = Wider Spacing (80 cm X 50 cm)
4. T3 = T0 + Garlic as intercrop
5. T4 = T0+ Marigold as intercrop
6. T5 = T1+ Garlic as intercrop
7. T6 = T1+ Marigold as intercrop
8. T7 = T2 + Garlic as intercrop
9. T8 = T2 + Marigold as intercrop

Data were collected at 15 days interval to record the symptoms, vector population count and disease incidence. Leaves and twigs were visually inspected for symptoms of Tomato Leaf Curl Virus (ToLCV), and disease incidence was assessed in each experimental plot along with vector population counts. All plants in a given plot were evaluated, and their symptoms were categorized as follows; severe (>75% of plants infected), moderate (>50% of plants infected), and mild (20 whiteflies per plant) (Gogoi et al. 2023; Dey et al. 2025).The number of diseased plants was counted in each plot of the experimental area, and the percent disease incidence was calculated.

3. results and discussion

The severity of symptoms (Fig 1) observed in the experimental area varied among treatments, ranging from mild to moderate and severe in the infected plants. The control (T0) exhibited severe symptoms and had the highest vector population; averaged to 10.53 numbers per leaf. In contrast, treatment T7 (wider spacing with garlic as an intercrop) noted no disease symptoms and had low vector population averaged to 0-1.50 numbers per leaf followed by treatment T8 (wider spacing with marigold) with mild disease symptoms and low vector populations of 0-2.33 numbers per leaf (Table 1 and Table 2).



**Fig. 1. Symptoms of tomato leaf curl disease. a= Upward curling of leaves. b= stunting of plant. c= puckering of leaves. d= reduction of the size of leaves. e= yellowing of leaves**

There was no disease incidence in T7, resulting in a 100 percent reduction in disease compared to the control followed by treatment T8 (recommended spacing + marigold as intercrop) with 22.40 percent disease incidence and a 75.18 percent reduction over control. The average disease incidence in all the treatments ranged from 0 to 54.91 per cent while the incidence in the control plot was 96.20 (T0) (Table 3 and Table 4).

**Table 1. Effect of different treatments on ToLCV disease incidence (%) under field condition**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Treatments | 45 DAT | | 60 DAT | 75 DAT | 90 DAT | 105 DAT | 120 DAT |
| T0 | 0 (0.30) | | 16.30 (23.80) | 55.13 (47.92) | 66.60 (54.67) | 95.20 (77.31) | 96.20 (78.73) |
| T1 | 0 (0.23) | | 10.20 (18.62) | 14.50 (22.37) | 20.40 (32.08) | 23.15 (28.75) | 27.77 (31.78) |
| T2 | 0 (0.17) | | 11.10 (19.45) | 30.40 (33.45) | 65.60 (54.07) | 83.30 (65.85) | 92.50 (74.07) |
| T3 | 0 (0.30) | | 16.66 (24.08) | 16.66 (24.08) | 42.10 (40.44) | 57.14 (49.08) | 88.88 (70.49) |
| T4 | 0 (0.30) | | 11.66 (19.96) | 24.50 (29.65) | 33.35 (35.26) | 45.66 (42.49) | 66.67 (54.72) |
| T5 | 0 (0.23) | | 5.45 (13.49) | 25.22 (30.13) | 33.33 (35.25) | 57.56 (49.33) | 83.33 (65.87) |
| T6 | 0 (0.23) | | 19.04 (25.86) | 22.34 (28.19) | 28.24 (32.08) | 39.70 (39.04) | 54.40 (47.50) |
| T7 | 0 (0.17) | | 0 (0.17) | 0 (0.17) | 0 (0.17) | 0 (0.17) | 0 (0.17) |
| T8 | 0 (0.17) | | 5.78 (13.90) | 12.20 (20.44) | 16.60 (24.03) | 18.10 (25.17) | 22.40 (28.27) |
| SEd | | | | | | | |
| Crop geometry (A) | |  | 0.52 | 0.99 | 1.02 | 0.66 | 0.44 |
| Intercropping (B) | |  | 0.52 | 0.99 | 1.02 | 0.66 | 0.44 |
| Interaction (AxB) | |  | 1.93 | 1.71 | 1.44 | 0.94 | 0.62 |
| CD (P=0.05) | | | | | | | |
| Crop geometry (A) | |  | 1.11 | 2.11 | 2.29 | 1.49 | 0.99 |
| Intercropping (B) | |  | 1.11 | 2.11 | 2.29 | 1.49 | 0.99 |
| Interaction (AxB) | |  | 1.93 | 3.66 | 3.25 | 2.12 | 1.40 |

*\*There was no disease development up to 30 days after planting.*

*Data are sum of three replications. Data within parentheses are angular transformed values*

**Table 2. Effect of different treatments on whitefly population (number per leaf) under field condition**

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Treatments** | **45 DAT** | **60 DAT** | **75 DAT** | **90 DAT** | **105 DAT** | **120 DAT** |
| T0 | 3.23 (1.80) | 4.55 (2.13) | 8.67 (2.94) | 10.53 (3.24) | 6.43 (2.54) | 2.50 (1.58) |
| T1 | 1.67 (1.29) | 2.90 (1.70) | 2.27 (1.51) | 3.56 (1.89) | 1.50 (1.22) | 0.08 (0.27) |
| T2 | 2.89 (1.70) | 3.22 (1.79) | 6.74 (2.60) | 8.98 (3.00) | 4.75 (2.18) | 1.96 (1.40) |
| T3 | 1.32 (1.15) | 3.99 (2.00) | 4.65 (2.16) | 6.60 (2.57) | 3.34 (1.83) | 1.67 (1.29) |
| T4 | 0.40 (0.63) | 2.92 (1.71) | 5.40 (2.32) | 4.50 (2.12) | 1.89 (1.37) | 0.56 (0.75) |
| T5 | 1.40 (1.18) | 0.56 (0.75) | 6.93 (2.63) | 4.37 (2.09) | 4.12 (2.03) | 1.49 (1.22) |
| T6 | 0.30 (0.55) | 6.30 (2.51) | 3.35 (1.83) | 3.50 (1.87) | 0.50 (0.71) | 0.25 (0.50) |
| T7 | 1.00 (1.22) | 1.50 (1.22) | 1.25 (1.12) | 1.33 (1.15) | 0.00(0.22) | 0.00(0.22) |
| T8 | 0.47 (0.68) | 0.80 (0.89) | 2.25 (1.50) | 2.33 (1.53) | 1.05 (1.02) | 0.00(0.22) |
| SEd |  |  |  |  |  |  |
| Crop geometry (A) | 0.043 | 0.036 | 0.033 | 0.024 | 0.017 | 0.001 |
| Intercropping (B) | 0.043 | 0.036 | 0.033 | 0.024 | 0.017 | 0.001 |
| Interaction (AxB) | 0.061 | 0.051 | 0.047 | 0.034 | 0.024 | 0.002 |
| CD (P=0.05) |  |  |  |  |  |  |
| Crop geometry (A) | 0.080 | 0.082 | 0.075 | 0.053 | 0.039 | 0.003 |
| Intercropping (B) | 0.080 | 0.082 | 0.075 | 0.053 | 0.039 | 0.003 |
| Interaction (AxB) | 0.138 | 0.116 | 0.106 | 0.076 | 0.055 | 0.004 |

**Table 3. Effect of different treatments on ToLCV disease incidence and yield of tomato**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Treatments** | **Disease incidence (%)** | **Per cent disease reduction over control** | **Yield (tonnes/ha)** | **Per cent increase of yield over control** |
| T0 | 54.91 | - | 19.5 | - |
| T1 | 14.88 | 72.90c | 73.3 | 69.67 |
| T2 | 47.15 | 14.13g | 29.4 | 33.60 |
| T3 | 36.91 | 32.78f | 44.7 | 56.24 |
| T4 | 30.31 | 44.80de | 56.5 | 65.39 |
| T5 | 34.15 | 37.81ef | 48.7 | 59.80 |
| T6 | 27.29 | 50.30d | 50.4 | 61.19 |
| T7 | 0 | 100.00a | 90.8 | 78.46 |
| T8 | 13.63 | 75.18b | 64.5 | 73.32 |

**Table 4. Severity of tomato leaf curl disease symptoms and vector population (number per leaf) in experimental area**

|  |  |  |
| --- | --- | --- |
| **Treatment** | **Symptom severity** | **Vector population** |
| T0 | +++ | **\*\*\*** |
| T1 | + | **\*** |
| T2 | ++ | **\*\*** |
| T3 | ++ | **\*\*** |
| T4 | ++ | **\*\*** |
| T5 | ++ | **\*\*** |
| T6 | ++ | **\*\*** |
| T7 | - | **\*** |
| T8 | + | **\*** |

*(+) = Mild (less than 50%), (++) = Moderate (50-75%), (+++) = Severe (75% and more)*

*(\*) = Low (Less than 50%), (\*\*) = Medium (50-75%), (\*\*\*) = High (75% and more)*

The regression analysis revealed a coefficient of 0.83 between whitefly population and ToLCV disease incidence, indicating that a 1% increase in whitefly population corresponds to a 0.83% increase in disease incidence. Additionally, correlation analysis demonstrated a strong positive relationship between disease incidence and whitefly population, with a correlation coefficient of 0.96. This suggests that each unit increase in whitefly population is associated with a 0.96 unit increase in disease incidence.

**Fig. 2. Effect of treatments on disease incidence, vector population and yield**

Furthermore, the correlation between disease incidence and weather variables showed distinct patterns; such as, disease incidence was negatively correlated with relative humidity, while it exhibited positive correlations with temperature and bright sunshine hours.

**Discussion:** The results suggest that intercropping with garlic or marigold can significantly reduce ToLCV incidence. Garlic, in particular, appears to be highly effective in managing both the disease and vector population, likely due to its repellent properties against whiteflies (Bemisia tabaci).Garlic (Allium sativum) possesses inherent pesticidal properties that are effective in managing a range of pests, including whiteflies, termites, aphids, ants, beetles, borers, caterpillars, slugs, and armyworms. The pesticidal efficacy of garlic is attributed to its strong aromatic compounds, which provide olfactory camouflage, thereby interfering with the insects' ability to locate their hosts and feed effectively (Moono and Musenge 2019). Wider spacing, in conjunction with appropriate intercropping, seems to have a positive impact on disease management and yield. This may be due to reduced crowding, which could decrease the spread of the virus and facilitate better airflow and light penetration, further minimizing disease incidence. Lower vector populations in treatments with intercropping (especially garlic) indicate that managing vector populations is crucial for controlling ToLCV. Garlic’s efficacy in repelling whiteflies indicates its role as an effective intercrop for vector repellence. Furthermore, it has been reported that marigolds contain a compound called limonene, which repels whiteflies without causing their death. Planting marigolds among tomato plants or hanging small pots of limonene around tomato fields to disperse the scent can effectively reduce whitefly populations in tomato crops (Conboy et al. 2019).The significant high yield in T7 (wider spacing + garlic) along with no disease incidence suggests a cost-effective and sustainable management practice potentially offsetting losses due to ToLCV.

4. Conclusion

Based on the findings, intercropping with garlic could be a highly beneficial strategy for tomato growers in Assam. Garlic's effect on reducing whitefly populations and preventing ToLCV makes it a valuable component in disease management. Combining wider spacing with intercropping could further improve disease management and crop yield. This practice should be recommended to growers to optimize both disease control and productivity. Additional studies could explore the long-term impacts of these practices on soil health and sustainability. Additionally, evaluating other potential intercrops and their effects on disease and vector management might provide further insights.

Consent (whereever applicable)

Consent from all the authors were taken before submitting this manuscript.

Ethical approval (whereever applicable)

This manuscript is ethically approved by all the authors.

**Disclaimer (Artificial intelligence)**

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

References

Fleming, A. (2013). Umami: Why the fifth taste is so important. In: The Guardian, 9. Available via DIALOG. <https://www.theguardian.com/lifeandstyle/wordofmouth/2013/apr/09/umami-fifth-taste>.

Parmar, U., Tembhre, D., Das, M.P., Pradhan, J. (2019). Effect of integrated nutrient management on growth, development and yield traits of tomato (*Solanum lycopersicon* L.). International Journal of Pharmacognosy, 8: 2764-2768

Anonymous. (2021a). Agricultural Production Statistics. In: Food and Agriculture Organization of United States. Available via DIALOG. <https://www.fao.org/faostat/agricultural-production-statistics>.

Anonymous. (2022a). Production volume of tomatoes in India FY 2015-2023. Statista. Available via DIALOG. <https://www.statista.com/statistics/1039712/india-production-volume-of-tomatoes>.

Mubeen, M., Iftikhar, Y., Shakeel, Q., Hassan, F., Abbas, A., Ahmad, U., Shahid, M. (2020). A brief description of tomato leaf curl virus and its management. Plant Protection, 04: 137-147

Subhasmita, S., Mandal, N.K., Jain, S. (2021). Tomato Leaf Curl-A serious impediment in India. *In*: Just Agriculture: Multi disciplinary e-News Letter, 1(9)

Das, R., Chowdhury, R., Singh, A., Sarkar, S. (2017). Diversity of Tomato Leaf Curl Virus (ToLCV), *Bemisia tabaci* and its transmission. International Journal of Current Microbiology and Applied Sciences, 6: 78- 87

Mandali, R., Lakshmi, K.V., Reddy, K.L. (2009). Management of whitefly transmitted tomato leaf curl virus using guard crops in tomato. Indian Journal of Plant Protection, 37: 101-103

Singh, R.K., Rai, N., Singh, A.K., Kumar, P., Singh, B. (2019). A critical review on Tomato leaf curl virus resistance in tomato. International Journal of Vegetable Sciences*,*25: 373-393

Anonymous. (2021b). Natural farming NITI initiative. NITI Aayog, India. Available via DIALOG. <https://www.niti.gov.in/natural-farming-niti-initiative>.

Trenbath, B.R. (1993). Intercropping for the management of pests and diseases. Field Crops Research, 34: 381-405

Anonymous. (2023). What are the advantages of intercropping and crop rotation. Byjus. Available via DIALOG. <https://byjus.com/question-answer/what-are-the-advantages-of-intercropping-and-crop-rotation>.

Kumar, D.P., Maitra, S., Shankar, T., Ganesh, P. (2019). Effect of crop geometry and age of seedlings on productivity and nutrient uptake of finger millet (*Eleusine coracana* L. Gaertn). International Journal of Agriculture Environment and Biotechnology, 12: 267-272

Gogoi, K., Borah, M., Nath, P.D., Mishra, R. (2023). Incidence and molecular characterization of cucumber mosaic virus in Pumpkin crop from Assam. The Pharma Innovation, 12: 1531-1535

Dey, P., Rajkumari, P., Deka, S.D., Mishra, R. (2025). Integrated Approaches to Combat Cucurbit Mosaic Disease in Cucumis sativus: Insights from Assam, India. Journal of Advances in Biology and Biotechnology, 28: 648-655

Moono, A., Musenge, D.C. (2019). Testing garlic (*Allium sativum*) intercropped with Tomato (*Solanum lycopersicum*) in the control of aphids. The International Journal of Multi-Disciplinary Research, ISSN: 3471-7102

Conboy, N.J.A., McDaniel, T., Ormerod, A., George, D., Gatehouse, A.M.R., Wharton, E. et al. (2019). Companion planting with French marigolds protects tomato plants from glasshouse whiteflies through the emission of airborne limonene. PLOS ONE, 14: e0213071 DOI: 10.1371/journal.pone.0213071