**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 cultivar “Swaraksha” was used to evaluate the treatments, including raisingof 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 yieldwere 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). Origin 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 2021, 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, nematode, and physiological disorders; 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 75 different viruses (Nazir et al. 2018, 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 in tropical and subtropical regions (Hasan et al. 2019, 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

The experiment was carried out at the experimental field of Department of Plant Pathology, Biswanath College of Agriculture, AAU, Biswanath Chariali. Biswanath is at 26º 73' N latitude, 93o 15' E longitude, and 48-849 m above mean sea level. The Biswanath is located in the North Bank Plain Zone. Biswanath Chariali has a humid subtropical, dry winter climate. Its yearly temperature is 26.02 0C.

A tomato hybrid cultivar “Swaraksha” was selected for the field experiment. The cultivar produces round fruits of medium firmness (80-90 g). This cultivar has total crop duration of 90-120 days and a potential yield of 800-900 q/ha. 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 experiment was conducted in the rabi season and cropping period extended from November, 2022 to March, 2023.

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 starting from 45 days after transplanting (DAT) up to 120 DAT to record the ToLCV disease 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. The number of diseased plants was counted in each plot of the experimental area, and the percent disease incidence was calculated as follows-

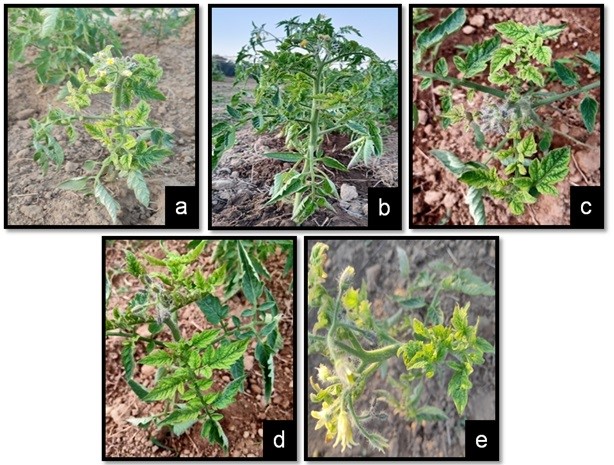
For each treatment plot, whitefly population count was determined by randomly selecting five plants from each plot.Three leaves were chosen from each selected plants; one leaf each from the upper, middle, and bottom portion of the plant (Nzanza and Mashela 2012). The average vector count was then calculated from three replications for each treatment. Data on fruit yield were also recorded for each treatment and further correlated with disease incidence and vector population.

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).

3. results and discussion

The characteristic symptoms of tomato leaf curl disease were observed in the experimental plot which included upward curling of leaves, stunted growth of the plant, leaf puckering, reduction of leaf size and yellowing of leaves (Fig 1).

The severity of symptoms observed in the experimental area varied among all the treatments, ranging from mild to moderate and severe in the infected plants (Table 1). The control (T0) exhibited severe symptoms with highest ToLCV disease incidence of 0 to 96.20 per cent and the highest vector population; ranged from 2.50 to 10.53 numbers per leaf. In contrast, treatment T7 (wider spacing with garlic as an intercrop) noted no disease incidence and symptoms with lowest vector population ranged from 0 to 1.50 numbers per leaf followed by treatment T8 (wider spacing with marigold as intercrop) showed mild disease symptoms and low disease incidence of 0 to 22.40 per cent with low vector populations ranged from 0- 2.33 numbers per leaf (Table 2 and Table 3).



**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**

**Table 1. 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)*

**Table 2. 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*

*T0 = Recommended Spacing (50 cm x 30 cm) (Control), T1 = Wide Spacing (70 cm x 40 cm), T2 = Wider Spacing (80 cm x 50 cm), T3 = T0 + Garlic as intercrop, T4 = T0+ Marigold as intercrop, T5 = T1+ Garlic as intercrop, T6 = T1+ Marigold as intercrop, T7 = T2 + Garlic as intercrop, T8 = T2 + Marigold as intercrop*

**Table 3. 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 |

*Data are mean of three replications. Data within parentheses are square root transformed values.*

*T0 = Recommended Spacing (50 cm x 30 cm) (Control), T1 = Wide Spacing (70 cm x 40 cm), T2 = Wider Spacing (80 cm x 50 cm), T3 = T0 + Garlic as intercrop, T4 = T0+ Marigold as intercrop, T5 = T1+ Garlic as intercrop, T6 = T1+ Marigold as intercrop, T7 = T2 + Garlic as intercrop, T8 = T2 + Marigold as intercrop*

Treatment T7 (wider spacing with garlic as an intercrop) showed the most effective result in managing ToLCV disease with no disease incidence and 100 per cent reduction of disease over control followed by treatment T8 (wider spacing + marigold as intercrop) noted 22.40 per cent disease incidence and 75.18 per cent reduction of disease over control. The average disease incidence in all the treatments ranged from 0 to 54.91 per cent. Highest yield of 90.80 tonnes/ha was observed in T7 (wider spacing with garlic as an intercrop) and the lowest yield of 19.50 tonnes/ha was recorded in the control (T0) (Table 4 and Fig 2).The treatment T7 (wider spacing with garlic as an intercrop) showed the highest per cent increase in yield over control, *viz*.; 78.46 per cent.

**Table 4. Effect of different treatments on ToLCV disease incidence and yield of tomato**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **Average disease incidence (%)** | **Average whitefly population (No./Leaf)** | **Per cent disease reduction over control** | **Yield (tonnes/ha)** | **Per cent increase of yield over control** |
| T0 | 54.91 | 5.99 | - | 19.5 | - |
| T1 | 14.88 | 2.00 | 72.90c | 73.3 | 69.67 |
| T2 | 47.15 | 4.76 | 14.13g | 29.4 | 33.60 |
| T3 | 36.91 | 3.60 | 32.78f | 44.7 | 56.24 |
| T4 | 30.31 | 2.61 | 44.80de | 56.5 | 65.39 |
| T5 | 34.15 | 3.15 | 37.81ef | 48.7 | 59.80 |
| T6 | 27.29 | 2.37 | 50.30d | 50.4 | 61.19 |
| T7 | 0 | 0.85 | 100.00a | 90.8 | 78.46 |
| T8 | 13.63 | 1.15 | 75.18b | 64.5 | 73.32 |

**Fig. 2. Effect of different treatments on ToLCV disease incidence, whitefly population and yield of tomato**

The regression analysis revealed a coefficient of 0.83 between whitefly population and ToLCV disease incidence (Fig 3), indicating that a 1 per cent increase in whitefly population corresponds to a 0.83 per cent 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. Yield was negatively correlated with disease incidence as well as whitefly population with correlation coefficient of 0.97 and 0.71, respectively (Table 5).

**Fig. 3.Normal probability plot between disease incidence and whitefly population**

**Table 5. Estimate of correlation**

|  |  |  |
| --- | --- | --- |
| **Variables** | **Coefficient** | **Correlation** |
| Whitefly population and disease incidence | 0.96 | Positively correlated |
| Whitefly population and yield | -0.71 | Negatively correlated |
| Disease incidence and yield | -0.97 | Negatively correlated |

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 (Table 6).

**Table 6. Correlation estimate of weather data with disease incidence (%)**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Treatments** | **RH (M)** | **RH (E)** | **Min. Temp.** | **Max. Temp.** | **BSSH** |
| T0 | -0.2887 | -0.772\* | 0.283959 | 0.394050 | 0.196073 |
| T1 | -0.18992 | -0.67941 | 0.082338 | 0.102054 | -0.09064 |
| T2 | -0.33572 | -0.67855 | 0.343034 | 0.457557 | 0.317247 |
| T3 | -0.4816 | -0.49958 | 0.420559 | 0.352848 | 0.276087 |
| T4 | -0.41591 | -0.6591 | 0.361225 | 0.348239 | 0.13496 |
| T5 | -0.49648 | -0.65632 | 0.476344 | 0.459691 | 0.219033 |
| T6 | -0.32449 | -0.60946 | 0.21829 | 0.166623 | 0.050748 |
| T7 | 0 | 0 | 0 | 0 | 0 |
| T8 | -0.25481 | -0.72369\* | 0.222475 | 0.332566 | 0.133797 |

**Discussion:** The results of the present study suggested that intercropping with garlic or marigold can significantly reduce ToLCV disease incidence by reducing the vector population. Garlic, in particular, appeared to be highly effective in managing vector population, likely due to its repellent properties against sucking pests; such as, whiteflies (Bemisia tabaci). Direct effects of intercropping with garlic or related volatiles releasing plants on aphids which is also a sucking pest through repellent properties; viz., emission of repellent volatile compound, toxic effect of the volatile compound on target insect, masking host plant odours by the volatiles and masking visual orientation as well as indirect effects; viz., stimulating natural enemies such as parasitoids and inducing resistance in host plant was reported by Zhou et al. 2013.These effects can also be attributed to garlic’s repellent properties against whiteflies, which is also a sucking pest of different crops.

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 (Kaluwa and Kruger, 2012). 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). Diallyl disulfide, an essential component of garlic volatiles, has been reported to possess insecticidal activity (Edris and Fadel 2002). Allicin (diallylthiosulfinate) and diallyl disulfide are the bioactive ingredients present in garlic which have insecticidal activity (Prowse et al. 2006).

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 of vector, which could decrease the spread of the virus and also facilitate better airflow and light penetration because of wider spacing producing congenial canopy environment, further minimizing disease incidence due to reduced virus transmission by vector and thereby better crop health with increased yield. Garlic is reported to be one of the potential crops that could be integrated as intercrop to decrease the crowding of sucking pests in its neighboring crops as, garlic crop repel pests through emission of volatile compounds and also attracts natural enemies to control pests (Zhou et al. 2013). Intercropping of garlic with cantaloupe crop significantly reduced infestations of B. tabaci compared between the intercropped area and the cantaloupe monoculture (Abd-Allah et al. 2018).

Furthermore, it has been reported that marigolds contain a volatile compound called limonene; a monocyclic terpene, which repels whiteflies. Limonene, a repellent volatile plant compound (VPC) released from leaves of marigold has been reported as the probable cause of the reduction in whitefly activity on tomato intercropped with marigold (Conboy et al. 2019). 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).

In the present study, lower vector populations in treatments with intercrop (especially garlic) resulting in no disease or lower disease incidence indicated that intercropping helped in reducing vector populations which is crucial for managing ToLCV disease. Garlic’s efficacy in repelling whiteflies indicates its role as an effective intercrop for vector repellence. The significant high yield in T7 (wider spacing + garlic as intercrop) with no disease incidence suggests a cost-effective and sustainable management practice potentially offsetting losses due to ToLCV disease.

4. Conclusion

Based on the findings, intercropping with garlic could be a highly beneficial and efficient strategy for tomato growers in Assam to manage especially virus diseases transmitted by the sucking pests. Garlic's effect on minimizing whitefly populations and reducing ToLCV disease incidence makes it a valuable component in disease management modules. Combining wider spacing with intercropping could further improve crop yield due to reduced disease. This practice could be recommended to growers for optimization of both disease management and productivity. Additional studies could explore the long-term impacts of these practices on soil health and sustainability. Furthermore, evaluating other potential intercrops and their effects on virus disease and vector management might provide new 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.

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