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Harnessing integrated disease management strategies to combat major tomato diseases and seasonal dynamics in Tamil Nadu

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Abstract

An extensive survey was conducted to observe the disease incidence in the major tomato-growing areas of Tamil Nadu during kharif, rabi and summer seasons. Our results showed that major diseases were effectively controlled by (seed priming with *Bacillus subtilis* (Bbv 57) @4g/kg of seed followed by soil application of *B. subtilis* (Bbv 57) @10g/kg of soil while filling plug trays, soil drenching with *B. subtilis*, (Bbv 57) @5% after seed germination and covering nursery beds with 50-mesh nylon net until transplanting) and in the main field (border row planting with two rows of maize 15 days before transplanting seedlings, followed by seedling dip with carbendazim 12% + mancozeb 63% WP (Wettable Powder) @ 0.1 % at the time of transplanting and sequential spraying with acephate 75% WP @1.5g/L on 10 days after transplanting (DAT), fipronil 5% SC (Suspension Concentrate) @1.5mL/L on 20 DAT, copper hydroxide 77% WP (2.0g/L) on 25 DAT, imidacloprid 70% WG @2g/15L on 40 DAT, fenamidone 10%+mancozeb 50% WDG (Water-Dispersible Granules) @ 0.25% two to three times from 45 DAT at 10 days intervals). The results of the IDM (Integrated Disease Management) experiment revealed minimum disease severity for damping off (3.95%) fusarium wilt (8.69%), early blight (5.66%), tomato leaf curl virus (10.56%) and spotted wilt virus (10.77%) compared to the control. The developed IDM module was tested and verified in the farmer's fields and the farmer's practice and control were compared confirming the IDM module as superior. Such an approach could also benefit prolonged tomato production and high economic returns.

Keywords

disease incidence; integrated disease management; seasonal occurrence; survey; tomato; yield

Introduction

Tomato (Lycopersicon esculentum), an important vegetable crop in India, is grown on an area of 4.58 million hectares, with a production of 74.62 million tonnes. Tamil Nadu is a major tomato-growing state, with an area of 22000 hectares and a production of 227700 tonnes. The most important diseases of tomatoes are damping off, fusarium wilt, early blight spotted wilt virus and tomato leaf curl virus (TLCV). These diseases are the primary problems in this region, with average intensity varying from 35-40% annually. Losses may increase to 86% due to early blight (1). Tomato production is seriously reduced due to increasing infections with early blight (*Alternaria solani*), late blight (*Phytophthora infestans*) (34) and leaf curl virus (ToLCV) diseases.

ToLCV has increased to alarming proportions in tomato cultivation particularly during summer season (February to May) in Southern India (2) and autumn season (August to December) in northern plains (3, 4) and early-autumn and autumn-winter season (September to February) in Eastern India (5, 6) causing yield loss up to 100% in favorable condition (7). The intensive agricultural practices in Tamil Nadu have created conditions conducive to disease development, which remain the leading drawback for vegetable growers.

Farmers used to manage foliar diseases with spray schedules utilizing two or more different fungicide groups or fungicide formulations containing two different chemical groups at least 8–10 times in one growing season to limit the development of fungicide-resistant strains, which have been reported overseas. On the other hand, management of virus vector whitefly with the use of systemic insecticides at least 10–12 times is a common practice among tomato growers in India.

Exclusive reliance on fungicides/insecticides as a control strategy against these biotic stresses has resulted in several undesirable effects like pesticide pollution, resurgence of secondary pests, fungicide/insecticide resistance, elimination of beneficial fauna and different human health hazards. Resistance management is a key consideration for these biotic stresses in tomatoes. The common methods of avoiding resistance to fungicides include minimizing the number of applications per season, using fungicides with different modes of action and applying them in alternation or as mixtures (8). It has also been reported that the use of a physical barrier can protect the crop against ToLCV disease (9). Relying solely on chemical pesticides for disease management is neither sustainable due to environmental concerns nor economically viable for farmers considering the cost-benefit balance. All these issues along with the growing responsiveness among the farmers regarding pesticide residues, environmental pollution, sub-soil water and increased problem of pathogen resistance towards pesticides, have been the convincing reasons for moving away from the total dependence on pesticides and adopting integrated strategies that would involve one or more than one concepts of plant disease management. Adoption of integrated disease management practices for vegetable crops is of utmost importance, as most vegetable crops are not harvested at the end of the season but are instead harvested over a long duration through multiple harvests. Moreover, tomato is even eaten raw, therefore, dependence on chemicals for the management of various diseases is a great health hazard to the consumer. Therefore, an attempt has been made to manage the important diseases of tomatoes through a sustainable integrated disease management (IDM) package, addressing multiple disease problems from nursery raising to crop harvest.

Materials and Methods

Survey of tomato diseases

The survey was conducted in three seasons, i.e. kharif (July - October), rabi (October-March) and summer season (March and June) on the tomato crop, which is grown in Coimbatore, Thiruppur, Dindigul, Karur, Erode, Salem, Trichy, Krishnagiri and Dharmapuri districts of Tamil Nadu. The survey has been executed with local farmers in selected five villages in each district for consecutive three years, where tomato is being grown. The survey was subjected to two growth stages of tomato i.e. seedling (3-6 weeks after transplanting) and maturity (8-12 weeks after transplanting).

The average disease infections were calculated as per the formula given below in Eqn. 1.

$$\text{Percent disease incidence} = \frac{\text{Number of infected plants}}{\text{Total number of plants observed}} \times 100 \qquad \text{(Eqn.1)}$$

Per cent disease index (PDI) value was visually estimated by whole-plant scoring under natural epidemic using a 0-5 scale as given below (Eqn. 2).

$$\text{Percent disease index} = \frac{\text{Sum of all numerical ratings}}{\text{Total no. of plant examined}} \times \frac{100}{\text{Maximum rating scale}} \qquad \text{(Eqn.2)}$$

For recording early blight intensity, the plants were scored on 0-5 scale (Table 1) given below and the per cent disease index was calculated using the formula.

Table 1. Whole-plant scoring using a 0-5 scale

Disease Score	Score Description
0	Free from infection
1	One or two necrotic spots on few lower leaves of the plant, covering nearly 1-10% surface area of plant
2	A few isolated spots on leaves covering 11-25% surface area of plant
3	Many spots coalesced on the leaves covering 26-50% of the surface area of the plants
4	Concentric rings on the stem petiole, fruit covering 51-75% leaf area of plant
5	Whole plant blighted leaves and fruits starting to fall covering more than 75% leaf area of the plant

Integrated disease management

An integrated disease management package was formulated considering the major problems identified through intensive survey and surveillance of tomato-growing areas over several years. It was evaluated using tomato hybrid (CO3). The sowing and transplanting of tomato hybrid CO3 were carried out during the rabi season, which is the main season of tomato cultivation. The experiment was conducted at HC&RI, TNAU and Coimbatore farms for three consecutive years. It was also validated at the farmer's field in Sattakalpudur, Kinathukadavu and Coimbatore districts. The relative incidence of damping off, early blight, spotted wilt virus, TLCV and yield constituted the basis of comparison with control.

Seeds of tomato hybrid (CO3), a susceptible hybrid to most diseases, were sown in well-prepared nursery beds. Nursery beds of 6 inches in elevation and 80 cm wide were prepared by thoroughly mixing farmyard manure (FYM). These beds were sufficiently moistened using bucket sprinkler irrigation manually. The beds were then covered with 100 mm thick transparent polythene sheet and each side was perfectly airtight with moist soil. After germination seed beds were covered with a 50-mesh nylon net and all the nursery management practices were followed in time without disturbing the insect-proof net. Twenty-five days old separately treated seedlings were transplanted to the main field, which was previously surrounded by two rows of maize, sown 15 days before transplanting of tomato seedlings during the 1st week of October each year. Plots were divided into six treatment combinations following a Randomized Block Design with four replications.

Treatment combination

Covering of nursery bed with a white nylon net with 50 mesh and 2 rows of maize sown 15 days before transplanting was common in all treatments.

T1. Treatment with biological control

i) Nursery treatment with *B. subtilis* (Bbv 57): Seed priming @ 4g/kg, ii) soil application @10 g/kg of soil while potting and iii) soil drenching @ 5% after seed germination.

Main field treatment with *B. subtilis* (Bbv 57): Seedling dip (5%) and three sprays with *B. subtilis* (Bbv 57) (1.0%) at 10 days interval.

T2. Treatment with fungicides Nursery treatment: Seed treatment with Captan 50% WP (2g/kg) + drenching with fosetyl Al 80% WP @ 0.1% immediately after germination + spray with copper hydroxide 77% WP (2.0 g/L) at 3–5 leaf stage.

Main field treatment: Seedling dip with 0.1 % (carbendazim 12% + mancozeb 63% WP) + spray with copper hydroxide 77% WP (2.0 g/L) on 25 DAT + spray with fenamidone 10% + Mancozeb 50% WDG (0.25%) three times at 10 days intervals from 45 DAT.

T3. Treatment with insecticides

Main field treatment: Spray with Acephate 75% WP @1.5 g/L on 10 days after transplanting + spray with fipronil 5% SC @ 1.5 ml/l on 20 DAT + spray with imidacloprid 70% WG @ 2g / 15 L on 40 days after transplant.

T4. Treatment with fungicides and insecticides

Nursery treatment: Seed treatment with Captan 50% WP (2g/kg) + drenching with fosetyl Al 80% WP @ 0.1% immediately after germination + spray with copper hydroxide 77% WP (2.0 g/L) at 3–5 leaf stage.

Main field treatment**:** Seedling dip with 0.1 % (carbendazim 12% + mancozeb 63% WP) + spray with acephate 75% WP @1.5 g/L on 10 days after transplanting + spray with fipronil 5% SC @ 1.5 mL/L on 20 DAT+ spray with copper hydroxide 77% WP (2.0 g/L) on 25 DAT + spray with imidacloprid 70% WG @ 2g / 15 L on 40 DAT + spray with fenamidone 10% + mancozeb 50% WDG (0.25%) two to three times from 45 DAT at 10 days intervals.

T5. Integrated management

Nursery treatment with *B. subtilis* (Bbv 57): Seed priming @ 4g/kg, ii) soil application @10 g/Kg of soil while potting and iii) soil drenching @ 5% after seed germination.

Main field treatment: Seedling dip with 0.1 % (carbendazim 12% + mancozeb 63% WP) + spray with acephate 75% WP @1.5 g/L on 10 days after transplanting + spray with fipronil 5% SC @ 1.5 mL/L on 20 DAT+ spray with copper hydroxide 77% WP (2.0 g/L) on 25 DAT + spray with imidacloprid 70% WG @ 2g / 15 L on 40 DAT + spray with fenamidone 10% + mancozeb 50% WDG (0.25%) two to three times from 45 DAT at 10 days intervals.

T6. No spray (Control)

Occurrence of early blight was observed fortnightly using a 0–5 scale and average PDI (Percent Disease Index) was calculated. PDI of damping off, fusarium wilt, spotted wilt virus, TLCV was observed.

Validation of efficient IDM package compared with farmers' practice was carried out during 2020-21 in the Sattakalpudur farmer's field, Coimbatore. Here control means free from any plant protection measures. Farmers' practices involve the indiscriminate use of pesticides without sufficient knowledge of diseases and insect pests.

Experimental data recording

Total yield and marketable fruits (excluding physical, disease and insect damage fruits) of the periodical harvests from the individual plot were counted and weighed to express total yield and marketable fruit yield per plot (kg) and then it was converted to fruit yield in hectare. The severity of different diseases (early blight, wilt, ToLCV and spotted wilt virus) was recorded in all the individual plots through visual observation and based on different disease grading scales.

Economic analysis

The incremental cost-benefit ratio (ICBR) over the control was calculated using Eqn. 3 considering the price of various inputs used, labor wages and interest on occupied capital for the half-life of total crop duration (4-5 months) @ 12.5% per year (as per the Commission for Agricultural Costs and Prices, Ministry of Agriculture and Farmers Welfare, Govt. of India) and the farm-gate price of tomato fruits.

$$\text{ICBR} = \frac{\text{Incremental Net Returns (INR)}}{\text{Incremental Cost of Cultivation (ICC)}} \quad \text{(Eqn.3)}$$

Incremental Net Returns (INR) = Net returns from the treatment - Net returns from the control

Incremental Cost of Cultivation (ICC) = Cost of treatment - Cost of control

Statistical analysis

The collected data were statistically analyzed using the IRRISTAT version 92 of the International Rice Research Institute, Biometrics unit, the Philippines (10).

Results and Discussion

A roving survey was carried out to determine the severity of tomato diseases in Tamil Nadu during three seasons. Five villages were selected from each district and data were recorded on disease severity. The results presented in Fig. 1 revealed that damping of ranged from 13.73% to 18.35%, fusarium wilt from 13.25% to 23.81%, early blight from 15.26% to 22.53% spotted wilt from 25.33% to 3.62% and leaf curl virus ranged from 27.10% to 36.33% in all the three season of surveyed districts. Fungal disease was found more severe during rabi season whereas virus disease incidences are high during summer season. High levels of disease severity may be attributed to the presence of the pathogenic population in this region, as confirmed in the present study. A higher occurrence of fungal diseases was observed during the rabi and kharif seasons due to the prevailing weather conditions like high relative humidity and intermittent rainfall. The incidence of fusarium wilt, leaf spot and damping off is higher in the rainy season. These findings were compared with other workers who reported early blight on tomato (11). The disease incidence was relatively higher in summer than the rabi transplanting crop. Virus disease severity was found to be highest in summer season, which may be due to the active vector population during the season. The results of the present investigation are in agreement with the results of different researchers, who worked on this aspect. ToLCV infected plant produced very few fruits when infected within 20 days after planting resulting in up to 92.30% yield loss. The tomato plants are susceptible to ToLCV infection in all the stages of their growth and 50-70% yield loss was observed due to ToLCV infection in tomato during February-May (11). 96% tomato yield loss occurred in summer season due to ToLCV (11). It was observed that ToLCV was present in all the fields of Belgaum, Dharward, Haveri districts of Karnataka with disease occurrence of 4% to 100 % during rabi and 60% to 100% during the summer season (2). A study described that tomato leaf curl virus is the most devastating disease causing yield loss of up to 100% during summer throughout India (11). This study calls attention to the need for an integrated disease management strategy for minimizing the losses due to various diseases of tomato in this region to ensure a high yield of crops and the wellbeing of the farmers community.

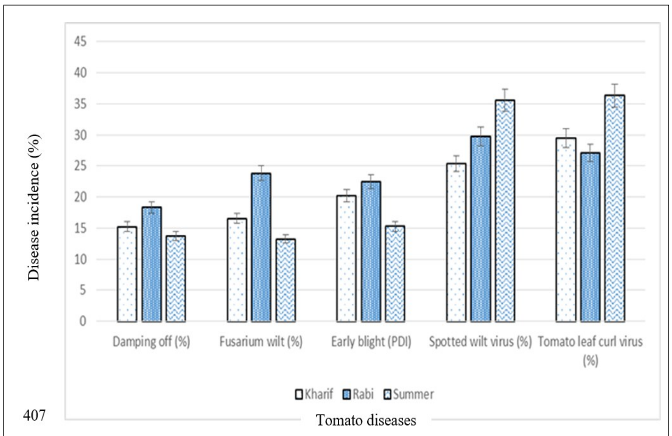

Fig. 1. Survey of tomato diseases at different seasons in Tamil Nadu.

Effect on diseases of the main field

The result of the field experiment revealed that all the treatments were effective in reducing tomato diseases. The results of the IDM experiment revealed that minimum disease severity of damping off (3.95) fusarium wilt (8.69), early blight (5.66), tomato leaf curl virus (10.56) and peanut bud necrosis virus (10.77) was recorded followed by treatment with fungicides and insecticides (T4) imidacloprid against control (Table 2).

In this backdrop, the integrated management practices involving imidacloprid (neonicotinoids) could reduce whitefly populations substantially in tomato plots in advance of their mass migrations, if any that were thought to occur in the fall following systemic chemical protection of such tomato plots in sequential spraying. Imidacloprid is the first nicotinoid used to control whiteflies (12, 13) in many crops. Our results agreed well with the observations of previous workers (14) who recommended a neonicotinoid group of insecticides (Acetamiprid, thiomethoxam, imidacloprid clothianidin, nitenpyram, thioclopric and dinotefuron) to reduce whitefly populations to save tomato plants against leaf curl virus diseases. Nicotinoids are derived from naturally occurring nicotine compounds that block postsynaptic nicotinergic acetylcholine receptors (14). They have low mammalian toxicity, minimum nontarget species effects and a broad range of efficacy. Nicotinoids are good at controlling phloem-feeding insects because of their high water solubility and good residual activity, which makes them great systemic insecticides (15, 16).

In the integrated management practices using fungicides (Fenamidone 10% + Mancozeb 50% WDG) which have both systemic and contact action, better reduction of fungal diseases was observed compared to other treatment combinations. Our results agreed well with the

Table 2. Effect of different treatments on tomato disease incidence

Treatments	Disease incidence/ intensity (%)				
	Damping off (PDI)	Fusarium wilt (%)	Early blight (PDI)	Spotted wilt virus (%)	*Tomato leaf curl virus* (%)
T1	5.71 (17.9)	14.9 (29.1)	11.2 (26.0)	23.9 (38.6)	24.11 (37.2)
T2	5.08 (16.7)	10.0 (26.5)	8.20 22.0)	24.2 (39.1)	22.30 (35.6)
T3	13.35 (27.8)	19.8 (34.0)	15.8 (30.6)	14.4 (28.8)	14.50 (28.0)
T4	4.91 (16.6)	10.1 (22.4)	7.53 (20.8)	15.1 (30.0)	14.37 (27.6)
T5	3.95 (14.3)	8.69 (19.6)	5.66 (17.8)	10.5 (24.6)	10.77 (24.1)
T6	18.35	23.8	22.5	29.7	27.10
CD (p=0.05)	**1.67**	**4.89**	**3.26**	**4.38**	**3.29**

All values are the mean of three years of data.

Data in parentheses are arcsine transformed values.

Table 3. Effect of different treatments on tomato yield

Treatments	Total yield (q/ha)	Marketable yield (q/ha)	BC ratio
T1	364.00	346.07	2.65
T2	416.97	399.00	3.32
T3	433.94	416.24	3.60
T4	484.50	467.37	3.81
T5	506.54	484.57	4.07
T6	332.75	311.82	2.53
CD (p=0.05)	**15.42**	**13.43**	**-**

All values are the mean of three years of data.

earlier observations (17). This result was also supported by the report of Ferro (1999) who found significant reduction in disease intensity with three or more applications of combined fungicide application in the field (18). The application of biocontrol agent, *B. subtilis* Bbv 57 (T1) and treatment with only insecticides (T3) did not substantially reduce target leaf spot disease incidence with respect to control. The lack of efficacy of the biocontrol agent, which is extremely safe for humans and the environment, makes it an unlikely candidate for use against target leaf spot disease in tomatoes, as reported earlier.

The treatment involved spraying mancozeb as one of the fungicides, which was found to be effective for managing tomato early blight, as reported previously (19). A spray of protective fungicide is less effective than those combined with a systemic product in controlling early blight disease because the protective fungicide does not enter into the system of the leaf and a substantial proportion of the fungicide may be washed from the leaves by the heavy water drops or rainfall. In contrast, systemic fungicides are effective when applied both before and after disease incidence, making timing less critical than products with limited post-infection.

The overall disease control performance of IDM module was calculated in terms of yield. Maximum fruit yield was recorded in integrated disease management module (506.54 q/ha) which also registered highest BC ratio of 4.07 compared to control (Table 4). It indicates that the present IDM module is effective in management of diseases and increases yield. The integrated management practices (T5) could drastically reduce the incidence of different diseases of tomato at appropriate stages that result in prolonged harvest of the crop and ultimately increase the maximum marketable fruit yield compared to other treatments. Our results also confirmed earlier observations (20), which reported that the combined effect of covering the seeding in the nursery with insect-proof net and spraying with fungicide in the field resulted in a significant increase in tomato yield, but the effect of the fungicide application alone gave an insignificant increase in yield (21). On the other hand, sequential spraying of the neonicotinoid group of insecticides in treatments T5 and T4 in the main field along with physical barriers in the nursery and main field, also reduced substantial vector (*Bemisia tabaci*) population which ultimately resulted less incidence of ToLCV disease and high marketable fruit yield. Our results support the observations of previous workers (22), who suggested that prophylactic

Table 4. Effect of IDM on yield of tomato yield at farmer's field

Treatments	Disease incidence/ intensity (%)				
	Damping off	Fusarium wilt	Early blight	Spotted wilt virus	*Tomato leaf curl virus*
Farmers Practice	7.22 (15.54)	17.33 (24.54)	11.35 (19.57)	24.96 (29.96)	25.27 (30.14)
IDM	5.52 (13.52)	11.33 (19.50)	6.03 (13.87)	11.00 (19.24)	11.83 (20.01)
Control	20.52 (26.93)	26.99 (31.27)	23.28 (28.82)	28.24 (32.08)	25.83 (31.49)
CD (p=0.05)	**0.55**	**2.42**	**2.63**	**2.49**	**2.06**

All values are the mean of five replications.

Data in parentheses are arcsine transformed values

applications of imidacloprid should be performed to reduce the whitefly population and leaf curl virus incidence in tomatoes, resulting in higher yield (12, 23).

Similarly, the incremental cost-benefit ratio (ICBR) was found to be the maximum in integrated management practices (T5) (1:4.07) followed by T4 (1: 3.81) and the minimum ICBR was recorded in T6 (1:2.53). This was due to the high excess yield recorded in integrated management practices, with the minimum difference in excess cost involved as compared to promising treatments. A comparison of ICBR among different management practices in tomato disease was also reported (3, 24).

Validation of IDM package at farmer's field

The validation of the developed IDM module at the farmer's field indicated that disease incidence was lower, including damping off (5.52), fusarium wilt (11.33), early blight (6.03), tomato leaf curl virus (11.00), peanut bud necrosis virus (11.83) compared to farmers practice and control (Table 4). The marketable yield of tomato in IDM was 506.73q/ha, which was significantly superior to the control (294.78q/ha). The cost-benefit ratio was significantly higher in the IDM module compared to the control (1:4.20) (Table 5). It was also concluded that the need-based plant protection measures applied in the IDM programme were more cost-effective and achieved economic yield with less environmental pollution than sole chemical methods. Hewson reported that the level of control and crop yield from IDM practices are better than conventional methods of control (25). Hewson reported yield in the IDM practices was 6.31 t/ha as compared to the control 5.25 t/ha in non-IDM practices and the average pesticide expenditure of IDM-trained farmers was significantly lower than non-IDM farmers.

In this study, the antagonists treated during the nursery stage are believed to have better chances of survival and colonization on the tomato root. Soil

Table 5. Effect of IDM on yield of tomato at farmer's field

Treatments	Total yield (q/ha)	Marketable Yield (q/ha)	BC ratio
Farmers Practice	367.93	352.43	2.87
IDM	522.23	506.73	4.20
Control	310.28	294.78	2.70
CD (p=0.05)	**10.94**	**9.52**	

All values are the mean of five replications.

application of biocontrol agents effectively reduced soil-borne and foliar pathogens in several crops (26, 27). The *P. fluorescens* strains Pf1 reduced the soil-borne infection through several mechanisms including the production of lytic enzymes (28), siderophores, salicylic acid and induction of hydrogen cyanide (29). Further disease development is prohibited by the timely application of fungicides (30).

Murugan (2002) reported that damage due to TSWV and TLCV was 45-65% higher in sole crop than tomato intercropped with mustard (31). The present IDM package is significantly superior over control and effective in the management of the leaf curl virus of tomato. The Whitefly population was also significantly reduced in IDM than in the control treatment (data are not shown here). In the previous studies, it was not possible to determine if increased yields were due to reduced insect populations or reduced viruses vectored by the insects, mulch effects on plant growth (32). Furthermore, mulches reflect more radiation toward the abaxial sides of leaves and they emit less long-wave radiation because they are cooler than light -absorbing mulches (33). The mulch effects on plant physiology and growth are not understood, but it is expected that positive and negative effects on yield, depending on the circumstances, occur (34). Results of the above-mentioned studies indicate that the development of a novel integrated approach is of great importance and is a promising approach to sustainable agriculture.

Conclusion

This survey revealed that fungal diseases are more prevalent during the rabi season, while virus diseases dominate the summer season in tomato cultivation in Tamil Nadu. The study suggests that the major tomato diseases can be effectively controlled through the integration of cultural, biological and chemical management practices, adopted both in the nursery and main field. As the cost of cultivation is less and the returns are higher on IDM than non-IDM farms. Mass adoption of this technology among the tomato growers could make a dent in increasing tomato productivity of the country as a whole. Future advancements in precision agriculture and sustainable practices could further enhance the effectiveness and scalability of IDM technologies in tomato cultivation. For instance, real-time disease monitoring through advanced sensors and satellite imaging can enable early detection and targeted interventions. The use of AI-driven analytics to optimize the timing and application of biocontrol agents or fungicides can significantly improve resource efficiency. Additionally, incorporating renewable energy solutions, such as solar-powered irrigation systems, could further reduce the carbon footprint of tomato cultivation while maintaining productivity. These advancements could pave the way for more resilient and environmentally sustainable tomato farming practices.

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Authors' contributions

PP wrote the original manuscript. KM reviewed and edited the manuscript. KA carried out technical editing. JI reviewed the manuscript. All authors read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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