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Evaluation of Integrated Pest and Disease Management Combinations against Major Insect Pests and Diseases of Tomato in Tamil Nadu, India

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Abstract: Tomatoes are one of the predominant vegetable crops grown throughout the year in Tamil Nadu, India. Their perishable nature and resource-intensive cultivation make them susceptible to biotic stress. The damage caused by invasive insect pests, bacterial wilt during the rainy season, and viral diseases are major yield-limiting factors, and the farmers mostly depend on calendar-based insecticide applications for insect pest and disease management in tomatoes. The desired tomato hybrids grafted onto bacterial wilt-resistant eggplant rootstocks offer protection against bacterial wilt during the rainy season. The integrated pest and disease management (IPDM) practices consist of resistant grafted tomato seedlings (wild eggplant rootstocks EG 203 and TS 03), bioinoculants (*Bacillus subtilis* + *Trichoderma asperellum* + *Purpureocillium lilacinum*), pheromone traps (*Phthorimaea absoluta* and *Helicoverpa armigera*), botanicals (azadirachtin), microbial pesticides (*Bacillus thuringiensis*, *Metarhizium anisopliae*, and *Beauveria bassiana*), and bio-rationals, which were evaluated in four locations in two major tomato-growing tracts of Tamil Nadu. The results revealed that the treatment EG 203 eggplant rootstock-grafted tomato along with IPDM practices performed better across all experimental locations than the other treatment combinations viz., TS 03 eggplant rootstock-grafted tomato + IPDM, tomato + IPDM, grafted tomato + farmers' practice and tomato + farmers' practice. The EG 203-grafted tomato recorded a higher yield than the farmers' practice with significantly superior biometric parameters. The treatment of EG 203-grafted tomato and IPDM practices can be adopted for safer tomato production by enabling a reduction in pesticide applications while enhancing productivity.

Keywords: grafted tomato; microbial pesticides; botanicals; pheromone traps; IPDM

1. Introduction

The solanaceous crop tomato (*Solanum lycopersicum* L.) is an important vegetable farmed globally to meet the demands of fresh markets and processing industries. With 20 million tonnes of tomatoes grown on 840,000 hectares, India produces 10% of the annual world tomato output [1]. Tamil Nadu, one of India's most important tomato-growing states, produces 720,000 metric tonnes from 44,000 hectares. Farmers may plant tomatoes throughout the year because of the availability of high-yielding hybrids, shade-net nurseries for seedling preparation, and the popularity of sub-surface irrigating systems. On the other hand, all-season tomato cultivation, plant succulence, intensive use of fertilizers and other agricultural inputs, and favorable environmental factors have predisposed tomatoes to insect pests, diseases, and nematodes, which are the main factors that challenge tomato production and result in lower yields.

Around 100 insect pests and 25 non-insect pests have been documented to attack tomatoes [2], feeding from germination to harvesting and significantly affecting the number and quality of the fruits [3]. The whitefly, *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae); the leafhopper, *Amrasca biguttula* (Ishida) (Hemiptera: Cicadellidae); the thrips, *Thrips tabaci* Lindeman (Thysanoptera: Thripidae); the tomato pinworm, *Phthorimaea absoluta* Meyrick (Lepidoptera: Gelechiidae); the American serpentine leafminer, *Liriomyza trifolii* (Burgess) (Diptera: Agromyzidae) and the tomato fruit borer, *Helicoverpa armigera* Hubner (Lepidoptera: Noctuidae) challenge tomato production in India [4–6]. The tomato fruit borer and tomato pinworm have the potential to cause 23–38% and 80–100% loss, respectively [7,8]. Whiteflies and thrips damage lead to 45% and 23% tomato yield loss, respectively [9,10].

Regarding diseases, over 200 species have been identified as tomato pathogens causing production problems [11]. Fungi, bacteria, and viruses commonly cause numerous diseases [12]. The bacterial wilt (*Ralstonia pseudosolanacearum*; Burkholderiaceae: Burkholderiales: Gammaproteobacteria), the fusarium wilt (*Fusarium oxysporum* Schltdl. (=*Fusarium oxysporum* f.sp. *lycopersici* (Sacc.) W.C. Snyder & H.N. Hansen) (Nectriaceae: Hypocreales: Sordariomycetes), the sclerotium wilt (*Athelia* (=*Sclerotium*) *rolfsii* (Curzi) C.C. Tu & Kimbr. (Atheliaceae: Atheliales: Agaricomycetes), the early blight (*Alternaria solani* Sorauer) (Pleosporaceae: Pleosporales: Dothideomycetes), the leaf curl disease caused by the tomato leaf curl New Delhi virus (ToLCNDV) (Geminiviridae: Geplafuvirales: Repensiviricetes), and the tomato spotted wilt caused by the tomato spotted wilt orthotospovirus (TSWV) (Tospoviridae: Bunyavirales: Ellioviricetes) are primary yield-impeding diseases on tomato production in Tamil Nadu [13–16]. Early blight causes fruit yield losses ranging from 50% to 86% [17], late blight causes losses ranging from 20% to 70% [18], and vascular wilting causes yield losses of 30% to 40% [19,20]. Still, under favorable weather conditions, yield reduction escalates to 80%. Bacterial leaf spot causes a 20% to 50% loss in tomato yield [21]. Viral diseases such as bud necrosis/spotted wilt, leaf curl, and mosaic (Tobamovirus) cause 45%, 35%, and 18% yield losses, respectively [22]. The other most severe and widespread tomato disease is root-knot produced by the nematode *Meloidogyne incognita* (Kofoid & White) (Tylenchida; Heteroderidae), which causes yearly crop loss ranging from 11 to 35% [23]. It makes plants more susceptible to fungal and bacterial diseases [24].

Farmers prefer to use pesticides to control pests and diseases. In Tamil Nadu, more than 70% of vegetable growers rely exclusively on pesticides to manage target insects and diseases [25]. Though pesticides protect against target insects, their indiscriminate use is associated with other consequences, such as increased production costs, environmental pollution, occupational hazards, resistance, insect pest resurgence, and product residues [10,26]. In recent years, experts have discovered various eco-friendly alternatives to pesticides for the long-term suppression of insects and diseases in tomatoes. Using several suppression techniques to address pest and disease concerns rather than relying on a single strategy helps overcome unnecessary pesticide consumption difficulties [27]. However, the availability of too many alternatives restricts farmers' capacity to accept such techniques due to the difficulties associated with the practice of alternative methods, the market readiness of proposed methods, and the prevalence of small- and marginal-scale vegetable production in South Indian states. Furthermore, the integrated pest and disease management (IPDM) combination solution depends on an area's unique combination of pests and diseases [28]. Therefore, a tailored IPDM module designed for micro-level needs seems more advantageous than the crop's generalistic integrated pest management (IPM) recommendations.

The bacterial wilt induced by *R. pseudosolanacearum* is the most significant impediment to tomato cultivation, especially during the rainy season (October–March) [13]. Emerging insect pests in recent years include the tomato pinworm, *P. absoluta*, and virus- and disease-transmitting sucking pests, *B. tabaci* and *T. tabaci* [29,30]. Furthermore, the root-knot nematode can cause issues throughout the reproductive stage of the crop, and curative nematode management measures do not provide the intended management [31]. As a result, an IPDM strategy must be developed to alleviate yield problems from the aforementioned biotic variables and to test IPDM combinations in farmers' fields in important tomato-growing regions in Tamil Nadu. Furthermore, IPDM requires tolerant or resistant varieties/hybrids, as the existing varieties/hybrids can only manage bacterial wilt at the expense of yield. The World Vegetable Center in Taiwan discovered bacterial wilt resistance sources in eggplant genotypes (*Solanum melongena* L. (Solanaceae)) [32]. These eggplant accessions can be grafted with selected tomato varieties, resulting in bacterial wilt resistance. The current study was conducted to evaluate IPDM treatments in key tomato-growing regions of Tamil Nadu.

2. Materials and Methods

2.1. Study Locations

The IPDM experiments were conducted in tomato farmers' fields in the Coimbatore and Dharmapuri (North-Western zone) districts of Tamil Nadu (Table 1) from October 2022 to March 2023. The study locations are major alfisol tracts with red loamy (Coimbatore) and non-calcareous red (Dharmapuri) soils.

Table 1. Details of the experimental locations and tomato hybrids used at each location.

Assigned Location Name	Location	District	Geo-Coordinates	Hybrid	Date of Transplanting	Experiment Area (m^2)
LI	Vandikaranur	Coimbatore	11.006123° N 76.830208° E	Shivam	26 September 2022	1860
LII	Karadimadai	Coimbatore	10.929349° N 76.854019° E	Shivam	30 September 2022	1274
LIII	Somanahalli	Dharmapuri	12.237983° N 78.097717° E	Madan	24 September 2022	1500
LIV	Kamalapuram	Dharmapuri	12.94662° N 78.149872° E	Shivam	23 September 2022	1465

2.2. Plant Sources

Two commercial tomato accessions were used for the experiments based on popularity, market preference, and farmers' choice: Shivam® (HyVeg, Coimbatore, India) and Madan® (Indus Valley Agro Seeds Pvt. Ltd., Hyderabad, India). The F1 hybrid Shivam® is a tall determinate to semi-determinate plant, with a flat round fruit shape with a green shoulder, weighing an average of 90–100 g, very firm in structure and acidic in taste; it matures 62–67 days after transplanting (DAT), and is intermediate in resistance to tomato leaf curl virus (ToLCV). The F1 hybrid Madan® is a semi-determinate plant with a flat round fruit shape, weighing an average of 90–100 g and maturing at 60–65 DAT.

For the grafting process, seeds of eggplant genotype EG 203 and TS 03, which are reported to be resistant to tomato bacterial wilt, were resourced from the World Vegetable Center, South and Central Asia, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Campus, Hyderabad, Telangana.

2.3. IPDM Components and Resources

The complete randomized block design (CRBD) was employed in all field trials, with 10 m length × 5 m width plot sizes and a 3 m buffer space between the blocks and along the periphery, embracing all directions. There were six treatments: eggplant rootstocks grafted with tomato F1 hybrid scions and superimposition of IPDM components (2 treatments); grafted tomato F1 hybrids with non-IPDM but farmers' pest management options (2 treatments); and tomato F1 hybrids raised with adoption of selected IPDM components and tomato F1 hybrids with farmers' pest management options (2 treatments) (Table 2). The IPDM practices chosen for deployment in field plots were need-based, and their sources are indicated in Tables 3 and 4. Each treatment was replicated four times. The following paragraphs describe the seedling preparation techniques, grafting procedure, and field activities employed in the trials.

Table 2. Details of treatments tested in the study.

Tr. No.	Treatments
T1	Eggplant rootstock (RS)-EG203-grafted tomato + IPDM
T2	Eggplant RS-TS03-grafted tomato + IPDM
T3	Tomato + IPDM
T4	Eggplant RS-EG203-grafted tomato + farmers' practice (FP)
T5	Eggplant RS-TS03-grafted tomato + FP
T6	Tomato + FP

EG 203 and TS 03 eggplant accessions used as rootstocks; IPDM—Integrated Pest and Disease Management Practices (Refer to Table 3 for details).

Table 3. IPDM interventions imposed in the treatments tested at different locations of Tamil Nadu (October 2022 to March 2023).

Location	45 DAT	60 DAT	75 DAT	90 DAT	120 DAT	135 DAT
Location I (Vandikaranur, Coimbatore)	*M. anisopliae* @ 5 mL/L.	*B. subtilis* @ 4 g/L	*B. thuringienisis* @ 2 mL/L	*B. subtilis* @ 4 g/L	*B. bassiana* @ 5 mL/L	
Location II (Karadimadai, Coimbatore)	-	*B. subtilis* @ 4 g/L + *M. anisopliae* @ 5 mL/L	*B. thuringienisis* @ 2 mL/L	*B. subtilis* @ 4 g/L	*B. bassiana* @ 5 mL/L	Tilt® 25%EC @ 1 mL/L
Location III (Somanahalli, Dharmapuri)	*M. anisopliae* @ 5 mL/L	*B. subtilis* @ 4 g/L	*B. thuringienisis* @ 2 mL/L *and B. subtilis* @ 4 g/L	*B. subtilis* @ 4 g/L	Tracer® 45%SC @ 0.4 mL/L	Tilt® 25%EC @ 1 mL/L
Location IV (Kamalapuram, Dharmapuri)	*M. anisopliae* @ 5 mL/L	*B. subtilis* @ 4 g/L	*B. thuringienisis* @ 2 mL/L	*B. subtilis* @ 4 g/L	*B. bassiana* @ 5 mL/L	

Table 4. Source details of components used in IPDM interventions.

Component	Particulars
Azadirachtin 1% EC (Econeem® Plus)	Ms. Margo Biocontrols Private Ltd., Hyderabad, India
M. anisopliae (Grub hunter®)	Ms. Bannariamman Sugars Ltd., Erode, India
B. bassiana (Larva hunter®)	
B. thuringien sis (Larva terminator®)	
B. subtilis	Department of Plant Pathology, Tamil Nadu Agricultural University, Coimbatore
T. asperellum	
P. lilacinum	Department of Nematology, TNAU, Coimbatore, India
Imidacloprid 17.8% SL (Confidor®)	Ms. Bayer India Ltd., Mumbai, India
Spinosad 45% SC (Tracer®)	Ms. Dow Agro Science Ltd., Hyderabad, India
Propiconozole 25% EC (Tilt®)	Ms. Syngenta India Ltd., Pune, India
Yellow sticky traps	Ms. Pest Control of India, Bengaluru, India
Blue sticky traps	
Sleeve traps (Fero-T®)	
Phthorimaea absoluta lures (TLM lure®)	
Helicoverpa armigera lures (Helilure®)	

Nursery Preparation and Grafted Eggplant–Tomato Seedlings Generation

For all field experiments, grafted tomato seedlings from F1 hybrid tomato seedlings and eggplant (rootstock) were prepared at a farmer-managed commercial shade-net vegetable nursery in Thondamuthur (10.9899° N, 76.8409° E), Coimbatore, Tamil Nadu. On 29 July 2022, bacterial wilt-resistant eggplant rootstocks EG 203 and TS 03 (WorldVeg, Taiwan, China) were seeded in 98 cell seedling pro-trays (Ms. Kaveri Agri Products, Krishnagiri, India). Decomposed coir pith (M/s. RAR Coir Industries, Salem, MA, USA) was employed as seedling rooting media. To achieve optimal germination conditions, seedling trays were stacked and covered with polythene sheets immediately after placing the seeds. After three days, the covers were removed, and the trays were spread out inside the shade-net nursery and maintained (30 ± 2 °C temperature, 80 ± 5% relative humidity, and 12.5:11.5 h Light: Dark). The seedlings were irrigated thrice daily using a sprinkling water can @ 500–750 mL per tray.

Tomato seeds were cultivated in pro-trays in the same nursery seven days after sowing (DAS) the eggplant seeds. Regular nursery management practices were utilized for eggplant and tomato seedlings, except bio-interventions [drenching with *Bacillus subtilis* G (Bacillaceae; Bacillales; Bacilli), *Trichoderma asperellum* Samuels, Lieckf. & Nirenberg (Hypocreaceae; Hypocreales; Sordariomycetes), and *Purpureocillium lilacinum* (Thom) Luangsa-ard, Houbraken, Hywel-Jones & Samson (Ophiocordycipitaceae; Hypocreales; Sordariomycetes)] applied solely in seedlings designated for IPDM plots. At 16 DAS for eggplant and 14 DAS for tomato, each bio-inoculant @ 5 g/L was mixed with water and drenched using an atomizer until the seedling beds were saturated. The seedlings were checked regularly for insect pest and disease incidence, and unhealthy seedlings were pulled out.

Healthy seedlings of tomatoes (scion) and eggplants (rootstock) aged 21 and 30 DAS with similar stem thickness (1.5–1.8 mm diameter) were used for grafting, and the grafting process described by Black et al. (2003) was used [33]. The stems of eggplant and tomato plants were sliced at a 30° angle above the cotyledons (about where the eggplant stem thickness equals the tomato scion thickness). The stem cut ends of each rootstock and scion were anchored in opposing fashion, their cut ends tightly opposing one another, and the grafting clips (Ms. Varsha Enterprises, Bengaluru, India) were carefully fixed at the union. Post grafting, the seedlings were housed inside healing chambers erected within the shade-net nursery to offer optimal conditions (90% RH) for graft union. The seedlings were removed from the healing chamber after 8–10 days and placed in the shade net for three days to harden. These seedlings were maintained by routine methods until used for planting in the experimental plots.

2.4. Field Preparation, Planting, and IPDM Imposition

The experimental fields were prepared following the agronomic practices recommended in the Tamil Nadu Agricultural University Crop Production Guide 2022 (https://agritech.tnau.ac.in/horticulture/horti_vegetables_tomato_index.html, accessed on 27 July 2022). The fields were ploughed twice to a fine tilth, and in IPDM plots, neem cake at a rate of 250 kg/ha was applied at the end of the second ploughing and incorporated into the top layer of soil. Only the base manures and fertilizers (single Super Phosphate @ 1172 kg/ha + farm yard manure @ 12.5 t/ha) were used during the field preparation. The remains of the total doses of fertilizers for the top dressing (200 kg Nitrogen: 62.5 kg Phosphorus: 250 kg Potassium/ha) were applied in 5–6 split doses through fertigation. Grafted tomato seedlings for each experimental location were carefully transported from the shade-net nursery and then shower-soaked with antagonistic organisms (*B. subtilis*, *T. asperellum*, and *P. lilacinum* each at 5 g/L) prepared in potable water (@20 L/seedlings of one ha), sprinkled by the atomizer before planting and placed in the shade for 45 min.

Raised beds of 90 cm width were prepared using a broad bed former with 30 cm spacing in between the beds. At the middle of each broad bed, one lateral drip was laid for irrigation and fertigation. The grafted tomato seedlings were planted at 120 × 60 cm spacing. In each replication, 70 seedlings were planted in all the locations. The field implementation of the IPDM treatment schedule in a phased manner at four locations is listed below (Supplementary Plate S1):

- Application of neem cake @ 250 kg/ha.
- Seedling drenching with Imidacloprid 17.8 SL @ 5 mL/L (10 days before planting).
- Seedling drenching with *B. subtilis* + *T. asperellum* + *P. lilacinum* each @ 5 g/L (at the time of planting) and shade drying for 30 min.
- Yellow sticky traps @ 100/ha were installed with *P. absoluta* lures for mass trapping one week after transplanting.
- Installation of blue sticky traps @ 100/ha one week after transplanting for mass trapping of sucking pests.
- Installation of pheromone traps @ 12/ha for *H. armigera* from 30 days after transplanting.
- Application of Econeem Plus® 1% @ 2 mL/L @ 1000 mL/ha at 30 days after planting to manage sucking pests and any borers.
- The treatment involved applying *B. subtilis* @ 0.5% on the 40th day and repeating the spray after 15 days.
- In the experimental fields, the lures for *H. armigera* and *P. absoluta* were replaced once every three weeks, and the yellow and blue sticky traps were replaced once every fortnight. No such interventions were imposed in the farmers' practice plots. The farmer's practice treatment was a calendar-based application of chemical pesticides.

Apart from the above IPDM practices, the bio-rational insecticides are applied on a need basis to manage insect pests and diseases at different experimental locations during the different growth stages (Table 3).

The source details of the products used in the present investigation are given in Table 4.

2.5. Observations of Insect Pests, Diseases, and Natural Enemies

Per conventional standards, insect infestations, disease incidences, and natural enemy buildup were recorded weekly [34]. Briefly, the population of sucking insect pests viz., aphids *Aphis gossypii* Glover (Hemiptera: Aphididae), leafhoppers *A. bigutulla bigutulla* whiteflies *B. tabaci*, thrips *T. tabaci*, and red spider mites *Tetranychus urticae* Koch (Arachnida: Tetranychidae) was recorded from five leaves, two from the middle, two from the lower, and one from the upper position of five randomly selected plants from each plot. On five randomly selected plants from each plot, larval counts of leaf miners *L. trifolii*, tomato pinworm *P. absoluta*, leaf-eating caterpillar *Spodoptera litura* Fabricius (Noctuidae: Lepidoptera), and tomato fruit borer *H. armigera* were recorded, and their mean population per plant was calculated. Similarly, the predatory insect population was counted on the same five randomly chosen plants where sucking pests and leaf- and fruit-damaging insects were counted. Adults of *P. absoluta* and *H. armigera* attracted by pheromone traps were counted every two weeks. The percent disease index for early leaf blight and bacterial leaf spot was worked out from five leaves from each plant and five randomly selected plants in each replicate of all the treatments. The percent disease incidence of fusarium wilt, leaf curl virus, and tomato mosaic virus were recorded weekly in twenty randomly selected plants in each replication of all the experimental plots [35]. The percent disease index and percent disease incidence were worked out as described below:

$$\text{Percent disease index} = \frac{\text{The sum of individual disease ratings}}{\text{Total number of plants assessed}} \times \frac{100}{\text{Maximum disease rating}}$$

$$\text{Percent disease index} = \frac{\text{Number of infected plants}}{\text{Total number of plants assessed}} \times 100$$

2.6. Observation of Plant Growth Parameters and Yield

Plant morphometric characteristics, such as branch, leaf, plant height (cm), and fruit numbers were recorded on 10 randomly selected plants at fortnightly intervals in all treatments and reported as mean per plant. The yield (marketable fruits) from each treatment and replication was recorded at each harvest, and the cumulative yield was calculated. The damaged and distorted fruits were excluded from the calculation of the mean yield.

2.7. Statistical Analysis

Before performing statistical analyses with analysis of variance (ANOVA) in Statistical Analysis System (SAS) version 13.0, the means of the data were computed for each observational time and subjected to square root and arcsine transformations, as appropriate. A combined analysis was conducted to study the effects of treatment, location, and mixed effects. For combined analysis, each experimental location was considered as a particular environment. The cumulative means of individual insect populations, disease index/incidence, and natural enemy populations were estimated for every location in the field experiments. Post hoc Tukey's standardized range was used to differentiate mean significance as needed (Honestly Significant Difference (HSD)) ($p < 0.05$).

3. Results

The sucking pest population varied significantly between treatments. The numbers of aphids and red spider mites were seen at the start of field studies in Coimbatore and then vanished after a week. As a result, they were not included in the study's findings. Treatment T5 (TS 03-grafted tomato + farmers' practice) had the most significant prevalence of sucking insect pests. In all four sites, the incidence of leafhoppers was lowest in T1 (EG 203-grafted tomato + IPDM), followed by T3 (tomato + IPDM). Except for L III (Somanahalli, Dharmapuri), which had no thrips incidence during the crop season, thrips and whitefly populations showed a similar infestation pattern across treatments. T4 (EG 203-grafted tomato + farmers' practice) and T5 (TS 03-grafted tomato + farmers' practice) had the most significant thrips populations at L I (Vandikaranur, Coimbatore) (F = 29.42 and DF = 15, $p < 0.0001$) (Table 5). Farmers' practice (T6) treatments performed better than T4 (EG 203-grafted tomato + farmers' practice) and T5 (TS 03-grafted tomato + farmers' practice) in controlling sucking pest numbers across locations.

T1 (EG 203-grafted tomato + IPDM) had the lowest numbers of leaf-damaging *P. absoluta*, *L. trifolii*, *S. litura*, and fruit-damaging *H. armigera*. Farmers' practice (T6) treatments across the locations also recorded fewer pest incidents than T4 (EG 203-grafted tomato + farmers' practice) and T5 (TS 03-grafted tomato + farmers' practice). The lowest *P. absoluta* population was found in L II (Karadimadai, Coimbatore) (F = 117.75 and DF = 15, $p < 0.0001$). T5 (TS 03-grafted tomato + farmers' practice) had the highest leaf feeders and borers population (Table 6). The T6 (farmers' practice) either significantly differed or equally performed as T3 (tomato + IPDM) across locations. T1 > T3 > T6 > T2 > T4 > T5 was the order of performance of different IPDM treatments in terms of sucking pests, leaf feeders, and borers (Table 7).

P. absoluta lures embedded in yellow sticky traps attracted more tomato pinworm adults in T2 (TS 03-grafted plants + IPDM) than in all the IPDM component-tested plots. The number of leafminers, whiteflies, and thrips in yellow sticky traps was also greater in T2 (TS 03-grafted plants + IPDM) than in the other two IPDM treatments. The maximum insect pest attraction in the yellow and blue sticky traps was recorded during November 2022's fortnight in all locations (Supplementary Figures S1 and S2). T6 (farmers' practice) recorded, significantly, the lowest number of natural enemies, viz., coccinellids (*Coccinella* spp. & *Scymnus* sp.), chrysopids (*Chrysoperla zastrowi sillemi*), anthocorids (*Orius* sp.), and spiders. In contrast, the T1 (EG 203-grafted tomato + IPDM) and T5 (tomato + IPDM) recorded, significantly, the highest natural enemies population. Anthocorid populations were not observed at L II (Karadimadai, Coimbatore) (Supplementary Tables S1–S4).

Table 5. Effect of various treatments against sucking insect pests in tomato.

Treatments	Nymphs and Adults (Nos./Leaf) * Mean ± SE											
	Leafhopper (*A. biguttula*)				Thrips (*T. tabaci*)				Whitefly (*B. tabaci*)			
	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV
T1	3.1 ± 0.39^{a}	3.3 ± 0.05^{a}	1.3 ± 0.08^{a}	1.9 ± 0.16^{a}	0.8 ± 0.08^{a}	0.1 ± 0.03^{a}	0.0 ± 0.00	0.1 ± 0.02^{a}	2.3 ± 0.14^{a}	1.5 ± 0.10^{a}	2.2 ± 0.14^{a}	2.0 ± 0.16^{a}
T2	4.5 ± 0.07^{bc}	5.0 ± 0.20^{c}	2.8 ± 0.26^{c}	3.6 ± 0.17^{c}	1.4 ± 0.03^{b}	0.4 ± 0.06^{b}	0.0 ± 0.00	0.3 ± 0.05^{bc}	3.6 ± 0.15^{b}	3.2 ± 0.12^{c}	3.6 ± 0.18^{cd}	3.6 ± 0.13^{c}
T3	3.5 ± 0.03^{ab}	4.0 ± 0.19^{b}	1.6 ± 0.02^{ab}	2.3 ± 0.13^{ab}	0.9 ± 0.08^{a}	0.3 ± 0.06^{ab}	0.0 ± 0.00	0.1 ± 0.03^{ab}	2.5 ± 0.19^{a}	1.9 ± 0.16^{ab}	2.7 ± 0.14^{ab}	2.5 ± 0.10^{ab}
T4	5.4 ± 0.41^{cd}	6.0 ± 0.11^{d}	3.7 ± 0.22^{d}	4.5 ± 0.20^{d}	1.8 ± 0.10^{c}	0.7 ± 0.07^{cd}	0.0 ± 0.00	0.4 ± 0.04^{cd}	4.3 ± 0.16^{b}	3.9 ± 0.13^{d}	4.3 ± 0.17^{de}	4.4 ± 0.19^{d}
T5	5.9 ± 0.09^{d}	6.4 ± 0.07^{d}	5.0 ± 0.23^{e}	5.6 ± 0.17^{e}	1.9 ± 0.07^{c}	0.9 ± 0.07^{d}	0.0 ± 0.00	0.5 ± 0.04^{d}	5.4 ± 0.06^{c}	4.8 ± 0.17^{e}	5.0 ± 0.17^{e}	5.7 ± 0.26^{e}
T6	3.9 ± 0.16^{ab}	4.4 ± 0.03^{b}	2.0 ± 0.10^{b}	2.7 ± 0.13^{b}	1.1 ± 0.11^{ab}	0.5 ± 0.05^{bc}	0.0 ± 0.00	0.2 ± 0.03^{ab}	2.9 ± 0.06^{a}	2.4 ± 0.07^{b}	3.0 ± 0.26^{abc}	2.8 ± 0.18^{b}
F value	17.39	97.57	113.58	77.87	29.42	31.83		17.09	52.75	87.30	39.17	71.94
Trt, DF	5, 15											
($p < 0.05$)	<0.0001											

L I—Vandikaranur, L II—Karadimadai, L III—Somanahalli and L IV—Kamalapuram; * Cumulative mean of six observations; SE—Standard Error; T1—EG 203-grafted tomato + IPDM; T2—TS 03-grafted tomato + IPDM; T3—tomato + IPDM; T4—EG 203-grafted tomato + farmers' practice; T5—TS 03-grafted tomato + farmers' practice; T6—tomato + farmers' practice; mean values followed by the same superscript alphabet (s) in the columns do not differ significantly by Tukey's HSD test at $p = 0.05$ level.

Table 6. Effect of various treatments against leaf feeders and borers in tomato.

Treatments	Larvae (Nos./Plant) * Mean ± SE															
	P. absoluta				*L. trifolii*				*S. litura*				*H. armigera*			
	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV
T1	3.62 ± 0.10^{a}	2.2 ± 0.13^{a}	1.6 ± 0.08^{a}	1.4 ± 0.41^{a}	1.5 ± 0.13^{a}	0.7 ± 0.03^{a}	0.9 ± 0.08^{a}	1.2 ± 0.17^{a}	0.5 ± 0.08^{a}	0.3 ± 0.06^{a}	0.2 ± 0.05^{a}	0.4 ± 0.07^{a}	0.7 ± 0.03^{a}	0.2 ± 0.04^{a}	0.4 ± 0.04^{a}	0.9 ± 0.13^{a}
T2	4.80 ± 0.18^{c}	3.4 ± 0.10^{c}	3.0 ± 0.04^{c}	3.0 ± 0.17^{c}	3.1 ± 0.28^{bc}	1.8 ± 0.15^{c}	2.2 ± 0.27^{c}	2.7 ± 0.18^{c}	1.3 ± 0.16^{bc}	1.1 ± 0.08^{b}	1.0 ± 0.09^{c}	1.5 ± 0.20^{c}	1.6 ± 0.16^{c}	0.7 ± 0.03^{c}	1.2 ± 0.12^{cd}	2.2 ± 0.17^{c}
T3	4.00 ± 0.11^{ab}	2.6 ± 0.14^{ab}	2.0 ± 0.05^{ab}	1.8 ± 0.12^{ab}	1.8 ± 0.14^{a}	1.0 ± 0.10^{ab}	1.4 ± 0.11^{ab}	1.6 ± 0.13^{ab}	0.8 ± 0.09^{ab}	0.5 ± 0.06^{a}	0.3 ± 0.04^{ab}	0.6 ± 0.09^{ab}	1.0 ± 0.05^{ab}	0.3 ± 0.05^{ab}	0.6 ± 0.07^{ab}	1.3 ± 0.06^{ab}
T4	5.92 ± 0.07^{d}	4.3 ± 0.07^{d}	3.7 ± 0.08^{d}	3.9 ± 0.14^{d}	3.9 ± 0.11^{cd}	2.7 ± 0.13^{d}	3.2 ± 0.18^{c}	3.5 ± 0.31^{c}	2.0 ± 0.16^{c}	1.4 ± 0.08^{bc}	1.6 ± 0.17^{d}	2.3 ± 0.24^{d}	2.2 ± 0.09^{cd}	1.2 ± 0.04^{d}	1.7 ± 0.16^{de}	2.8 ± 0.14^{cd}
T5	6.44 ± 0.13^{d}	4.9 ± 0.08^{e}	4.7 ± 0.11^{e}	4.8 ± 0.18^{e}	4.3 ± 0.23^{d}	3.2 ± 0.07^{d}	3.8 ± 0.23^{c}	4.7 ± 0.13^{d}	2.6 ± 0.11^{d}	1.8 ± 0.07^{c}	2.0 ± 0.13^{d}	2.9 ± 0.13^{e}	2.6 ± 0.12^{d}	1.5 ± 0.04^{d}	2.3 ± 0.30^{e}	3.4 ± 0.21^{d}
T6	4.28 ± 0.15^{abc}	2.9 ± 0.13^{b}	2.4 ± 0.17^{b}	2.3 ± 0.09^{b}	2.2 ± 0.27^{b}	1.3 ± 0.09^{b}	1.7 ± 0.22^{bc}	2.0 ± 0.21^{b}	1.1 ± 0.16^{b}	0.6 ± 0.12^{a}	0.6 ± 0.10^{b}	0.9 ± 0.14^{b}	1.2 ± 0.10^{bc}	0.5 ± 0.09^{b}	0.9 ± 0.05^{bc}	1.6 ± 0.28^{b}
F value	61.80	117.75	114.83	83.39	49.23	106.09	59.75	58.70	27.49	39.16	60.54	84.42	49.31	88.88	38.07	47.98
Trt, DF	5, 15															
($p < 0.05$)	<0.0001															

L I—Vandikaranur, L II—Karadimadai, L III—Somanahalli and L IV—Kamalapuram; * Cumulative mean of six observations; SE—Standard Error; T1—EG 203-grafted tomato + IPDM; T2—TS 03-grafted tomato + IPDM; T3—tomato + IPDM; T4—EG 203-grafted tomato + farmers' practice; T5—TS 03-grafted tomato + farmers' practice; T6—farmers' practice; mean values followed by the same superscript alphabet (s) in the columns do not differ significantly by Tukey's HSD test at $p = 0.05$ level.

Table 7. Combined analysis of insect pest incidence in tomatoes for four locations in Tamil Nadu.

Source	df	*A. biguttula*		*T. tabaci*		*B. tabaci*		*P. absoluta*		*L. trifolii*		*S. litura*		*H. armigera*	
		F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F
Model	35	56.59	**<0.0001**	87.47	**<0.0001**	38.59	**<0.0001**	81.08	**<0.0001**	42.54	**<0.0001**	22.78	**<0.0001**	38.61	**<0.0001**
Location	3	228.71	**<0.0001**	833.32	**<0.0001**	22.10	**<0.0001**	337.92	**<0.0001**	60.99	**<0.0001**	28.49	**<0.0001**	152.04	**<0.0001**
Treatment	5	245.01	**<0.0001**	74.78	**<0.0001**	250.44	**<0.0001**	352.40	**<0.0001**	249.16	**<0.0001**	168.21	**<0.0001**	169.49	**<0.0001**
Treatment × Location	15	3.47	0.0003	11.56	**<0.0001**	1.13	0.3541	2.84	0.0021	0.79	0.6822	1.62	<0.0949	0.82	0.6551

The analyses for each variable showed significant differences among the interaction effect of treatments and provinces, are shown in bold.

Across the four locations, the T1 (EG 203-grafted tomato + IPDM) and T3 (tomato + IPDM) had the lowest percent disease index of bacterial leaf spot and early blight, as well as the lowest percent disease incidences of fusarium wilt, leaf curl, and mosaic disease. Across locations, L IV (Kamalapuram, Dharmapuri) had the lowest percent disease index of bacterial leaf spots and early blight (F = 120.47 and DF = 15; F = 450.17 and DF = 15, $p < 0.0001$). Fusarium wilt, leaf curl, and mosaic disease incidences, on the other hand, were lowest in L III (Somanahalli, Dharmapuri) (F = 270.19 and DF = 15; F = 264.93 and DF = 15; F = 106.16 and DF = 15, $p < 0.0001$). Except for T1 (EG 203-grafted tomato + IPDM) and T3 (tomato + IPDM), the farmers' practice (T6) fared better than others, with considerably decreased disease infections. T5 (TS 03-grafted tomato + farmers' practice) recorded significantly increased diseases than others (Tables 8 and 9).

The biometric parameters, number of branches, leaves, fruits, and plant height in grafted plants in IPDM treatments were considerably superior (Figures 1–4). The EG 203 eggplant rootstock-grafted tomato considerably varied from the TS 03 with enhanced biometric parameters (Branch F = 84.85 and DF = 15; Leaves F = 532.01 and DF = 15; Plant height F = 564.45 and DF = 15; Fruits F = 1038.34 and DF = 15;) among the grafted tomato plants. Across every location, the EG 203 rootstock-grafted plants outperformed the other ones. Though the grafted tomato plants took longer to establish, their development was on par with conventional tomato plants after a fortnight (Figures 1–4 and Table 10). Furthermore, the field stand of the grafted tomato plants was roughly one month longer than that of the conventional tomato plants, resulting in increased economic production. The tomato plants in the farmer's practice ranked third in terms of biometric metrics, trailing only the EG 203-grafted tomato + farmers' practice plants and greatly outperforming the TS 03 eggplant-grafted tomato + IPDM plants. The biometric parameters were distributed as follows: L IV (Kamalapuram) > L I (Vandikaranur) > L II Karadimadai > L III (Somnahalli).

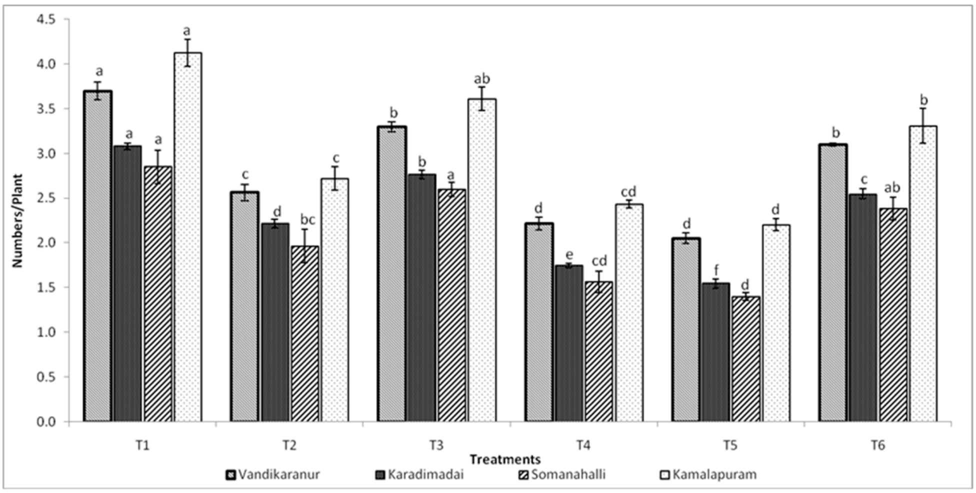

Figure 1. Mean (±SE) number of branches in tomato plants recorded across experimental locations in Tamil Nadu. Bars are means of four replications at each location, and bars followed by the same letter(s) are not significantly different by Tukey's HSD test ($p < 0.05$).

Table 8. Effect of various treatments against bacterial, fungal, and virus diseases on tomato.

Treatments	Bacterial Leaf Spot *				Early Blight *				Fusarium Wilt *				Tomato Leaf Curl Virus *				Tomato Mosaic Virus *			
	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV	L I	L II	L III	L IV
T1	1.3 ± 0.05^{a}	1.5 ± 0.06^{a}	0.9 ± 0.06^{a}	0.8 ± 0.11^{a}	3.1 ± 0.10^{a}	2.4 ± 0.22^{a}	2.1 ± 0.05^{a}	1.6 ± 0.08^{a}	2.4 ± 0.08^{a}	2.5 ± 0.12^{a}	0.8 ± 0.08^{a}	2.0 ± 0.10^{a}	2.1 ± 0.07^{a}	1.6 ± 0.13^{a}	1.0 ± 0.14^{a}	0.9 ± 0.09^{a}	1.4 ± 0.05^{a}	1.1 ± 0.12^{a}	0.8 ± 0.12^{a}	0.7 ± 0.11^{a}
T2	2.4 ± 0.15^{c}	2.9 ± 0.07^{c}	1.9 ± 0.14^{c}	1.8 ± 0.04^{c}	5.4 ± 0.07^{d}	4.2 ± 0.24^{c}	4.5 ± 0.16^{c}	3.1 ± 0.09^{c}	4.3 ± 0.12^{c}	4.1 ± 0.06^{c}	2.3 ± 0.05^{d}	3.9 ± 0.09^{d}	3.4 ± 0.05^{c}	2.9 ± 0.12^{c}	2.1 ± 0.04^{c}	1.9 ± 0.07^{c}	2.9 ± 0.08^{c}	2.2 ± 0.14^{c}	1.7 ± 0.08^{c}	1.3 ± 0.10^{b}
T3	1.6 ± 0.07^{ab}	1.8 ± 0.15^{ab}	1.1 ± 0.07^{ab}	1.0 ± 0.09^{ab}	3.4 ± 0.09^{b}	2.7 ± 0.18^{a}	2.4 ± 0.17^{a}	1.9 ± 0.14^{a}	2.9 ± 0.16^{b}	4.1 ± 0.10^{c}	1.3 ± 0.10^{b}	2.4 ± 0.03^{b}	2.4 ± 0.08^{ab}	1.9 ± 0.14^{a}	1.3 ± 0.04^{ab}	1.2 ± 0.11^{ab}	1.8 ± 0.13^{a}	1.3 ± 0.07^{a}	1.1 ± 0.15^{ab}	0.8 ± 0.10^{a}
T4	4.8 ± 0.07^{d}	5.6 ± 0.16^{d}	4.9 ± 0.15^{d}	3.7 ± 0.09^{d}	10.9 ± 0.07^{e}	10.9 ± 0.27^{d}	9.9 ± 0.13^{d}	6.9 ± 0.05^{d}	7.1 ± 0.06^{d}	8.0 ± 0.13^{d}	3.1 ± 0.09^{e}	6.4 ± 0.09^{e}	6.2 ± 0.07^{d}	5.5 ± 0.12^{d}	5.1 ± 0.12^{d}	3.5 ± 0.13^{d}	4.8 ± 0.15^{d}	3.7 ± 0.06^{d}	3.1 ± 0.11^{d}	2.1 ± 0.06^{c}
T5	5.9 ± 0.08^{e}	6.4 ± 0.08^{e}	5.9 ± 0.10^{e}	4.6 ± 0.07^{e}	11.9 ± 0.09^{f}	12.3 ± 0.24^{e}	11.4 ± 0.11^{e}	7.7 ± 0.06^{e}	8.3 ± 0.08^{e}	8.1 ± 0.19^{d}	6.3 ± 0.07^{f}	7.9 ± 0.09^{f}	7.3 ± 0.15^{e}	6.6 ± 0.21^{e}	6.1 ± 0.10^{e}	4.1 ± 0.14^{e}	5.8 ± 0.15^{e}	4.8 ± 0.14^{e}	3.8 ± 0.15^{d}	2.6 ± 0.13^{c}
T6	2.0 ± 0.18^{b}	2.0 ± 0.04^{b}	1.5 ± 0.12^{bc}	1.3 ± 0.16^{bc}	4.2 ± 0.09^{c}	3.5 ± 0.26^{b}	3.0 ± 0.15^{b}	2.3 ± 0.11^{b}	3.2 ± 0.08^{b}	3.1 ± 0.26^{b}	1.7 ± 0.09^{c}	3.0 ± 0.14^{c}	2.9 ± 0.10^{b}	2.2 ± 0.09^{b}	1.6 ± 0.12^{bc}	1.5 ± 0.12^{b}	2.3 ± 0.09^{b}	1.7 ± 0.11^{b}	1.5 ± 0.09^{bc}	1.0 ± 0.11^{ab}
F value	279.59	310.06	237.92	120.47	1485.04	1779.90	855.65	450.17	327.95	588.90	270.19	750.95	459.95	745.14	264.93	179.10	210.42	203.51	106.10	41.07
Trt, DF	5, 15																			
($p < 0.05$)	<0.0001																			

L I—Vandikaranur, L II—Karadimadai, L III—Somanahalli and L IV—Kamalapuram; * Cumulative mean of six observations; SE—Standard Error; T1—EG 203-grafted tomato + IPDM; T2—TS 03-grafted tomato + IPDM; T3—tomato + IPDM; T4—EG 203-grafted tomato + farmers' practice; T5—TS 03-grafted tomato + farmers' practice; T6—farmers' practice; mean values followed by the same superscript alphabet (s) in the columns do not differ significantly by Tukey's HSD at the $p = 0.05$ level.

Table 9. Combined analysis of disease incidence in tomatoes for four locations in Tamil Nadu.

Source	df	Bacterial Leaf Spot		Early Blight		Fusarium Wilt		Tomato Leaf Curl Virus		Tomato Mosaic Virus	
		F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F
Model	35	130.77	**<0.0001**	590.86	**<0.0001**	328.82	**<0.0001**	218.88	**<0.0001**	84.90	**<0.0001**
Location	3	100.48	**<0.0001**	558.43	**<0.0001**	784.44	**<0.0001**	372.10	**<0.0001**	225.88	**<0.0001**
Treatment	5	845.32	**<0.0001**	3744.09	**<0.0001**	1753.10	**<0.0001**	1279.12	**<0.0001**	439.67	**<0.0001**
Treatment × Location	15	2.51	0.0061	17.02	**<0.0001**	23.71	**<0.0001**	6.80	0.0001	3.80	0.0001

The analyses for each variable, which showed significant differences among the interaction effect of treatments and provinces, are shown in bold.

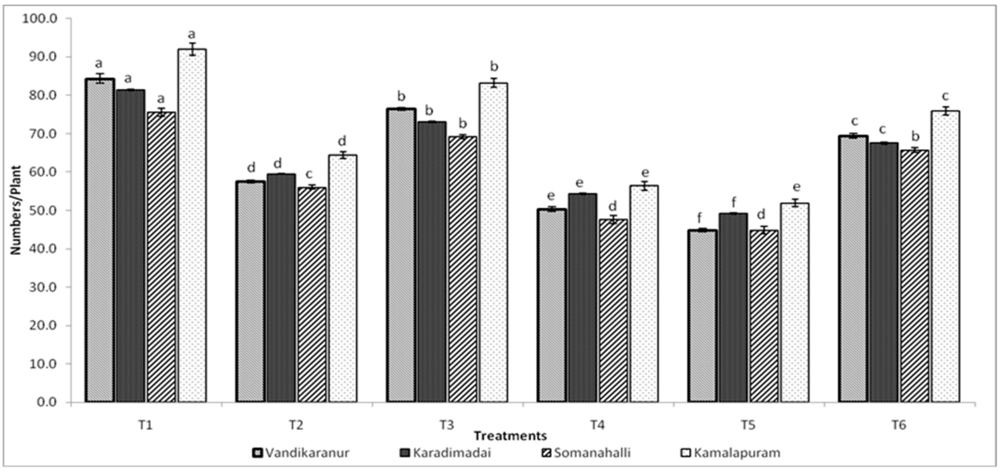

Figure 2. Mean (±SE) number of leaves (trifoliate) in tomato plants recorded across experimental locations in Tamil Nadu. Bars are means of four replications at each location, and bars followed by the same letter(s) are not significantly different by Tukey's HSD test ($p < 0.05$).

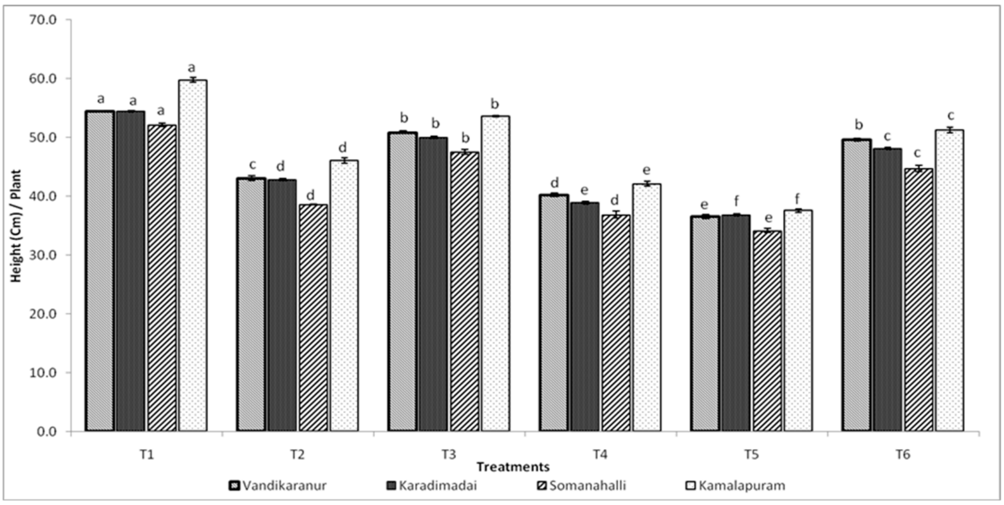

Figure 3. Mean (±SE) plant height (in cm) of tomato plants recorded across experimental locations in Tamil Nadu. Bars are means of four replications at each location, and bars followed by the same letter(s) are not significantly different by Tukey's HSD test ($p < 0.05$).

T1 (EG 203-grafted plants + IPDM) yielded significantly more than the other treatments in all locations. T1 and T3 yields were statistically equal at L II (Karadimadai). At L I (Vandikaranur) and L IV (Kamalapuram), T6 (farmers' practice) and T3 (tomato + IPDM) yielded statistically comparable yields. T5 (TS 03-grafted plants + farmers' practice) yielded considerably less than others across locations (Figure 5).

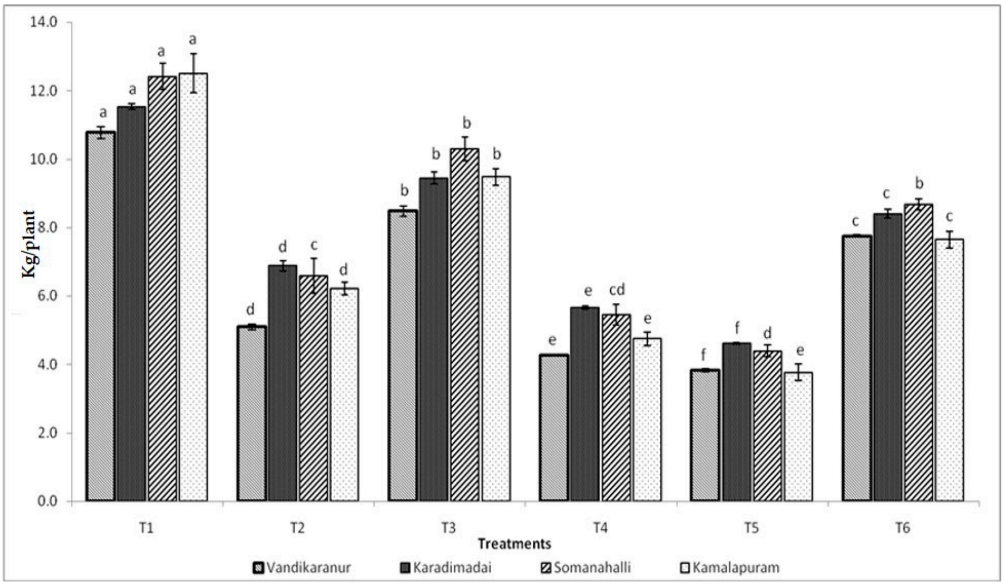

Figure 4. Mean (±SE) fruit yield (kg/plant) of tomato plants recorded across experimental locations in Tamil Nadu. Bars are means of four replications at each location, and bars followed by the same letter(s) are not significantly different by Tukey's HSD test ($p < 0.05$).

Table 10. Combined analysis of biometric observations in tomatoes for four locations in Tamil Nadu.

Source	df	Branches		Leaves (Trifoliate)		Height		Fruit		Yield	
		F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F	F	Pr > F
Model	35	51.65	**<0.0001**	219.11	**<0.0001**	293.35	**<0.0001**	85.72	**<0.0001**	17.45	**<0.0001**
Location	3	171.11	**<0.0001**	208.92	**<0.0001**	329.24	**<0.0001**	34.19	**<0.0001**	42.58	**<0.0001**
Treatment	5	246.77	**<0.0001**	1385.89	**<0.0001**	1837.24	**<0.0001**	569.88	**<0.0001**	88.09	**<0.0001**
Treatment × Location	15	0.56	0.8931	6.35	**<0.0001**	5.71	**<0.0001**	2.62	0.0043	1.13	0.3539

The analyses for each variable showed significant differences among the interaction effect of treatments and provinces, are shown in bold.

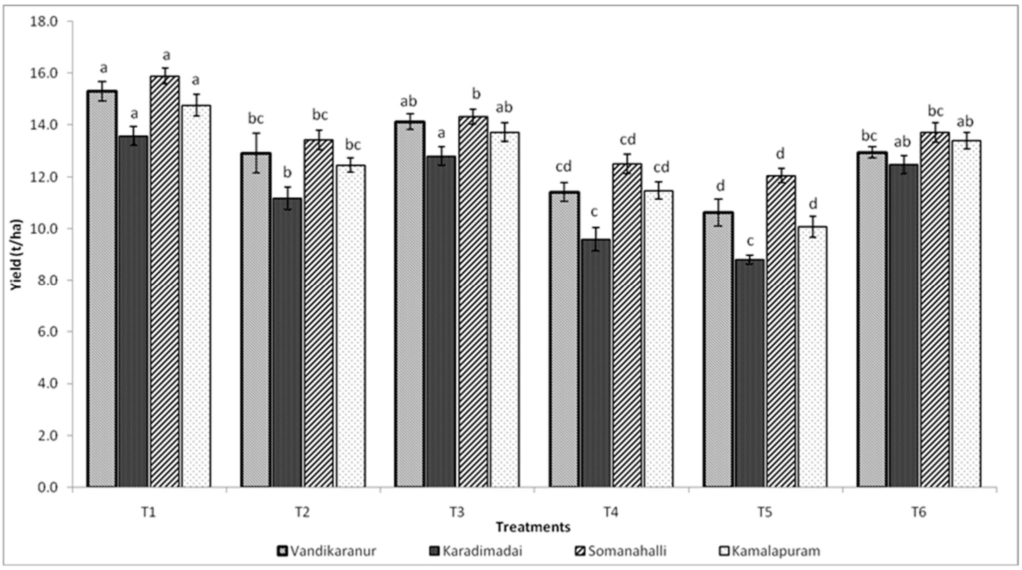

Figure 5. Mean (±SE) tomato fruit yield (t/ha) recorded in four different locations in Tamil Nadu, among the different grafting and IPDM combination treatments. Bars are means of four locations at each location, and bars followed by the same letter(s) are not significantly different by Tukey's HSD test ($p < 0.05$).

4. Discussion

Seedlings of commercially preferred tomato hybrid cultivars grafted on bacterial-resistant eggplant rootstocks (two accessions used) and implementable Integrated Pest and Disease Management (IPDM) practices as a package experimented in combinations and evaluated across four locations in major tomato-growing tracts in Tamil Nadu. The combinations were matched for performance to the farmer-adopted insecticide-intensive practices, commonly called farmers' practices. The higher plant intensity in sunflower increased the abundance of insect pests and diseases [36]. Raising tomato plants in a spacing of 50 × 60 cm reduced the critical insect pest abundance in tomato fields, thereby reducing insecticide usage [37]. The maintenance of optimum plant population in drip irrigation systems was one of the crucial components in the present investigation.

The IPDM components of weekly application of a mixture of the biopesticides (*B. thuringiensis* subsp. *aizawai*, *B. subtilis*, and *B. bassiana*) and need-based application of insecticides increased tomato yield and income by an average of 23 and 34%, respectively, compared to the conventional farmers' practices in Cambodia [38]. The tomato grafted with the bacterial-resistant eggplant rootstock EG 203 and imposing IPDM practices recorded reduced insect pest and disease incidence than other combinations. In the present IPDM treatments, *B. thuringiensis* and *M. anisopliae* were utilized for insect suppression. The tomato IPM package accommodated the sequential application of *B. bassiana*, petroleum oil 97%, azadirachtin 1.2%, and *B. thuringiensis* subsp. *kurstaki* at 15, 30, 45, and 60 DAT, significantly reducing the pest incidence and giving a higher yield [39]. In insect-specific IPM treatments for *L. trifolli*, the alternate spraying of lambda-cyhalothrin 5% EC (0.005%), *B. bassiana* @ 1.25 kg/ha, abamectin 1.9% EC @ 0.009%, and azadirachtin 1500 ppm @ 2 mL/L was found to be on par with insecticide treatments [40].

In yet another study, planting African marigolds along field boundaries and in between one row for every eight tomato rows, combined with two sprays of HaNPV @ 350 LE/ha and Decidan® 32.8% EC @ 1.5 mL/L registered the least tomato fruit borer damage (3.44%) and highest yield (176.75 q/ha) [41]. Sridhar et al. (2019) revealed that egg parasitoid *Trichogramma pretiosum*, yellow sticky traps, azadirachtin 5% EC, and spinetoram 12% SC @ 1.25 mL/L were the best suppressive IPM components against the tomato pinworm *P. absoluta* [5]. Previous findings suggested combining botanical and microbial components could enhance their activity against insect pests [42]. However, egg parasitoids were not employed to manage *P. absoluta* in the present IPM evaluation studies. Nevertheless, *P. absoluta* lures embedded in yellow sticky traps were used in the currently tested IPDM treatments. These traps were highly effective and attracted moths effectively (Figure 5). Also, in the present investigation, the neem-based insecticide (Econeem® Plus) was used in the early tomato growth stages; at the same time, biopesticides were used in the tomato reproductive phases based on the economic thresholds (ETL) adjudication for borers and leaf feeders. The sequential application of microbial components such as HaNPV (@ 1.5×10^{12} POB/ha) and Bt formulation (Delfin® 25% WG) and Neemazol® 1.2% EC were equally as suppressive as chemical insecticides against target pests [43].

An insect management treatment comprising emamectin benzoate 5% @ 200 mL/ha + chlorantraniliprole 18.5% EC @ 150 mL/ha+ novaluron 10% EC 1 L/ha recorded the lowest *H. armigera* (0.43 larva/plant) incidence and fruit damage (7.63%) than other treatments comprising *Trichogramma* spp. @ 150,000/ha + HaNPV @ 300 LE/ha + neem seed kernel extract (NSKE) @ 10%, which recorded 1.28 larvae/plant and 23.05% fruit damage [30]. In our present experiments, the insecticide spinosad 45% SC was applied whenever the *P. absoluta* or *H. armigera* population was severe and exceeded ETLs in the IPDM plots. However, the number of applications of spinosad 45% SC that followed was at the maximum of one in location III (Kamalapuram; Dharmapuri) in IPDM interventions. Periodic pesticide usage in farmers' practice (T6) decreased the prevalence of *P. absoluta*, *L. trifolii*, *S. litura*, and *H. armigera* more successfully than the other combinations and came second.

When the cases of the prevalence of tomato diseases are concerned, *T. harzianum* metabolites efficiently manage tomato bacterial wilt [44], and the observations of direct killing of bacterial cells by the *T. harzianum* metabolites confirmed it. Antimicrobial compounds secreted by *Trichoderma* spp. had parasitic activity on plant pathogens [45]. Practicing IPM components viz., treating seedlings with 1% *T. harzianum*, two rounds of HaNPV @ 250 LE/ha, installing pheromone traps, plant staking, and removal of older leaves were found to reduce the *H. armigera* damage, early blight (*A. solani*), and buckeye rot (*Phytophthora nicotianae var. parasitica* (Dastur) Waterhouse at North Himalayas [46]. The severity of early blight, buck eye rot, and fruit borer incidence in organic, chemical, and integrated treatments were >6.8%, >4.4%, and >2.1%, respectively [47]. Biological control agents also reduced root rot fungus and other diseases [48,49]. The *T. asperellum*, *B. subtilis*, and *P. lilacinum* were used for seedling drenching and were also applied on a need basis in the IPDM experimental plots in the present investigation. These interventions reduced tomato disease incidences in the IPDM experimental plots across the studied locations.

The combination of cultural, physical, mechanical, crop diversification, biological, and need-based insecticide usage, in addition to reducing the incidence of insect pests and diseases, positively impacted the environment [50] since there are drastic reductions in synthetic insecticide usage, unless warranted, to bring down pest and disease loads. Trumble and Alvarado-Rodriguez (1993) revealed that though IPM practices in tomatoes recorded more insect pest incidence than conventional insecticidal applications, they brought a higher net profit [51]. In the present results, the EG 203-grafted tomato with IPDM (T1) recorded a higher yield than the farmers' practice, with a yield of 13.6 to 15.9 t/ha across four locations. In contrast, the yield range in farmers' practice was 8.8 to 12.5 t/ha (Figure 5). De Costa et al. (2021) held the opinion that the willingness to adopt IPM was higher among older, more educated, and full-time farmers [52]. As part of the experimental studies, field day demonstrations were organized at the experimental sites, enclaving the educated and full-time farmers; 70–75% of the farmer participants were educated and young and endorsed that the IPDM strategies selected for the studies were better-performing, implementable and convinced themselves to adopt the IPDM components. The dissemination of these technologies will reduce insecticide usage and increase profit for tomato growers.

5. Conclusions

The effectiveness of tomato plants grafted with wilt-resistant eggplant rootstocks (EG 203 and TS 03) and IPDM treatments was evaluated against the pest and disease management methods used by farmers in the major tomato-growing regions of Tamil Nadu. The IPDM practices, comprising application of neem cake, seedling drenching with bioinoculants, installation of sticky traps with *P. absoluta* lures, and need-based application of bio-rationals such as azadirachtin 1%, *B. thuringiensis*, *M. anisopliae*, *B. bassiana*, and *B. subtilis,* were included in the module. Tomato grafted to the eggplant rootstock EG 203 recorded significantly lower insect pest and disease incidences, more natural enemies, and higher yield. The large-scale validation of these packages and subtle changes based on the micro-farm level requirements may enable the farmer to reduce the expenditure on tomato plant protection and harness more profits.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/horticulturae10070766/s1, Plate S1: Integrated Pest & Disease Management interventions in the IPM interventions across the experimental locations; Figure S1: Pooled mean number of insect pests attracted to yellow sticky traps among tomato IPDM combination modules tested in Tamil Nadu in four experimental locations; Figure S2: The mean number (four replications) of thrips attracted to blue sticky traps among tomato IPDM combination modules tested in Tamil Nadu in four experimental locations. Table S1: Effect of various modules against natural enemies on tomato in location 1:Vandikaranur (Coimbatore Dt.); Table S2: Effect of various modules against natural enemies on tomato in location 2: Karadimadai (Coimbatore Dt.); Table S3: Effect of various modules against natural enemies on tomato in location 3: Somanahalli (Dharmapuri Dt.); Table S4: Effect of various modules against natural enemies on tomato in location 4: Kamalapuram (Dharmapuri Dt.).

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