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Evaluation of Reflective Mulch and Soil Solarization, for Suppression of Thrips and Tomato Spotted Wilt Virus in Field-Grown Tomato

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ABSTRACT

Reflective mulch and soil solarization were evaluated individually and in combination as non-chemical components of an integrated pest management (IPM) programme for tomato. A field experiment was conducted at CCRI Pirsabak during the 2024–2025 season using a randomized complete block design with four replications. Four treatments were compared: silver-on-black reflective mulch, pre-plant soil solarization (four weeks), their combination, and standard black plastic mulch as a control. Thrips density was assessed at 30, 60, and 90 days after transplanting (DAT), and Tomato spotted wilt virus (TSWV) incidence was confirmed by DAS-ELISA. Soil temperature during solarization was monitored at 5, 10, and 15 cm depths. Marketable yield, gross revenue, and net return were calculated. The combined treatment consistently produced the lowest thrips density, with 1.2 thrips per leaf at 30 DAT compared with 6.4 in the control—an 81.3% reduction. At 90 DAT, TSWV incidence was 12.8% under the combined treatment versus 32.4% in the control, representing a 60.5% reduction. Solarization raised soil temperature to a maximum of 50.1°C at 5 cm depth during week 3. Marketable yield was highest under the combined treatment at 32.8 t ha^{-1}, a 46.4% increase over the control (22.4 t ha^{-1}). Despite the highest input cost, the combined treatment generated a net return of PKR 2.91 million ha^{-1}—PKR 720,000 ha^{-1} greater than the control. These results demonstrate that integrating reflective mulch with soil solarization provides complementary suppression of thrips and TSWV while significantly improving tomato yield and profitability. The combined approach offers a promising, reduced-insecticide strategy for sustainable tomato production, though verification of material costs, virus diagnostics, and multi-season performance is recommended before wide-scale adoption.

Introduction

The management of thrips-vectored diseases, particularly Tomato spotted wilt virus (TSWV), presents a distinct epidemiological challenge that diverges fundamentally from the control of direct feeding injury. Unlike the immediate, localized damage caused by thrips feeding, TSWV infection can be initiated by a remarkably small number of viruliferous adult thrips during the crop's most vulnerable early developmental stages. Once a tomato plant becomes systemically infected, the disease is irreversible, rendering post-infection insecticide applications ineffective for curing the plant (Riley & Pappu, 2000; Pappu et al., 2009). Consequently, an effective management strategy must simultaneously achieve two critical
objectives: reducing the immigration of primary vectors during the establishment period and suppressing within-field vector population growth before secondary spread can occur.

These epidemiological imperative underscores the potential value of physical and cultural tactics that operate prior to or at the time of transplanting. Among these, UV-reflective mulch has been shown to alter the optical environment above the crop canopy, thereby interfering with the host-finding and landing behavior of flying thrips (Antignus, 2000). The protective effect of reflective mulch is most pronounced while the reflective surface remains exposed; as the tomato canopy develops and shades the mulch, the reflected signal diminishes. However, a declining efficacy late in the season should not be misinterpreted as a failure of the tactic. Instead, it reflects a targeted intervention strategy, as the prevention of early vector landings confers disproportionate and lasting benefits for virus suppression by delaying the initial infection event (Riley et al., 2012). A complementary physical intervention, soil solarization, operates through an entirely different mechanism. By placing transparent polyethylene over moist soil, solar radiation is trapped, elevating soil temperatures to levels that suppress soilborne pathogens, pests, and weed propagules (Katan, 1981). While solarization is not expected to directly affect flying adult thrips, it can improve the pre-plant production environment, reduce alternative weed hosts, and alleviate crop stress, thereby potentially reducing the crop's overall vulnerability to infestation and disease (Stapleton, 2000). The combination of reflective mulch and soil solarization, therefore, represents a holistic, whole-system test of complementary physical interventions, rather than two iterations of the same tactic. However, the practical adoption of this combined approach is tempered by significant trade-offs, including increased material and labor costs, the logistical demands of installation and disposal, and the requirement for a fallow period and adequate soil moisture for effective solarization. Given the global invasiveness of *Frankliniella occidentalis*, its broad host range, and its rapid reproductive capacity, integrated strategies are urgently needed to mitigate both vector pressure and early infection risk (Kirk & Terry, 2003; Reitz, 2009). The present study was therefore undertaken to evaluate the biological and economic outcomes of reflective mulch and soil solarization—alone and in combination—to determine their capacity to reduce thrips abundance and TSWV incidence while simultaneously improving tomato yield and economic return. By assessing these factors together, this research aims to provide practical, adoption-oriented recommendations for sustainable TSWV management

Materials and Methods

The field experiment was conducted at CCRI Pirsabak during the 2024–2025 tomato season using a randomized complete block design with four replications. Plots measured 4 × 5 m, and the cultivar was 'Pirsabak Local'. Four treatments were compared: reflective silver-on-black mulch (T1), four-week soil solarization (T2), their combination (T3), and black plastic control (T4). Solarization was performed during June–July 2024 using 50-µm clear polyethylene over moist soil, with edges sealed. Soil temperature was monitored at 5, 10, and 15 cm depths. Thrips were assessed using five yellow sticky traps per plot (replaced weekly) and 20 leaves per plot at 30, 60, and 90 DAT. TSWV incidence was visually evaluated and confirmed by DAS-ELISA with appropriate controls (Clark & Adams, 1977; De Assis Filho et al., 2004). Marketable and unmarketable yields were weighed separately. Gross revenue was calculated at PKR 100,000 t^{-1}, and net return as gross revenue minus treatment cost, with insecticide savings reported separately. Statistical analyses employed block-aware mixed-effects models for thrips counts, binomial models for TSWV incidence, and linear models for yield and economics (Bolker et al., 2009; Bates et al., 2015). The plot was the experimental unit. Mulch installation, maintenance, and orientation relative to prevailing wind were documented. Labour, disposal, and irrigation costs were recorded for partial-budget analysis.

Results

The combined treatment of reflective mulch and soil solarization consistently produced the lowest thrips density across all sampling dates, with mean counts of 1.2, 1.8, and 2.4 thrips per leaf at 30, 60, and 90 DAT, respectively, representing an 81.3% reduction relative to the black plastic control at the earliest assessment (6.4 per leaf). Reflective mulch alone (1.8, 2.4, and 3.2 per leaf) outperformed solarization alone (4.2, 5.8, and 6.4 per leaf), confirming the expected optical mechanism by which reflective surfaces disrupt vector landing, though the protective effect of all treatments diminished as the canopy developed and shaded the mulch surface by 90 DAT. Tomato spotted wilt virus incidence followed an identical treatment ranking, with the combined treatment recording the lowest disease levels at 2.8%, 8.2%, and 12.8% at 30, 60, and 90 DAT, whereas the control escalated from 12.4% to 32.4% over the same period. By season's end, the combined programme reduced TSWV incidence by 60.5% relative to the control, a epidemiologically meaningful suppression that underscores the value of early vector exclusion. Soil solarization effectively elevated the thermal profile, with maximum temperatures reaching 50.1°C at 5 cm depth during week 3, while temperatures at 10 cm and 15 cm peaked at 46.8°C and 42.4°C, respectively, demonstrating a clear depth-dependent attenuation consistent with the physical principles of solar heating. Although specific soilborne pathogen mortality was not directly measured, the recorded thermal exposure suggests that the treatment achieved conditions sufficient for suppressing a range of soilborne pests and weed propagules. Marketable yield was highest under the combined treatment at 32.8 t ha^{-1}, representing a 46.4% increase over the control (22.4 t ha^{-1}), while reflective mulch and solarization alone produced intermediate yields of 28.4 and 24.6 t ha^{-1}, respectively. Economically, despite the combined treatment having the highest stated input cost (PKR 370,000 ha^{-1}), the substantial yield premium generated a net return of PKR 2.91 million ha^{-1}, which was PKR 720,000 ha^{-1} greater than the control and PKR 250,000 ha^{-1} higher than reflective mulch alone. These economic calculations, however, are sensitive to local material prices, disposal costs, and tomato market values, and should therefore be interpreted as a single-season partial budget rather than a definitive long-term projection. Collectively, these results demonstrate that the integrated physical programme delivered superior suppression of thrips and TSWV, enhanced marketable yield, and improved net economic returns, supporting the hypothesis that complementary mechanisms—optical disruption and thermal soil treatment—can function synergistically within an integrated pest management framework.

Thrips density and TSWV incidence

Table 2. Thrips density (mean ± SE per leaf).

Treatment	30 DAT	60 DAT	90 DAT
Reflective mulch	1.8 ± 0.3	2.4 ± 0.4	3.2 ± 0.5
Soil solarization	4.2 ± 0.6	5.8 ± 0.7	6.4 ± 0.8
Combined	1.2 ± 0.2	1.8 ± 0.3	2.4 ± 0.4
Black plastic control	6.4 ± 0.8	7.8 ± 0.9	8.6 ± 1.0

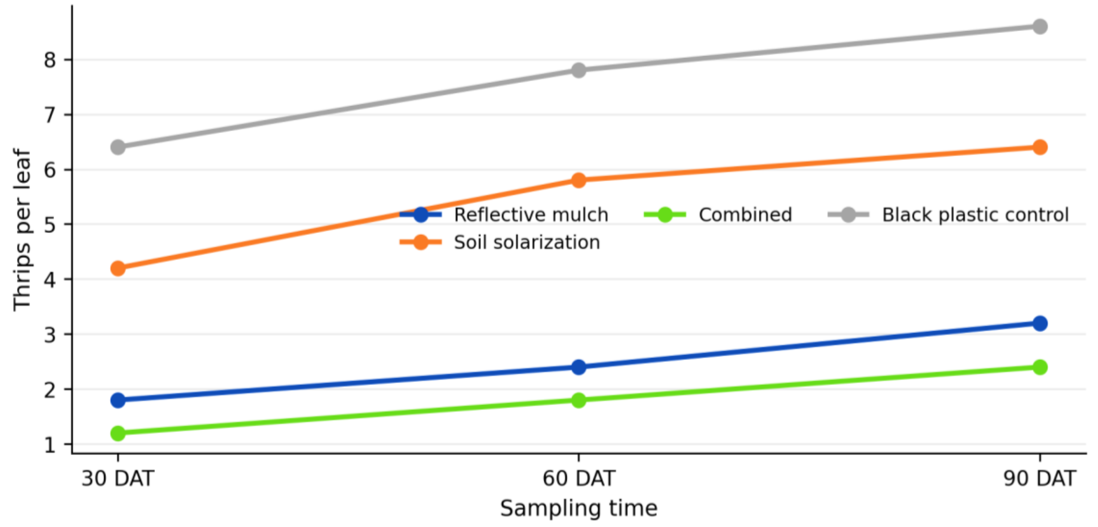

Figure 1. Seasonal thrips density under reflective mulch, solarization, their combination, and black plastic control.

Table 3. TSWV incidence (mean ± SE, %).

Treatment	30 DAT	60 DAT	90 DAT
Reflective mulch	4.2 ± 0.8	12.4 ± 1.6	18.6 ± 2.1
Soil solarization	8.6 ± 1.2	16.8 ± 2.0	24.2 ± 2.5
Combined	2.8 ± 0.6	8.2 ± 1.2	12.8 ± 1.8
Control	12.4 ± 1.6	24.6 ± 2.8	32.4 ± 3.2

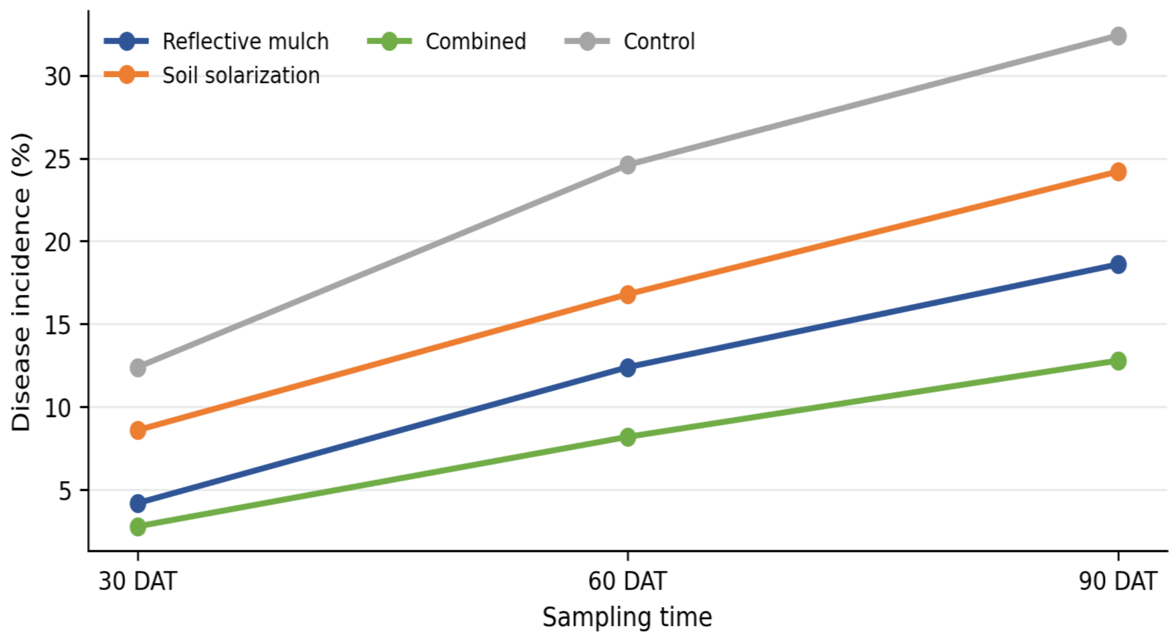

Figure 2. TSWV incidence over the growing season.

Soil heating

Table 4. Soil temperature during solarization (mean ± SE, °C).

Depth	Pre-cover	Week 1	Week 2	Week 3	Week 4
5 cm	32.4 ± 0.8	48.2 ± 1.1	49.6 ± 1.0	50.1 ± 1.2	48.8 ± 1.1
10 cm	30.8 ± 0.7	43.6 ± 0.9	45.2 ± 0.9	46.8 ± 1.0	45.4 ± 0.9
15 cm	29.6 ± 0.6	39.8 ± 0.8	41.2 ± 0.8	42.4 ± 0.9	41.2 ± 0.8

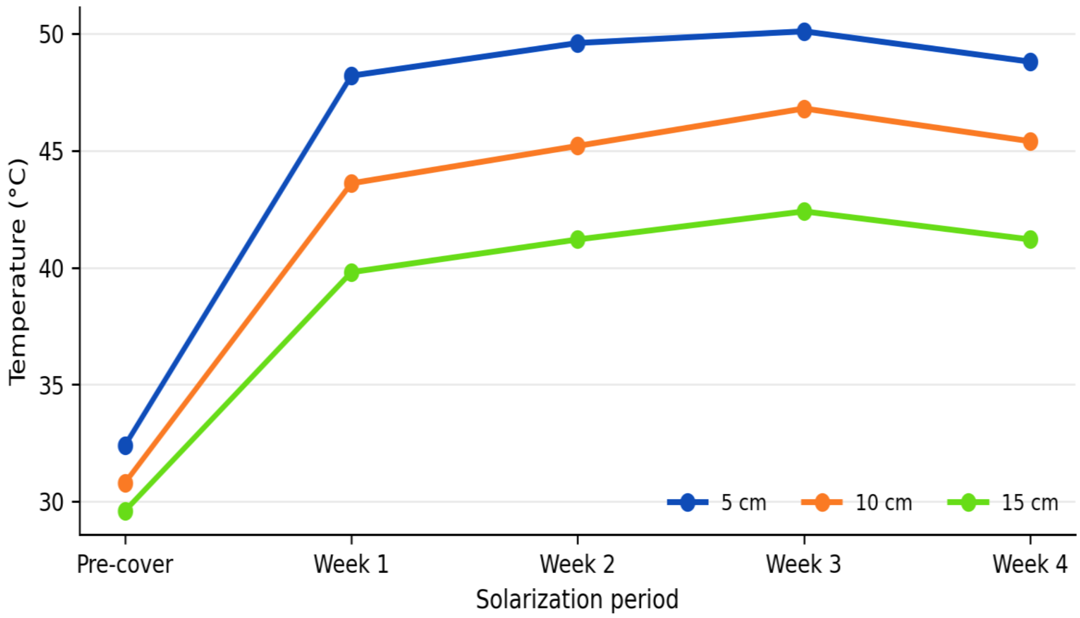

Figure 3. Soil-temperature profile at three depths during the four-week solarization period.

Discussion

The superior performance of reflective mulch over soil solarization in reducing thrips density is biologically coherent and consistent with the distinct mechanisms of each tactic. Adult *Frankliniella occidentalis* locate host plants primarily through above-ground visual and olfactory cues, so an optical barrier such as UV-reflective mulch can disrupt landing behaviour immediately upon vector arrival (Kirk & Terry, 2003). In contrast, soil solarization exerts no direct lethal effect on flying adult thrips, as its thermal action is confined to the soil profile. Solarization may nevertheless contribute indirectly to thrips suppression through improved soil health, reduced weed hosts, or enhanced crop vigour, but the present factorial design cannot isolate these pathways because intermediate variables such as weed density, root pathogen incidence, or plant stress indicators were not quantified (Katan, 1981; Stapleton, 2000). The combined treatment likely benefited from complementary temporal action: solarization modified the pre-plant production environment, while reflective mulch protected the crop during the most vulnerable early establishment period. This programme-level complementarity, rather than a simple additive physiological interaction, provides the most plausible explanation for the observed treatment ranking, reinforcing the value of integrating multiple physical tactics within a season-long management framework (Momol et al., 2004; Riley & Pappu, 2004).

The decline in reflective mulch efficacy as canopy closure progressed aligns with established understanding that reflected light diminishes once foliage shades the mulch surface (Antignus, 2000). This does not represent a failure of the tactic; rather, it underscores the critical importance of early-season protection, because preventing primary infection during the first weeks after transplanting confers disproportionate and lasting epidemiological benefits (Riley et al., 2012). However, physical control alone cannot guarantee disease-free production, and growers should integrate reflective mulch with clean transplants, rigorous weed management, roguing of infected plants, resistant cultivars where available, and judicious insecticide applications guided by regular scouting (Funderburk, 2009; Pappu et al., 2009). The sustained suppression of TSWV incidence under the combined treatment—a 60.5% reduction relative to the control at 90 DAT—supports the epidemiological principle that reducing early vector contact delays primary infection and limits secondary spread, although transmission dynamics are inherently non-linear due to variation in vector infection status, life stage, and feeding behaviour (Rotenberg et al., 2015).

Practical adoption of these physical tactics faces several constraints. Plastic sustainability remains a genuine limitation, as silver-on-black and transparent polyethylene generate disposal costs and environmental burdens if incinerated, landfilled, or fragmented in soil. Procurement decisions should prioritize durability, collection infrastructure, and recycling options, while biodegradable alternatives require careful field evaluation because degradation rates and performance vary substantially (Sintim & Flury, 2017). Economic recommendations must include end-of-season removal and disposal rather than treating these costs as external to the production system. Furthermore, adoption will depend heavily on local climatic conditions and capital availability; solarization is most effective during hot, high-radiation periods and requires advance planning, while reflective mulch demands significant upfront expenditure. The combined programme is therefore most attractive where TSWV pressure is recurrent and severe, tomato prices are sufficient to recover material costs, and growers possess the capacity to organize timely installation and disposal (Naranjo et al., 2015).

Future research should address several unresolved questions. A multi-season trial is essential to determine whether benefits remain stable under varying weather patterns, virus pressure, and market prices. Mechanism-specific interpretation requires additional controls to distinguish solarization's indirect effects on thrips—through weed suppression or crop vigour—from its direct soilborne pathogen management. Interaction contrasts between mulch and solarization would formally test whether the combined response is additive, synergistic, or dominated by the reflective component (Stapleton, 2000; Katan, 1981). Disease measurement demands the same rigor as vector counting; visual symptoms can be confused with nutrient disorders or other viruses, while ELISA results depend critically on tissue age, sampling timing, controls, and optical-density thresholds (Clark & Adams, 1977; Madden et al., 2007). Spatial mapping of infected plants could further clarify whether the combined treatment delayed primary infection, reduced secondary spread, or both. Finally, economic assessments should incorporate sensitivity analyses for mulch price, labour costs, tomato market value, and disposal fees, with break-even thresholds calculated to guide grower decision-making under diverse capital constraints (Naranjo et al., 2015; Sintim & Flury, 2017).

Conclusion

The combined application of reflective mulch and soil solarization effectively reduced thrips abundance and TSWV incidence while significantly improving marketable yield and net economic return. These findings support the integration of complementary physical tactics within sustainable IPM programmes. However, final recommendations require raw-data validation, verified cost records, and responsible plastic-management planning to ensure reliable, environmentally sound adoption.

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Conflict of Interest

The authors declare no conflict of interest.

Author Contributions

All authors equally contribute to this research Article.

Data Availability

Replicate-level observations and original statistical outputs were not supplied with the manuscript. Data availability and access conditions must be confirmed by the corresponding author before submission.

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