Efficacy of Biorational Spray Schedules for Sustainable Management of Citrus Thrips (*Scirtothrips dorsalis* Hood) in Acid Lime

L. Ranjith kumar[1*]; C.Madhumathi[2]; L.Rajesh Chowdary[3]

[*1]Scientist (Entomology), Citrus Research Station, Petlur, Dr YSRHU, A.P., India
[2]Principal Scientist & Head (Horticulture), Citrus Research Station, Petlur, Dr YSRHU, A.P., India
[3]Scientist (Entomology), Agriculture Research Station, Darsi, ANGRAU, A.P., India
*Corresponding Author

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Abstract— *Citrus thrips (Scirtothrips dorsalis Hood) is a major constraint in acid lime production, causing leaf distortion, flower drop and severe fruit scarring. Excessive reliance on synthetic insecticides has led to resistance development, residue concerns and disruption of natural enemies. Field experiments were conducted during 2022–23 and 2023–24 at Citrus Research Station, Petlur, Tirupati (Dt), Andhra Pradesh, India to evaluate the efficacy of different biorational insecticide spray schedules against citrus thrips. Eight treatments comprising neem-based botanicals, horticultural mineral oil (HMO), entomopathogenic fungi and Spinosad were evaluated in a randomized block design with three replications. Two sequential sprays were applied at petal fall and pea-size fruit stages. Treatments involving HMO @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit and Azadirachtin 1% EC (2 ml/lit) followed by Spinosad 48 SC @ 0.25 ml/lit recorded the lowest thrips population, minimum fruit infestation (3.6–4.1%) and highest yield (20.9–22.4 t/ha) across both seasons. Entomopathogenic fungi provided moderate but significant control, whereas mineral oil alone was less effective under higher pest pressure. The study clearly demonstrates that rotation of biorational insecticides with different modes of action ensures effective suppression of citrus thrips, reduces fruit damage and enhances yield. Such biorational spray schedules offer an environmentally safe, residue-free and sustainable alternative to conventional insecticides and can be effectively integrated into IPM programmes for acid lime cultivation.*

Keywords— ***Acid lime, Azadirachtin, Horticultural mineral oil, IPM, Spinosad, Thrips.***

I. INTRODUCTION

Acid lime (*Citrus aurantifolia* Swingle) is a commercially important citrus species cultivated extensively in southern India, particularly in Andhra Pradesh, where it contributes significantly to farm income and export-oriented horticulture. Productivity and fruit quality in acid lime are severely constrained by insect pests, among which thrips, especially *Scirtothrips dorsalis* Hood, are considered one of the most economically damaging pests in tropical and subtropical citrus-growing regions (Childers & Achor, 1995; Seal et al., 2006).Both nymphs and adults of *S. dorsalis* feed on meristematic tissues, including tender leaves, flower buds, and young fruits. Their feeding results in epidermal cell collapse, leading to leaf curling, bronzing, flower drop, and characteristic scab-like fruit scarring, which substantially reduces market acceptability and export value (Childers, 1997; Reddy & Kumar, 2012). Damage occurring during early fruit development is particularly critical, as even low thrips populations can result in severe cosmetic injury and economic loss.Management of *S. dorsalis* in citrus orchards has largely relied on repeated applications of broad-spectrum synthetic insecticides. However, the pest is highly polyphagous, multivoltine, and capable of rapid population buildup, leading to frequent spray interventions (Seal et al., 2006). Prolonged and indiscriminate use of chemical insecticides has resulted in resistance development, disruption of natural enemy complexes, pest resurgence, and concerns related to pesticide residues on fruits, especially those destined for domestic consumption and export markets (Morse & Hoddle, 2006; Isman, 2006).

In recent years, biorational insecticides have gained considerable attention as environmentally safer alternatives to conventional chemicals. These include botanical insecticides, such as neem-based formulations, and microbial agents, such as entomopathogenic fungi. Azadirachtin, the principal bioactive compound in neem, functions primarily as an insect growth regulator, antifeedant, and oviposition deterrent, thereby suppressing pest populations without causing immediate mortality (Schmutterer, 1990; Isman, 2006). Entomopathogenic fungi such as *Beauveria bassiana* and *Metarhizium anisopliae* infect insects through cuticular penetration, leading to systemic mycosis and death, and are generally considered compatible with beneficial arthropods (Shah & Pell, 2003; Vega et al., 2009).Although the efficacy of biorational insecticides against thrips has been demonstrated in vegetable and ornamental cropping systems, their field-level performance in perennial citrus orchards under tropical agroclimatic conditions remains inadequately validated. Moreover, information on optimized spray schedules and rotational use of biorationals for sustainable thrips management in acid lime is scarce. It is hypothesized that sequential application of neem-based formulations and microbial insecticides can effectively suppress *S. dorsalis* populations, reduce fruit damage, and minimize adverse impacts on natural enemies. In this context, the present study was undertaken to evaluate the efficacy of selected biorational insecticides and their spray schedules against citrus thrips in acid lime. Development of effective biorational-based spray schedules is expected to assist citrus growers in rational pesticide selection, resistance management, improved fruit quality, enhanced export potential, and promotion of sustainable eco-friendly agriculture.

II. MATERIALS AND METHODS

The field experiment was conducted in an established acid lime (*Citrus aurantifolia* Swingle) orchard at Citrus Research Station, Petlur, *Tirupati* district of Andhra Pradesh, India during 2022–23 and 2023–24 to evaluate the efficacy of different spray schedules of biorational insecticides against citrus thrips (*Scirtothrips dorsalis* Hood). The experiment was laid out in a Randomized Block Design (RBD) with eight treatments, including an untreated control, and three replications. Acid lime trees of uniform age, size, and vigour were selected for the study to minimize variability. Eight treatments comprising different biorational insecticide spray schedules, including an untreated control, were evaluated against citrus thrips in acid lime. Each treatment involved two sequential sprays, with the first spray at petal fall stage and the second spray at pea-size fruit stage (Table 1). Each treatment in every replication consisted of three trees, and thus a total of nine trees per treatment were maintained for observation. Individual replications were separated by buffer rows to avoid spray drift and treatment interference.

TABLE 1
TREATMENT DETAILS

Treatment No.	Treatment Description
T1	Azadirachtin 1% EC (10000 ppm) @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit
T2	Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by Azadirachtin 1% EC (10000 ppm) @ 2 ml/lit
T3	Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by HMO @ 10 ml/lit
T4	*Metarhizium anisopliae* (1 x 10^9 CFU's/gm) @ 5 g/lit followed by HMO @ 10 ml/lit
T5	*Lecanicillium lecanii* (1 x 10^8 CFU's/gm) @ 5 g/lit followed by Azadirachtin (10000 ppm) @ 2.0 ml/lit
T6	Horticultural Mineral Oil (HMO) @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit
T7	*Lecanicillium lecanii* (1 x 10^8 CFU's/gm) @ 5 g/lit followed by Spinosad 48 SC @ 0.25 ml/lit
T8	Control (water spray)

Two rounds of spray applications were imposed as per the treatment schedule. The first spray was applied at the petal fall stage, which coincides with the initiation of thrips infestation. The second spray was carried out at the pea-size fruit stage, a critical period for thrips-induced fruit scarring. All treatments were applied using a hand-operated knapsack pneumatic sprayer, ensuring uniform coverage of the foliage and developing fruits. The spray volume was adjusted according to tree canopy size to achieve thorough wetting without runoff. Spraying was done during the early morning hours under calm weather conditions to ensure effective deposition and minimize spray drift. The untreated control trees were maintained without any insecticidal application throughout the experimental period. The observations were recorded at '0' days as pre-count and post-count at 3rd, 7th, 10th and 14th days after each spray. The data on number of thrips per tender shoot or flower bud was recorded. In addition to direct population counts, the intensity of thrips infestation and damage was also assessed using a 1–5 visual rating scale (1 = Low; 2 = Moderate; 3 = High; 4 = Severe; 5 = Very severe). Percent fruit infestation was recorded during harvest. The data on average population of thrips was transformed using square root transformation ($\sqrt{x+0.5}$) and data in the form of percentage was transformed into arc sine values subjected to statistical analysis as suggested by Panse and Sukhatme (1985). The standard error (S.E.) and critical difference (C.D.) at 5% level of probability was calculated and yield data was subjected to statistical analysis.

III. RESULTS

3.1 Efficacy During 2022–23:

The results revealed that during the year 2022–23, significant differences were observed among the biorational spray schedules in reducing thrips incidence in acid lime. Among the treatments, T6, T1, and T3 recorded the lowest thrips population at 3, 7, and 14 days after spraying (DAS) and were statistically on par with each other, while differing significantly from the remaining treatments. Treatment T6 (Horticultural Mineral Oil @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) recorded 4.50, 3.18, and 1.74 thrips per shoot at 3, 7, and 14 DAS, respectively. This was closely followed by T1 (Azadirachtin 1% EC @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) with 4.64, 3.24, and 1.86 thrips per shoot, and T3 (Horticultural Mineral Oil @ 10 ml/lit applied twice) with 4.70, 3.30, and 1.98 thrips per shoot at the respective observation intervals. Similarly, minimum fruit infestation of 3.80% and 4.05% and maximum fruit yield of 22.40 t/ha and 21.90 t/ha were recorded in T6 and T1, respectively. These treatments were statistically on par with each other and significantly superior to the remaining treatments (Table 2).

3.2 Efficacy During 2023–24:

During 2023–24, a similar trend was observed. Treatments T6, T1, and T3 again recorded the lowest thrips incidence at 3, 7, and 14 DAS and were statistically on par with each other, while differing significantly from other treatments. Treatment T6 recorded 5.50, 4.10, and 2.90 thrips per shoot at 3, 7, and 14 DAS, respectively, followed by T1 with 5.64, 4.20, and 3.04 thrips per shoot and T3 with 5.72, 4.24, and 3.12 thrips per shoot. Correspondingly, the lowest fruit infestation of 3.60% and 3.85% and the highest fruit yield of 21.40 t/ha and 20.90 t/ha were recorded in T6 and T1, respectively. These treatments remained statistically on par with each other and were significantly superior to the remaining spray schedules (Table 3).

Overall, across both seasons, T6 and T1 consistently proved superior in reducing thrips population, minimizing fruit infestation, and enhancing fruit yield, followed by T3, indicating the effectiveness of biorational spray schedules involving mineral oil and azadirachtin in rotation with Spinosad.

TABLE 2
EFFICACY OF BIORATIONALS AGAINST CITRUS THRIPS DURING 2022–23 AT CRS, PETLUR

Sl. No.	Treatments	Mean No. of Thrips/Shoot				Fruit Infestation (%)	Yield (t/ha)
		1 DBS	**3 DAS**	**7 DAS**	**14 DAS**		
1	Azadirachtin 1% EC @ 2 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit	9.10 (3.10)*	4.64 (2.27)	3.24 (1.93)	1.86 (1.54)	4.05 (11.61)**	21.9
2	HMO @ 10 ml/lit fb Azadirachtin 1% EC @ 2 ml/lit	8.70 (3.03)	6.42 (2.63)	4.82 (2.31)	3.24 (1.93)	4.81 (12.67)	19.58
3	HMO @ 10 ml/lit fb HMO @ 10 ml/lit	9.24 (3.12)	4.70 (2.28)	3.30 (1.95)	1.98 (1.57)	4.62 (12.41)	19.7
4	*M. anisopliae* @ 5 g/lit fb HMO @ 10 ml/lit	8.94 (3.07)	6.54 (2.65)	4.98 (2.34)	3.40 (1.97)	5.42 (13.46)	18.2
5	*L. lecanii* @ 5 g/lit fb Azadirachtin @ 2 ml/lit	9.18 (3.11)	6.62 (2.67)	5.05 (2.36)	3.52 (2.00)	5.20 (13.18)	18.44
6	HMO @ 10 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit	8.96 (3.08)	4.50 (2.24)	3.18 (1.92)	1.74 (1.50)	3.80 (11.24)	22.4
7	*L. lecanii* @ 5 g/lit fb Spinosad 48 SC @ 0.25 ml/lit	9.05 (3.09)	5.60 (2.47)	3.90 (2.10)	2.34 (1.69)	4.42 (12.14)	20.14
8	Control (water spray)	9.10 (3.10)	11.80 (3.53)	13.82 (3.78)	16.10 (4.07)	9.10 (17.56)	15.88
	SE.m.±	0.09	0.06	0.05	0.04	0.16	0.39
	CD @ 5%	NS	0.18	0.17	0.11	0.49	1.12

DAS – Days after spray; DBS – Days before spray; fb – followed by; HMO – Horticultural Mineral Oil

Figures in parentheses are (√x+0.5) transformed values

***** Figures in parentheses are arc sine transformed values***

TABLE 3
EFFICACY OF BIORATIONALS AGAINST CITRUS THRIPS DURING 2023–24 AT CRS, PETLUR

Sl. No.	Treatments	Mean No. of Thrips/Shoot				Fruit Infestation (%)	Yield (t/ha)
		1 DBS	**3 DAS**	**7 DAS**	**14 DAS**		
1	Azadirachtin 1% EC @ 2 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit	8.20 (2.95)*	5.64 (2.48)	4.20 (2.17)	3.04 (1.88)	3.85 (11.32)**	20.9
2	HMO @ 10 ml/lit fb Azadirachtin 1% EC @ 2 ml/lit	7.20 (2.77)	6.04 (2.56)	4.70 (2.28)	3.60 (2.02)	4.60 (12.38)	18.58
3	HMO @ 10 ml/lit fb HMO @ 10 ml/lit	8.80 (3.05)	5.72 (2.49)	4.24 (2.18)	3.12 (1.90)	4.42 (12.14)	18.7
4	*M. anisopliae* @ 5 g/lit fb Azadirachtin 1% EC @ 2 ml/lit	7.80 (2.88)	6.20 (2.59)	5.04 (2.35)	3.80 (2.07)	5.30 (13.31)	17.2
5	*L. lecanii* @ 5 g/lit fb HMO @ 10 ml/lit	7.10 (2.76)	6.10 (2.57)	4.92 (2.33)	3.50 (2.00)	5.18 (13.16)	17.44
6	HMO @ 10 ml/lit fb Spinosad 48 SC @ 0.25 ml/lit	7.50 (2.83)	5.50 (2.45)	4.10 (2.14)	2.90 (1.84)	3.60 (10.94)	21.4
7	*L. lecanii* @ 5 g/lit fb Spinosad 48 SC @ 0.25 ml/lit	8.00 (2.92)	6.18 (2.58)	5.60 (2.47)	4.20 (2.17)	4.30 (11.97)	19.14
8	Control (water spray)	7.40 (2.81)	8.90 (3.07)	9.50 (3.16)	10.20 (3.27)	7.10 (15.45)	16.5
	SE.m.±	0.07	0.02	0.03	0.03	0.27	0.57
	CD @ 5%	NS	0.06	0.09	0.09	0.81	1.71

DAS – Days after spray; DBS – Days before spray; fb – followed by; HMO – Horticultural Mineral Oil

Figures in parentheses are (√x+0.5) transformed values

***** Figures in parentheses are arc sine transformed values***

IV. DISCUSSION

The present investigation demonstrated that biorational insecticide spray schedules, when applied sequentially at critical phenological stages of acid lime, effectively suppressed citrus thrips (*Scirtothrips dorsalis* Hood) and improved fruit yield and quality. Among the evaluated treatments, T6 (Horticultural Mineral Oil → Spinosad) and T1 (Azadirachtin → Spinosad) consistently recorded the lowest thrips population, minimum fruit infestation, and highest yield, highlighting the importance of rotating biorationals with different modes of action. The superior performance of horticultural mineral oil followed by Spinosad may be attributed to the initial physical and behavioral disruption caused by mineral oils, which interfere with respiration, feeding, and oviposition of thrips, leading to rapid suppression of early infestations (Beattie et al., 2002; Rae et al., 2014). The subsequent application of Spinosad, a biologically derived insecticide, ensured effective control of surviving individuals through its action on nicotinic acetylcholine and GABA receptors, resulting in quick mortality and prolonged suppression (Sparks et al., 2001). Similarly, the effectiveness of Azadirachtin followed by Spinosad underscores the value of integrating botanical insect growth regulators with bioinsecticides. Azadirachtin acts as an antifeedant and growth regulator, reducing feeding, molting, and reproduction of thrips, while Spinosad provides rapid knockdown of residual populations (Schmutterer, 1990; Isman, 2006). Comparable efficacy of azadirachtin-based IPM strategies against sucking pests has been widely reported. Treatments involving mineral oil alone provided moderate suppression, indicating that oils are more effective when used as part of a rotation rather than as standalone treatments, particularly under sustained pest pressure (Rae et al., 2014; Rao et al., 2013). In contrast, entomopathogenic fungi showed lower field efficacy, likely due to environmental constraints such as temperature, humidity, ultraviolet radiation, and slower speed of action under open field conditions (Shah & Pell, 2003; Vega et al., 2009).

Effective suppression of thrips during petal fall and pea-size stages significantly reduced fruit scarring and enhanced yield, emphasizing the importance of timely intervention at early fruit development stages, when thrips damage directly affects marketable quality (Childers & Achor, 1995).From an Integrated Pest Management (IPM) perspective, the study strongly supports the adoption of biorational spray rotations, which enhance control efficacy, reduce resistance risk, conserve natural enemies, and minimize pesticide residues on citrus fruits. Overall, the results confirm that biorational-based spray schedules integrating mineral oils, botanicals, and Spinosad provide an environmentally safe, economically viable, and sustainable strategy for citrus thrips management in acid lime.

V. CONCLUSION

The present study conclusively demonstrated that biorational insecticide spray schedules are effective in managing citrus thrips (*Scirtothrips dorsalis* Hood) in acid lime when applied at critical crop growth stages. Among the evaluated treatments, T6 (Horticultural Mineral Oil @ 10 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) and T1 (Azadirachtin 1% EC @ 2.0 ml/lit followed by Spinosad 48 SC @ 0.25 ml/lit) were found to be the most effective, recording the lowest thrips population, minimum fruit infestation, and highest fruit yield. These treatments were statistically on par with each other and significantly superior to the remaining spray schedules. The study further established that sequential application of biorationals with different modes of action provided prolonged suppression of thrips populations up to 14 days after spraying. Integration of mineral oils or botanical insecticides with Spinosad proved particularly effective in reducing early pest pressure, minimizing fruit scarring, and enhancing marketable yield. Treatments involving entomopathogenic fungi alone showed comparatively lower field efficacy, highlighting the influence of environmental conditions on microbial performance.

Overall, the results emphasize that biorational-based spray rotations can serve as a viable, eco-friendly alternative to conventional insecticides and can be effectively incorporated into Integrated Pest Management (IPM) strategies for sustainable acid lime production.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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