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INTEGRATED MANAGEMENT OF FRUIT FLIES IN CHIKOO (*MANILKARA ZAPOTA*) ORCHARDS USING BAITS, LURES, NEEM EXTRACT AND SANITATION

[a]Nasir Shah, [b]Muhammad Ibrahim*, [c]Norman Javed Gill, [c]Israr Ullah, [b]Muhammad Kamran, [d]Syed Shamsullah

[a] *Department of Entomology, Lasbela University of Agriculture, Water and Marine Sciences (LUAWMS), Lasbela, Pakistan*
[b] *Directorate of Agriculture Research Fruit, Agriculture Research Institute (ARI), Quetta, Pakistan.*
[c] *Department of Agriculture Extension Balochistan, Pakistan.*
[d] *Department of Plant Pathology, University of Agriculture, Faisalabad, Pakistan.*

A B S T R A C T

This study evaluated the effectiveness of integrating sanitation with Male Annihilation Technique (MAT), Bait Application Technique (BAT), and neem seed extract (NSE) for fruit fly management in chikoo orchards using a factorial randomized complete block design (RCBD). Baseline observations confirmed uniform pest distribution across treatments. Over the season, sanitation significantly enhanced treatment efficacy, with sanitation plots consistently recording lower adult fly captures and pupae emergence compared to non-sanitation plots. Among treatments, MAT was most effective in reducing adult male populations, while BAT resulted in the lowest pupae emergence, indicating strong suppression of ovipositing females. The sanitation + MAT combination achieved the greatest reduction in adult fly populations (up to 89–95%), whereas sanitation + BAT recorded the lowest pupae counts (as low as 11 pupae per sample in late season). Overall, integrating sanitation with lure- and bait-based strategies provided superior control compared to individual approaches. These findings demonstrate that integrating sanitation with lure-based traps, protein-based baits, and natural repellents offers a practical, ecologically sound, and economically viable strategy for sustainable fruit fly management in chikoo orchards.

Keywords: Tephritidae flies, Orchard Hygiene, Trap, Neem, *Bactrocera dorsalis*, *B. zonata*.

Corresponding Author: Muhammad Ibrahim
Email: ibrahimafridi811@gmail.com

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INTRODUCTION

Chikoo is currently cultivated as a minor fruit only in coastal areas of Sindh and Balochistan provinces in Pakistan. In 2021-22, total area under its cultivation was 1837 hectares with total production of 10467 tonnes (GOP, 2023). Human population surge has increased the demand of food especially fresh fruits and vegetables. However, several diseases and insect pests are hindrance for both quantity and quality of fruits and vegetables (Ansari et al., 2019).

Among insect pests, Tephritidae (Diptera) fruit flies are the most harmful insect pests of fruits and vegetables. In Pakistan, fruit fly infestation in orchards has been recorded throughout the cropping season especially summer months from July to September, with peaks in August (Kakar et al., 2014). Fruit fly infestation can cause fruits losses, loss to producers, traders and governments (Follett and Neven, 2006). The percentage of male adults of peach fruit fly captured in trap from the orchards of guava and mango was 46.62 and 74.66%, respectively (Khan et al., 2005). *Bactrocera zonata* is also one of the most abundant and devastating fruit flies causing 3-100% fruit losses in different vegetables and fruits (Ahmad and Begum, 2017). From 40-80% direct loss to the export of main crops has been estimated (Dias *et al*., 2018) and importing countries are reluctant to the fruits detected with fruits flies (Lanzavecchia et al., 2014). Sapota fruit is present on the tree at most of their stages of development (Yahia and

Gutierrez-Orozco, 2011; Kishore and Mahanti, 2016). Fruit fly (*B. dorsalis* Hendel) maximum activity was observed from March to August in sapota orchard (Nandre and Shukla, 2014) which survived during the months of Mar, May, Jul-Sep, Nov, Jan and Feb (Arthikirubha et al., 2017).

Number of control methods have been used to manage fruit flies, and among these control measures, the most frequently used are the synthetic insecticides such as Malathion and Spinosad as cover sprays for swift management (Williams et al., 2003; Yee, 2007; De Bon et al., 2014). Sprays of such insecticides not only harms non-target beneficial arthropods and phytotoxic effects on plants but also causes ecological backlashes (Mostafalou and Abdollahi, 2013; Li et al., 2018). Environmental concerns have alerted the researchers for long to explore the alternate means of managing insect pests of agriculture crops. Male annihilation technique (MAT) and bait application techniques (BAT) are considered economical, feasible and reliable for farmers (Stonehouse et al., 2002a).

Male Annihilation Technique (MAT) is a population-suppression strategy designed to disrupt the reproductive cycle of fruit flies by selectively removing males, thereby reducing successful mating events (Dominiak and Nicol, 2012), whereas Bait Application Techniques (BAT) target the protein requirement of females, particularly sexually immature individuals that actively seek protein to develop viable eggs, through application of a protein-toxicant mixture on host trees, an approach shown to effectively suppress fruit fly populations (Allwood et al., 2002); for instance, use of BAT against *B. cucurbitae* in cucurbit fields resulted in a 48% improvement over unprotected farms (Stonehouse et al., 2007), and integration of male annihilation traps with protein baits achieved complete eradication of B. dorsalis, *B. xanthodes*, and *B. cucurbitae* (Allwood et al., 2002). In parallel, botanical extracts have been investigated for fruit fly management (Ilyas et al., 2017; Ugwu et al., 2021; Shah et al., 2024), with plant-derived insecticides demonstrating both deterrent and acute toxic effects (Khater, 2012); notably, azadirachtin, the principal bioactive compound of neem and a key ingredient in several commercial bioinsecticides (Acheuk et al., 2022), has shown efficacy, as neem seed kernel extract (0.5%) applied twice at 15-day intervals significantly reduced melon fruit fly damage in cucumber (Mir and Mir, 2015), and neem oil treatments significantly lowered settlement of *B. zonata* compared to untreated fruits (53.3%) (Khattak et al., 2012). Moreover, integrated application of MAT, BAT, and MAT combined with neem resulted in the lowest fruit infestation levels in mango orchards, with maximum mean percent reduction over the control recorded under MAT combined with BAT (89–95%) or MAT combined with neem (76–85%) (Latif and Abdullah, 2005).

Sanitation in an orchard is of prime importance to enhance the effectiveness for bait, lure and repellent. Adults fly emergence was effectively prevented by sanitation and burying fruit 0.46 m deep in ground (Klungness et al., 2005) and reduces fruit damage (Hasyim et al., 2008) with Lure (Singh et al., 2013) and baits (Piñero et al., 2009) combined sanitation can be effective in reducing fruit fly infestation. This study tested the hypothesis that an integrated pest management (IPM) strategy combining orchard sanitation with bait lures and natural insect repellents would significantly reduce fruit fly populations in chikoo orchards, thereby improving fruit yield, quality, and overall orchard health.

MATERIALS AND METHODS

Field study was undertaken in a chikoo orchard located at coconut farm (25°46'38.6"N 66°37'05.7"E), Uthal, District Lasbela during year 2020. Lasbela has a coastal climate charterized by short, mild winters and hot, wet summers with an annual rainfall ranging from 127-254 mm. This part of Balochistan falls in monsoon where summers rains occur from July to mid-September and mean temperature fluctuates between 25-30º C (Khan et al., 2021).

The selected chikoo orchard for this study was surrounded by coconut, ber and vegetable (*solanaceous* and *cucurbitaceous*) plantations. The plants in this six acres chikoo orchard were planted at 25×25 square feet. Regular cultural practices of pruning, irrigation, fertilization and pruning were carried out uniformly in the whole orchard. A two-factor factorial experiment was arranged, including two sanitation practices: sanitation and no sanitation and three treatments: Male annihilation technique (MAT), Bait application technique (BAT) and Neem Seed extract (NSE) 2% spray, randomly applied in the orchard blocks under factorial RCBD design replicated three times. Each treatment unit plot comprised of about 24 trees. Nine observations of fly population from June 01 to September 30 at fortnight interval were recorded. For sanitation, plant debris and dropped fruits from ground were buried 3 feet deep in ground away from the orchard. Plywood blocks (3×3 inches size and 0.5 inches thickness) were used for MAT. The blocks were soaked in a mixture of ethanol solvent 95%, methyl eugenol 25% (STEDEC) and Malathion 57% EC (Fyfanon, Jaffer) with a ratio of 6:4:1 (v:v:v) (Stonehouse et al., 2007) for 48 h and left for drying for 24 h. Four soaked plywood blocks per acre were hung

on the tree trunk at the height of 4.5 feet at distance of 20 m apart in shaded parts and replaced every 20 days. Bait spray included commercial hydrolyzed protein (Bio Guard, Kanzo, Evyol Group) + deltamethrin 2.5% EC (Jaffar) with dose of 40 ml and 5 ml, respectively in 1 L of water and was sprayed on the lower branches of the tree canopy at four spots acre^{-1} at weekly intervals till harvest. For Neem seed extract (2%), two kg of finely grinded neem seed powder was mixed with 30 g of detergent and wrapped in a muslin cloth before dipping it in 5 L distilled water. After a day, the concentrate was squeezed out and diluted to 2% by distilled water. Neem seed extract 2% was applied on the chikoo trees as cover spray at 15 days intervals.

Fruit flies monitoring

B. dorsalis and *B. zonata* were monitored pre- and post-treatment using trap jar. Traps held cotton soaked in methyl eugenol 25% (STEDEC) and Malathion 57% EC (Fyfanon, Jaffer) for trapping male fruit flies before application of treatments and hanged only for 24 h. During experiment, such traps were hanged on the lower branches of trees at heights of 4.5 feet only for 24h one per replication and repeated at fortnightly intervals.

Infestation Level

For the determining level of infestation (Stonehouse et al., 2002b), one kg of infested dropped fruit was randomly collected from each replication before and after each treatment. The infested fruits were placed in a rearing cage (1.5 ft. length and 1 ft. width) with floor having one inch layer of sand for fruit fly pupation. Number of pupae from each rearing cage were counted to determine the infestation level (number of pupae kg^{-1} infested fruits) of fruit flies before treatment and fortnightly after treatments.

Statistical analysis

The data collected before treatments, and fortnightly after treatments were statistically analyzed using RCBD with three blocks using Staistix 8.1 (Analytical Software, Tallahassee, Florida, USA) software for analysis of variance (ANOVA) and means were compared by Fischer's least significant difference (LSD) test at $P \leq 0.05$.

RESULTS AND DISCUSSION

Monitoring revealed uniformly high fruit fly populations at the start, with no differences among plots (Table 1). From mid-July onward, sanitation plots consistently recorded lower fly counts, with suppression intensifying through August and September. Among treatments, MAT was most effective, followed by NSE and then BAT. The combination of sanitation + MAT yielded the lowest populations (291 by mid-August, 38 by late September), while non-sanitation + BAT plots had the highest (576 and 179, respectively). Results indicate that sanitation enhances treatment efficacy, and MAT-based strategies provide the strongest control, with significant interactions between sanitation and treatment observed.

Table 1: Mean number of fruit flies trapped per monitoring trap in different treatment plots in chikoo orchard (June to September).

Number of fruit flies trap^{-1}						
Sanitation	Treatments			Total Means	Comparisons	LSD ($P \leq 0.05$)
	MAT	BAT	NSE			
				01-Jun		
Sanitation	618 ab	668 a	604 ab	630 A	Treatment	69.68 NS
No Sanitation	629 ab	574 ab	557 b	586 A	Sanitation	56.89 NS
Total Means	623 A	621 A	580 A		T × S	98.54 NS
				15-Jun		
Sanitation	344 d	378 cd	461 bc	394 B	Treatment	62.23 NS
No Sanitation	532 ab	587 a	478 b	532 A	Sanitation	50.81 *
Total Means	438 A	483 A	470 A		T × S	88.00 *
				30-Jun		
Sanitation	378 c	519 b	382 c	427 B	Treatment	80.15 *
No Sanitation	558 b	749 a	450 bc	586 A	Sanitation	65.44*
Total Means	468 B	634 A	416 B		T × S	113.35 NS
				15-Jul		
Sanitation	325 c	304 c	268 c	299 B	Treatment	66.73 *
No Sanitation	429 b	571 a	302 c	434 A	Sanitation	54.49 *
Total Means	377 A	437 A	285 B		T × S	94.37 *

				30-Jul		
Sanitation	253 d	426 ab	375 bc	352 A	Treatment	55.86 *
No Sanitation	314 cd	494 a	377 bc	395 A	Sanitation	45.61 NS
Total Means	284 C	461 A	376 B		T × S	79.00 NS
				15-Aug		
Sanitation	291 c	452 b	481 b	408 B	Treatment	57.35 *
No Sanitation	508 ab	576 a	494 b	526 A	Sanitation	46.83 *
Total Means	400 B	514 A	487 A		T × S	81.11 *
				30-Aug		
Sanitation	217 d	308 cd	376 bc	300 B	Treatment	65.61 NS
No Sanitation	468 ab	496 a	404 ab	456 A	Sanitation	53.57 *
Total Means	343 A	402 A	390 A		T × S	92.79 *
				15-Sep		
Sanitation	78 d	148 bc	100 cd	109 B	Treatment	45.76 *
No Sanitation	157 bc	289 a	185 b	210 A	Sanitation	37.36 *
Total Means	118 B	218 A	143 B		T × S	64.72 NS
				30-Sep		
Sanitation	38 d	132 b	105 c	92 B	Treatment	18.93 *
No Sanitation	103 c	179 a	117 bc	133 A	Sanitation	15.45 *
Total Means	70 C	156 A	111 B		T × S	26.76 *

MAT: Male annihilation technique, BAT: Bait application technique, NSE: Neem seed extract. Means sharing similar lowercase letters and Total means sharing similar uppercase letters are not significantly different in their respective rows and columns (LSD test, $P \leq 0.05$). Comparison: critical value for comparison with * = significant and NS = non-significant difference.

The study showed that sanitation significantly reduced fruit fly pupae emerging from fallen chikoo fruits throughout the season. Baseline data on 1-Jun confirmed uniform pest pressure across plots (Table 2). By 15-Jun, sanitation plots had lower pupae counts (27 vs. 40.56), with BAT emerging as the most effective treatment in both sanitation (15) and non-sanitation (32) plots. This trend continued through June and mid-season (15–30 Jul), where sanitation plots consistently recorded fewer pupae and BAT maintained superior efficacy (23–26 pupae), while MAT showed higher emergence. Late-season observations (15 Aug–30 Sep) confirmed sanitation's continued effectiveness, with the sanitation + BAT combination yielding the lowest pupae counts (11 by 15-Sep), whereas non-sanitation + BAT plots recorded higher counts (36). Towards the end of the season, BAT remained effective, though differences among treatments diminished as pest pressure naturally declined.

Table 2: Mean number of pupae emerged from kg^{-1} fallen chikoo fruit collected from different treatment plots in chikoo orchard, observed at various intervals.

Number of pupae emerged kg^{-1}						
Sanitation	Treatments			Total Means	Comparisons	LSD ($P \leq 0.05$)
	MAT	BAT	NSE			
				01-Jun		
Sanitation	128 b	124 b	162 a	138 A	Treatment	21.81 NS
No Sanitation	149 ab	132 ab	146 ab	143 A	Sanitation	17.81 NS
Total Means	139 AB	128 B	154 A		T × S	30.84 NS
				15-Jun		
Sanitation	44 ab	15 d	23 cd	27 B	Treatment	10.69 *
No Sanitation	58 a	32 bc	31 bc	40.56 A	Sanitation	8.72 *
Total Means	51 A	24 B	28 B		T × S	15.11 NS
				30-Jun		

Sanitation	23 cd	22 cd	19 d	22 B	Treatment	7.58 *
No Sanitation	65 a	34 b	32 bc	44 A	Sanitation	6.19 *
Total Means	44 A	28 B	26 B		T × S	10.72 *
				15-Jul		
Sanitation	43 bc	15 d	30 c	30 B	Treatment	9.31 *
No Sanitation	61 a	31 bc	44 bc	45 A	Sanitation	7.60 *
Total Means	52 A	23 C	37 B		T × S	13.17 NS
				30-Jul		
Sanitation	44 abc	19 d	36 bc	33 B	Treatment	11.05 *
No Sanitation	53 a	34 cd	49 ab	45 A	Sanitation	9.02 *
Total Means	49 A	26 B	43 A		T × S	15.62 NS
				15-Aug		
Sanitation	36 ab	24 b	34 ab	32 B	Treatment	10.81 NS
No Sanitation	47 a	38 ab	42 a	43 A	Sanitation	8.83 *
Total Means	42 A	31 B	38 A		T × S	15.29 NS
				30-Aug		
Sanitation	31 bc	28 c	26 c	28 B	Treatment	9.98 NS
No Sanitation	47 a	43 ab	32 bc	41 A	Sanitation	8.15 *
Total Means	39 A	36 A	29 A		T × S	14.12 NS
				15-Sep		
Sanitation	23 b	11 d	14 cd	16 B	Treatment	5.99 *
No Sanitation	35 a	36 a	21 bc	31 A	Sanitation	4.89 *
Total Means	29 A	23 AB	18 B		T × S	8.47 *
				30-Sep		
Sanitation	18 ab	10 b	17 ab	15 B	Treatment	7.57 NS
No Sanitation	25 a	26 a	22 a	24 A	Sanitation	6.18*
Total Means	22 A	18 A	20 A		T × S	10.71 NS

MAT: Male annihilation technique, BAT: Bait application technique, NSE: Neem seed extract. Means sharing similar lowercase letters and Total means sharing similar uppercase letters are not significantly different in their respective rows and columns (LSD test, $P \leq 0.05$). Comparison: critical value for comparison with * = significant and NS = non-significant difference.

The findings of this study highlight the complementary roles of MAT, BAT, and sanitation in managing fruit fly populations in chikoo orchards. Consistent with previous reports on sapota orchards (Nandre and Shukla, 2014; Yahia and Gutierrez-Orozco, 2011; Kishore and Mahanti, 2016), fruit flies persist throughout the season due to continuous fruit availability, with *B. dorsalis* being a dominant species (Arthikirubha et al., 2017). MAT primarily targets adult males using male lures such as methyl eugenol, effectively breaking the reproductive cycle by reducing the number of males available for mating (Dominiak and Nicol, 2012), which explains the lower male fly captures in monitoring traps. In contrast, BAT employs protein-toxicant mixtures that attract females actively seeking protein to become reproductively mature, leading to reduced oviposition and consequently lower pupae emergence (Table 3) in fallen fruits (Allwood et al., 2002; Khan et al., 2015). This differential targeting explains why MAT is more effective at suppressing adult males, while BAT more directly reduces the next generation by limiting egg-laying females.

Sanitation further amplifies the efficacy of both MAT and BAT by removing fallen and infested fruits, thereby eliminating breeding sites and interrupting the life cycle at the egg, larval, and pupal stages (Hasyim et al., 2008; Klungness et al., 2005). Incorporating neem-based extracts, such as neem seed kernel extract or oil, adds a repellent and ovicidal effect, deterring adult oviposition and reducing pupae survival (Valencia-Botin et al., 2004; Khattak et al., 2009; Mir and Mir, 2015). Together, this integrated approach offers significant ecological and economic advantages: ecologically, it reduces reliance on synthetic insecticides, minimizing non-target impacts and environmental contamination; economically, it enhances fruit yield and quality while lowering pest management

costs by reducing repeated chemical applications (Stonehouse et al., 2007; Al-Eryan et al., 2018). Overall, the combination of sanitation, MAT, BAT, and neem creates a robust, multi-stage suppression strategy, controlling both adult populations and subsequent generations, making it a highly effective IPM framework for chikoo orchards.

Table 3: Total mean number of fruit flies trapped per monitoring trap and total mean number of pupae emerged from kg^{-1} fallen chikoo fruit in different treatment plots in chikoo orchard throughout the observation period (June to September).

Treatments			
	MAT	BAT	NSE
Fruit flies $trap^{-1}$	347 B	436 A	362 B
LSD ($P \leq 0.05$)			18.57 *
Pupae emerged kg^{-1}	52 A	37 C	44 B
LSD ($P \leq 0.05$)			4.05 *
Sanitation Practices			
	Sanitation		No Sanitation
Fruit flies $trap^{-1}$	335 B		429 A
LSD ($P \leq 0.05$)			15.16 *
Pupae emerged kg^{-1}	38 B		51 A
LSD ($P \leq 0.05$)			3.31 *

MAT: Male annihilation technique, BAT: Bait application technique, NSE: Neem seed extract. Means sharing similar letters are not significantly different in respective rows (LSD test, $P \leq 0.05$). Value against LSD ($P \leq 0.05$) is critical value for comparison with * = significant and NS = non-significant difference.

CONCLUSION

The integration of treatment methods with sanitation provided the most effective strategy for sustainable fruit fly management in chikoo orchard. Among the treatments, BAT proved most effective in reducing pupae emergence, while MAT was highly effective in minimizing adult male populations. These findings underscore the importance of sanitation in IPM with potential applications for other fruit crops affected by similar pests. However, for more promising results these integrations may be explored by future research on larger scale and employed cooperatively at community level.

AUTHORS' CONTRIBUTION

NS field research, writing original draft; MI formal analysis, writing original draft, methodology; NJG, IU conceptualization, methodology; MK, SS writing review, editing and validation.

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