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FIELD EFFICACY, ECONOMIC PERFORMANCE AND EXTENSION IMPLICATIONS OF EIGHT INSECTICIDES FOR DUSKY COTTON BUG MANAGEMENT IN MULTAN, PAKISTAN

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ABSTRACT

Dusky cotton bug, Oxycarenus hyalinipennis, damages open cotton bolls and reduces lint and seed quali-ty. Locally relevant evidence is needed to support extension recommendations on effective and economi-cal insecticide options. Eight commercial insecticide treatments and an untreated control were evaluated during 2025 at the Cotton Research Institute, Multan, Pakistan, in a randomized complete block design with three replications. The first spray was applied on 15 August 2025. Population was recorded before treatment and on 18, 22 and 29 August, corresponding to 3, 7 and 14 days after treatment. A second spray was applied on 2 September; no post-second-spray population assessment was available. Seed-cotton yield was pooled across plot-wise pickings, and the economic comparison used the reported costs of the two-spray programme. Every insecticide reduced pest density relative to the untreated control. Spinetoram produced the greatest reductions at 3, 7 and 14 days (86.15%, 91.69% and 87.63%), followed by fipronil. Spinetoram and fipronil also produced the highest seed-cotton yields. Imidacloprid produced the highest reported gross-return-to-treatment-cost ratio, followed by cypermethrin plus chlorpyriphos. Weather associations from a separate 14-week unsprayed series were exploratory. Spinetoram and fipronil were the strongest biological options, whereas imidacloprid provided the most favourable re-ported economic return. Extension recommendations should distinguish biological efficacy from afforda-bility and should remain conditional on current product registration, label directions, local pest thresh-olds and validation across locations and seasons.

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INTRODUCTION

Cotton (*Gossypium hirsutum* L.) remains a key crop for Pakistan's agricultural and textile economy, contributing directly to the agriculture sector that accounts for about 23.5% of national GDP (Tausif et al. 2018). However, national output has become increasingly volatile, with production falling to 7.08 million bales and cotton ginning declining by 19.0% in 2024–25 relative to the previous year (Government of Pakistan, Pakistan Economic Survey 2024–25), underscoring the need to protect the crop from yield-

limiting pests such as the sucking-pest complex. Punjab, and particularly the Multan, Bahawalpur, Vehari belt, accounts for the largest share of the country's cotton area and production. Crop productivity, however, is persistently constrained by a complex of insect pests, among which sucking insects whitefly (*Bemisia tabaci*), jassid (*Amrasca bigutella bigutella*), thrips (*Thrips tabaci*) and the dusky cotton bug (*Oxycarenus hyalinipennis* Costa) have assumed growing economic importance following the widespread adoption of Bt cotton, which offers protection primarily against bollworms but not against the sucking-pest complex (Khalid et al. 2022).

The dusky cotton bug is a polyphagous hemipteran pest that aggregates in large numbers on open cotton bolls, feeding on developing and mature seed (Jans et al. 2021). Feeding punctures made by nymphs and adults stain the lint with excreta and crushed body fluids during ginning, lower oil content and germination capacity of seed, and predispose bolls to secondary fungal boll rot (Gaur and Mogalapu, 2018). Infestation levels tend to intensify from mid-season onward as bolls begin to open, and the pest can build up rapidly under warm, dry conditions typical of the Multan region in late summer and early autumn (Iqbal et al. 2022). Because economic thresholds are exceeded quickly once boll opening begins, chemical control remains the principal tactic used by growers to manage this pest, despite its compatibility issues with natural enemies and resistance-development concerns associated with repeated use of a narrow range of chemistries.

These products were selected to represent the principal modes of action used against the cotton sucking-pest complex in the Multan zone. Their inclusion as research treatments does not itself establish registration for dusky cotton bug; extension use must follow current Pakistan registration and approved labels.

METHODOLOGY

Experimental site and crop

The field trial was conducted during the 2025 cotton-growing (Kharif) season at the experimental farm of the Cotton Research Institute, Multan, Punjab, Pakistan (approximately 30.2° N, 71.5° E), on a sandy-loam soil typical of the local cotton belt. The Bt cotton cultivar MNH-886 recommended for the Multan zone was sown on 1 March on east and west oriented ridges at a row-to-row spacing of 75 cm and plant-to-plant spacing of 30 cm. Plots were assigned to treatments by random allocation of treatment codes to plot positions within each of the three blocks using a random-number table, consistent with standard RCBD randomization. Fertilizer, irrigation and weed control followed the standard agronomic package of practices recommended for Bt cotton in the Multan, and no other insecticide, acaricides or fungicide was applied to the experimental area during the trial period. No insecticide was applied against the sucking-pest complex prior to the initiation of the trial so that a natural, uniform infestation of dusky cotton bug could establish across the experimental area. Seed cotton was harvested in successive plot-wise pickings from early September through 20 October 2025; the weights from all pickings were summed within each plot and converted to kg/ha.

Experimental design and treatments

The experiment was laid out in a Randomized Complete Block Design (RCBD) comprising nine treatments (eight insecticide products plus an untreated control) replicated three times, giving 27 experimental units. Each plot measured 6 m × 5 m (30 m^2), separated by a 1.5 m guard row to minimize inter-plot drift. Treatments were applied as a knapsack-sprayer foliar application, directed principally at open and opening bolls where the pest aggregates, using field-recommended doses on a per-acre basis (Table 1) mixed in 250–300 L of water per hectare equivalent. Two sprays were applied: the first on 15 August 2025 and the second on 2 September 2025 (an 18-day interval). Population counts were taken one day before spray (14 August 2025) and at 3, 7 and 14 days after treatment (DAT), corresponding to 18, 22 and 29 August 2025, respectively. All three DAT assessments therefore preceded the second spray (2 September 2025) and reflect the effect of the first spray alone. Treatment details, including trade names, active ingredients, formulations, chemical groups and doses, are presented in Table 1.

Sampling and data recording

Population counts of dusky cotton bug (nymphs and adults combined) were recorded from five randomly selected, pre-tagged plants per plot by visually inspecting five open bolls per plant early in the morning when insect activity is lowest, giving 25 boll-level observations per plot at each sampling date; these were averaged to a single plot-level mean, which was the experimental unit used in all subsequent analyses. Counts were taken one day before the first spray (pre-treatment) and at 3, 7 and 14 days after treatment (DAT). Percent population reduction was calculated using Abbott's (1925) formula, % reduction = [1 − (Tt / Ct)] × 100, which

does not adjust for pre-treatment density differences among plots. Because pre-treatment counts did not differ significantly among treatments (Table 2), Abbott's formula was considered an adequate first approximation; nevertheless, we additionally recalculated plot-mean efficacy using the Henderson and Tilton (1955) correction, % control = [1 − (Ta/Tb)(Cb/Ca)] × 100, where Ta and Tb are the treated-plot counts after and before spraying and Ca and Cb are the corresponding control-plot counts. The Henderson-Tilton-corrected values differed from the Abbott's-formula values by less than 2 percentage points at every sampling date and did not change the ranking or statistical grouping of treatments (see note below Table 3), confirming that the small, non-significant pre-treatment differences did not materially bias the reported efficacy estimates. Seed cotton was weighed separately for every plot at each picking; successive picking weights were summed within plot before conversion to total yield per hectare.

Economic analysis

Treatment cost was defined as the reported product cost plus application and labour charges for two sprays on a per-hectare basis. Gross additional return was calculated as yield increase over the untreated control multiplied by the 2025 seed-cotton price of PKR 220/kg. Net return equalled gross additional return minus treatment cost. The gross-return-to-treatment-cost ratio was calculated as gross additional return divided by treatment cost. A ±10% seed-cotton-price sensitivity analysis was used to assess whether treatment rankings changed under plausible output-price variation.

Weather data and population–weather relationship

To determine the influence of weather on natural population build-up of dusky cotton bug, an unsprayed monitoring row was maintained separately from the RCBD trial and observed weekly, from Standard Week (SW) 26 to SW 39 of 2025 (late June to late September), covering the period from early square/boll formation through peak boll opening. Weekly mean population (nymphs + adults/plant) was recorded from ten randomly selected plants. Corresponding weekly meteorological data maximum and minimum temperature, morning and evening relative humidity, and total rainfall were obtained from the meteorological observatory of the Cotton Research Institute, Multan.

Statistical analysis

Population data were analysed separately at 3, 7 and 14 days after the first spray using analysis of variance for a randomized complete block design, with treatment as the fixed effect and block as the replication factor. Treatment means were separated using Tukey's honestly significant difference test at $P < 0.05$. Because the same plots were observed repeatedly, these date-specific analyses describe treatment differences at each assessment and do not constitute a formal test of treatment, time or treatment × time effects. Yield was analysed by randomized-block analysis of variance. Pearson correlations and simple linear regressions were used only to describe associations between weekly pest population and individual weather variables in the separate unsprayed monitoring series. The three-predictor weather model was treated as exploratory because it contained 14 temporally ordered observations and substantial collinearity. Analyses were conducted using Statistix 8.1.

RESULTS

Treatments evaluated

The eight insecticide products tested, representing six chemical groupings (phenylpyrazole, pyrethroid–organophosphate and pyrethroid–pyridazinone combinations, spinosyn, neonicotinoid and avermectin), along with their formulations, trade names and doses, are summarized in Table 1.

Table 1. Treatments evaluated against dusky cotton bug.

Treatment	Active ingredient(s)	Formulation	Trade name	Dose	Chemical group
T1	Fipronil	5% SC	Fiprox	500 ml/acre	Phenylpyrazole
T2	Deltamethrin + Triazophos	360 EC	Adder Plus	500 ml/acre	Pyrethroid + Organophosphate
T3	Cypermethrin + Chlorpyriphos	505 EC	Nurelle-D	500 ml/acre	Pyrethroid + Organophosphate
T4	Bifenthrin + Pyridaben	200 EC	Goldstar	250 ml/acre	Pyrethroid + Pyridazinone
T5	Spinetoram	25% WG	Delegate	80 g/acre	Spinosyn
T6	Imidacloprid	200 SL	Confidor	200 ml/acre	Neonicotinoid
T7	Thiamethoxam	25% WG	Actara	50 g/acre	Neonicotinoid
T8	Emamectin benzoate	1.9% EC	Proclaim	250 ml/acre	Avermectin
T9	Untreated Control	-	-	-	-

The products were evaluated as locally available commercial formulations at the stated research rates. These efficacy results do not supersede pesticide labels or national registration requirements. Any extension recommendation based on this trial must be restricted to products and uses currently registered in Pakistan and applied strictly according to the approved label.

Effect on dusky cotton bug population

Pre-treatment population counts did not differ significantly among treatments ($P > 0.05$), confirming a uniform initial infestation across the experimental area (mean 8.56–9.55 bugs/plant; Table 2). Following application, population density declined sharply in all insecticide-treated plots by 3 DAT and remained significantly lower than the control throughout the 14-day observation period, whereas the untreated control showed a continuous increase in population from 10.40 to 13.50 bugs/plant over the same period, consistent with the natural build-up of the pest as more bolls opened (Table 2). Among the products, Delegate 25WG (spinetoram) recorded the lowest post-treatment population at all three sampling dates (1.44, 0.98 and 1.67 bugs/plant at 3, 7 and 14 DAT, respectively), statistically at par with Fiprox 5SC (fipronil) and, at 7 DAT, also with Actara 25WG (thiamethoxam). Adder Plus 360EC (deltamethrin + triazophos) and Nurelle-D 505EC (cypermethrin + chlorpyriphos) consistently showed the highest population among the treated plots, indicating comparatively weaker suppression, although both remained significantly superior to the untreated control at every sampling date (Table 2).

Table 2. Population of dusky cotton bug before and after application of tested insecticides (mean ± SE per plant).

Treatment	Pre-treatment population/plant	3 DAT (mean ± SE)	7 DAT (mean ± SE)	14 DAT (mean ± SE)
T1	8.91 ± 0.41	1.91 ± 0.09 ab	1.15 ± 0.05 ab	2.20 ± 0.13 ab
T2	9.55 ± 0.32	4.15 ± 0.18 f	2.84 ± 0.16 e	4.49 ± 0.23 e
T3	9.31 ± 0.39	3.56 ± 0.15 ef	2.56 ± 0.14 e	4.14 ± 0.17 de
T4	9.16 ± 0.39	2.83 ± 0.15 d	1.96 ± 0.08 d	3.24 ± 0.14 cd
T5	8.67 ± 0.32	1.44 ± 0.08 a	0.98 ± 0.06 a	1.67 ± 0.07 a
T6	8.67 ± 0.36	2.44 ± 0.11 cd	1.76 ± 0.10 cd	2.66 ± 0.18 c
T7	8.56 ± 0.27	2.15 ± 0.12 bc	1.49 ± 0.08 bc	2.27 ± 0.16 bc
T8	9.45 ± 0.29	3.28 ± 0.14 de	2.23 ± 0.15 de	3.54 ± 0.17 d
T9	9.16 ± 0.31	10.40 ± 0.46 g	11.80 ± 0.51 f	13.50 ± 0.66 f

Means within a column followed by the same letter do not differ significantly (Tukey's HSD, $P > 0.05$). DAT = Days After Treatment.

Percent population reduction over control

Percent reduction relative to the untreated control, calculated using Abbott's formula, followed the population pattern and peaked at 7 days after the first spray before declining slightly at 14 days. The 14-day assessment occurred on 29 August 2025, four days before the second application, and therefore represents residual efficacy of the first spray. Spinetoram produced the greatest reduction at each interval (86.15%, 91.69% and 87.63% at 3, 7 and 14 days, respectively), followed by fipronil (81.63%, 90.25% and 83.70%) and thiamethoxam (79.33%, 87.37% and 83.19%). Deltamethrin plus triazophos was the weakest treatment but remained superior to the untreated control.

Table 3. Percent population reduction of dusky cotton bug over untreated control

Treatment	% reduction over control 3 DAT	% reduction over control 7 DAT	% reduction over control 14 DAT
T1	81.63 a	90.25 a	83.70 ab
T2	60.10 d	75.93 d	66.74 d
T3	65.77 cd	78.31 cd	69.33 d
T4	72.79 bc	83.39 bc	76.00 c
T5	86.15 a	91.69 a	87.63 a
T6	76.54 b	85.08 b	80.30 bc
T7	79.33 b	87.37 ab	83.19 b
T8	68.46 c	81.10 c	73.78 cd

Values within a column followed by the same letter do not differ significantly (Tukey's HSD, $P > 0.05$). DAT = Days After Treatment.

Sensitivity check using Henderson–Tilton correction: Values recalculated from treatment means were within two percentage points of the Abbott estimates and preserved the treatment ranking. Because replicate-level corrected values were unavailable, this calculation is presented only as a descriptive sensitivity check and was not subjected to a separate inferential analysis.

Effect on seed cotton yield and economic analysis

Seed cotton yield differed significantly among treatments and was closely aligned with the level of pest suppression achieved (Table 4). The highest yield was recorded in plots treated with Delegate 25WG (2088.6 kg/ha) and Fiprox 5SC (2085.0 kg/ha), statistically at par with each other and significantly higher than the untreated control (1449.9 kg/ha), which had the lowest observed yield. Fibre quality (lint staining, boll rot incidence) and populations of other sucking pests (whitefly, jassid, thrips) were not measured in this trial, therefore, the observed yield differences were associated with the insecticide treatments and measured dusky cotton bug suppression; no quality-related mechanism can be inferred. Adder Plus 360EC and Nurelle-D 505EC-treated plots, despite giving significant control relative to the untreated check, produced the lowest yields among the insecticide treatments, consistent with their comparatively weaker and shorter residual suppression of the pest.

Economic ranking differed from biological efficacy (Table 4). Imidacloprid produced the highest reported gross-return-to-treatment-cost ratio (9.5), followed by cypermethrin plus chlorpyriphos (9.0) and deltamethrin plus triazophos (8.0).

Spinetoram produced the highest yield but the lowest ratio (2.8) because of its higher reported treatment cost. At seed-cotton prices 10% below and above the base value, the corresponding ratio ranges were: fipronil, 4.05–4.95; deltamethrin plus triazophos, 7.20–8.80; cypermethrin plus chlorpyriphos, 8.10–9.90; bifenthrin plus pyridaben, 6.30–7.70; spinetoram, 2.52–3.08; imidacloprid, 8.55–10.45; thiamethoxam, 5.85–7.15; and emamectin benzoate, 3.15–3.85. The ranking was therefore unchanged by the ±10% output-price sensitivity analysis.

Table 4. Effect of tested insecticides on seed cotton yield and cost-benefit ratio.

Treatment	Seed cotton yield (kg/ha)	Yield increase over control (kg/ha)	Cost of treatment (PKR/ha)	Net return (PKR/ha)	Cost-benefit ratio	Gross additional return (PKR/ha)
T1	2085.0 a	635.1	31049	108673	1 : 4.5	139,722
T2	1959.5 b	509.6	14014	98098	1 : 8.0	112,112
T3	1974.1 b	524.2	12814	102510	1 : 9.0	115,324
T4	2008.4 ab	558.5	17553	105317	1 : 7.0	122,870
T5	2088.6 a	638.7	50184	90330	1 : 2.8	140,514
T6	2051.7 ab	601.8	13936	118460	1 : 9.5	132,396
T7	2065.9 ab	616.0	20849	114671	1 : 6.5	135,520
T8	1986.5 b	536.6	33729	84323	1 : 3.5	118,052
T9 (Control)	1449.9 c	-	-	-	-	–

Means within the yield column followed by the same letter do not differ significantly (Tukey's HSD, $P > 0.05$). Seed cotton price used for economic analysis: PKR 220/kg (2025 season).

Relationship between weather factors and dusky cotton bug population

Weekly population of dusky cotton bug in the unsprayed monitoring row increased steadily over the season, from a negligible level in late June (SW 26–30) to a peak of 2.67 bugs/plant by SW 39 as boll opening progressed and the monsoon receded (Table 5). This build-up coincided with a marked decline in morning relative humidity (from 79.1% to 49.2%) and rainfall (from over 40 mm/week during the monsoon to less than 2 mm/week by late season), while maximum and minimum temperature fluctuated within a comparatively narrow range without a strong directional trend.

Table 5. Weekly population of dusky cotton bug in relation to weather factors.

Standard week	Max. temp. (°C)	Min. temp. (°C)	Morning RH (%)	Evening RH (%)	Rainfall (mm)	DCB population/plant
SW-26	38.7	27.4	79.1	51.2	43.9	0.20
SW-27	38.6	26.1	79.0	54.0	52.0	0.20
SW-28	40.1	26.7	78.3	50.4	35.6	0.20
SW-29	37.0	26.8	75.2	45.8	47.6	0.20
SW-30	39.6	25.0	67.6	44.6	33.9	0.20
SW-31	36.4	26.5	64.5	41.4	33.0	1.16
SW-32	38.3	25.2	66.4	42.8	20.3	1.09
SW-33	38.2	25.2	65.7	37.2	16.5	1.46
SW-34	39.9	25.8	60.8	37.7	13.1	1.31
SW-35	38.4	24.1	60.3	38.2	20.6	1.10
SW-36	37.6	24.6	56.5	36.1	0.8	2.04
SW-37	40.1	26.4	54.0	34.4	0.7	1.66
SW-38	40.4	26.8	51.8	29.2	1.7	1.43
SW-39	37.4	27.0	49.2	31.4	0.3	2.67

Correlation analysis showed that dusky cotton bug population had a weak, statistically non-significant relationship with minimum temperature ($r = -0.134$, $P = 0.649$) and maximum temperature ($r = -0.178$, $P = 0.543$), whereas its correlation with rainfall ($r = -0.900$, $P < 0.001$) and mean relative humidity ($r = -0.891$, $P < 0.001$) was strong, negative and highly significant (Table 6). Simple linear regression confirmed rainfall and relative humidity as the strongest single predictors of population build-up, individually accounting for 80.9% and 79.4% of the variability in weekly population, respectively, compared with only 1.8% and 3.2% for minimum and maximum temperature. A multiple linear regression combining maximum temperature, mean relative humidity and rainfall as independent variables explained 94.5% of the total variability in population ($R^2 = 0.945$, adjusted $R^2 = 0.928$), given by the equation: Population = 11.049 − 0.236 (maximum temperature) + 0.002 (relative humidity) − 0.042 (rainfall). Because relative humidity and rainfall were themselves strongly correlated over the season ($r = 0.94$), we checked this three-predictor model for multicollinearity: variance inflation factors were low for maximum temperature (VIF = 1.2) but high for relative humidity and rainfall (VIF = 9.7 and 10.1, respectively), confirming substantial collinearity between these two predictors. This explains why the partial regression coefficient for relative humidity is small and positive in the multiple-regression equation despite its strong negative bivariate correlation with population ($r = -0.891$): once rainfall is held constant, the model cannot reliably separate the independent contribution of relative humidity, and the sign and magnitude of its partial coefficient should not be interpreted causally. A Durbin-Watson statistic of 1.63 on the regression residuals indicated only mild positive autocorrelation among the 14 temporally ordered weekly observations, consistent with the shared seasonal trend in both the weather variables and pest phenology (boll opening progressing week by week) rather than necessarily reflecting an independent causal effect of each variable. Given the small sample size ($n = 14$) and the collinearity between relative humidity and rainfall, this regression should be regarded as descriptive of the co-occurring seasonal pattern rather than as a validated predictive or causal model.

Table 6. Correlation and regression coefficients between weather factors and dusky cotton bug population

Weather factor	Correlation coefficient (r)	P-value	Regression equation (Y = a + bX)	R^2
Minimum temperature	-0.134 NS	0.6486	Y = 3.784 − 0.1047X	0.018
Maximum temperature	-0.178 NS	0.5428	Y = 5.347 − 0.1109X	0.032
Rainfall	-0.900 *	< 0.001	Y = 1.944 − 0.0384X	0.809
Relative humidity (mean)	-0.891 *	< 0.001	Y = 5.280 − 0.0796X	0.794

*Significant at $P < 0.05$; NS = non-significant. Relative humidity is the mean of morning and evening observations (Table 5).

DISCUSSION

The superior and comparatively longer-lasting performance of spinetoram and fipronil may be related to their ingestion and contact modes of action, which could favour extended suppression of hemipteran pests aggregating within boll clusters; this remains a plausible explanation rather than a tested mechanism, since resistance status, residue persistence and actual pest exposure were not measured in this trial. The pattern nonetheless agrees with the field observations of Khan et al. (2020) and Shera and Kumar (2021), who similarly reported spinetoram and fipronil among the more effective options against sucking pests and dusky cotton bug, respectively, and with Freed et al. (2018), who found that newer chemistries generally outperformed older ones against the cotton sucking-pest complex. Similarly, the comparatively lower and faster-declining efficacy of the pre-mixed pyrethroid–organophosphate products (Adder Plus 360EC, Nurelle-D 505EC) may reflect eroding field efficacy of these long-used combination chemistries against sucking pests in Punjab's cotton belt, possibly linked to their long history of use against the bollworm complex; however, in the absence of resistance-monitoring data or bioassays in the present study, this should be read as a hypothesis consistent with the resistance concerns raised by Naeem et al. (2018) and Jamil et al. (2021) for pyrethroid- and organophosphate-based products used repeatedly in the same cropping system, rather than as a confirmed cause.

These results indicate that the choice of insecticide for dusky cotton bug management should be guided jointly by biological efficacy and cost-effectiveness rather than efficacy alone, echoing the conclusions of Tariq et al. (2022) and Iqbal et al. (2023), who likewise found that the most biologically effective products against cotton sucking pests were not always the most economical. Where pest pressure is severe or lint-quality preservation is a priority, Delegate 25WG or Fiprox 5SC would be justified despite higher cost; where pest pressure is moderate and cost is the limiting factor, Confidor 200SL, Nurelle-D 505EC or Goldstar 200EC provide economically efficient alternatives, consistent with the favourable cost-benefit performance reported for imidacloprid-based products by Ali et al. (2022) and Yousaf et al. (2023). Rotating chemistries across these groups, rather than repeated use of a single compound or a single pre-mixed product, is advisable to delay the development of insecticide resistance in dusky cotton bug populations, in line with general resistance-management principles for sucking pests of cotton and with the resistance-monitoring evidence of Naeem et al. (2018). It should be emphasised that the eight trade products were compared at their commercial, field-recommended rates (Table 1) rather than at equivalent active-ingredient doses, so the rankings above reflect product-level performance under label-recommended use and cannot be used to infer intrinsic active-ingredient potency. For rotation planning, the active ingredients fall into distinct IRAC mode-of-action groups fipronil (Group 2B), deltamethrin, cypermethrin and bifenthrin (Group 3A), triazophos and chlorpyriphos (Group 1B), pyridaben (Group 21A), spinetoram (Group 5), imidacloprid and thiamethoxam (Group 4A), and emamectin benzoate (Group 6) and any rotation sequence should alternate between, rather than within, these IRAC groups. All products were applied at their currently labelled rates for cotton in Pakistan; because sucking-pest natural enemies (e.g., coccinellids, chrysopids, spiders) were not monitored in this trial, our recommendations are limited to the products and conditions tested here and should be read alongside independent evidence on natural-enemy safety before being adopted as a natural-enemy-compatible IPM programme.

In the exploratory unsprayed monitoring row, population increase coincided with declining humidity and rainfall as boll opening progressed; these temporal associations do not establish that either weather variable independently governed population build-up. This finding is in close agreement with Rafiq et al. (2017), Sattar et al. (2011), Zia et al. (2013) and Wakil et al. (2010), all of whom reported humidity and rainfall, rather than temperature, as the dominant weather drivers of sucking-pest and dusky cotton bug population dynamics in Punjab's cotton belt, and it parallels the strong humidity–population associations noted by Gogi et al. (2013), Ahmad et al. (2021), Iqbal et al. (2021), Abbas et al. (2022) and Aslam et al. (2020) for the wider sucking-pest complex.

Taken together, the findings show that biological efficacy and treatment cost can lead to different product rankings. The separate weather observations are exploratory and should not be treated as validation of a spray-timing rule. Rotation and integration with non-chemical tactics remain appropriate objectives for future IPM research. Such an integrated, rotation-based

strategy is likely to sustain insecticide efficacy against dusky cotton bug over successive seasons more effectively than reliance on any single product or chemical group. It should be emphasized that the present trial evaluated insecticides alone and did not test a complete integrated pest management (IPM) programme: field sanitation, destruction of alternate malvaceous hosts, economic-threshold-based spray decisions, conservation of natural enemies, and non-chemical tactics such as trap crops or resistant/tolerant cultivars were neither implemented nor assessed here. These components are recognized elements of sucking-pest IPM in cotton and warrant dedicated evaluation, ideally alongside the chemical options tested in this study, before a comprehensive management recommendation can be made.

Implications for agricultural extension and advisory services

The findings support a two-criterion advisory message: the treatment with the greatest biological suppression may not provide the best short-term economic return. Extension personnel should therefore present efficacy, treatment cost and expected yield response together rather than recommend products solely by percentage control. For high pest pressure, spinetoram or fipronil may merit consideration because of stronger suppression; where affordability is the dominant constraint, the reported economics favor imidacloprid. These are conditional research findings, not universal product prescriptions. Recommendations should be aligned with current registration and label directions, locally validated economic thresholds, resistance-management guidance and protection of beneficial arthropods. Demonstration plots and farmer field schools could be used to communicate correct identification of dusky cotton bug, threshold-based decisions, calibrated application, rotation among modes of action and avoidance of unnecessary repeat sprays.

Limitations

This trial was conducted at one site during one season with three blocks; treatment rankings therefore require validation across seasons, locations and pest-pressure levels. Efficacy observations ended before the second spray, so population suppression reflects the first application only, whereas yield and reported treatment costs relate to the two-spray field programme. The repeated observations were summarized using date-specific randomized-block analyses because replicate-level longitudinal data were not available for mixed-model reanalysis. Henderson–Tilton values calculated from treatment means are descriptive and not an independently replicated analysis. Product registration records, natural-enemy effects, fibre quality and resistance status were not evaluated. The weather series was observational, contained only 14 temporally ordered observations and showed substantial collinearity between rainfall and relative humidity. Economic conclusions depend on the reported aggregate treatment costs and the 2025 output price; although ±10% price variation did not alter rankings, a complete cost-component audit would strengthen transferability.

CONCLUSION

Under the conditions of this single-site 2025 trial, all eight insecticide treatments reduced dusky cotton bug density relative to the untreated control. Spinetoram and fipronil provided the strongest suppression after the first spray and produced the highest seed-cotton yields, while imidacloprid produced the most favorable reported gross-return-to-treatment-cost ratio. These results demonstrate why agricultural advisers should communicate biological efficacy and economic performance as complementary criteria. The findings should be used as locally generated evidence for further validation rather than as a stand-alone spray recommendation. Wider extension guidance requires confirmation across environments, compliance with current registration and labels, locally validated economic thresholds, natural-enemy assessment and mode-of-action rotation within an integrated pest-management programme.

REFERENCES

Abbas, Q., Alam, S. and Zaman, M. 2022. Impact of abiotic factors on the population fluctuation of dusky cotton bug, Oxycarenus hyalinipennis Costa, in cotton agro-ecosystem. Journal of Agricultural Research, 60(1): 55–63.

Abbott, W.S. 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology, 18(2): 265–267. https://doi.org/10.1093/jee/18.2.265a

Ahmad, S., Ashfaq, M. and Khan, M.A. 2021. Population dynamics of sucking insect pests of cotton and their relationship with weather factors in

Southern Punjab, Pakistan. Journal of Entomology and Zoology Studies, 9(2): 45–51.

Ali, A., Rizwan, M. and Iqbal, J. 2022. Comparative efficacy of new chemistry insecticides against sucking insect pest complex of cotton under field conditions. Pakistan Journal of Agricultural Sciences, 59(3): 401–409.

Arif, M.J., Gogi, M.D., Mirza, M.J., Zia, K. and Hafeez, F. 2019. Impact of plant spacing and abiotic factors on population dynamics of sucking insect pests of cotton. Pakistan Entomologist, 41(1): 19–24.

Aslam, M., Razzaq, M. and Naeem, M. 2020. Correlation of sucking insect pest populations of cotton with abiotic factors under semi-arid conditions of Punjab. Journal of Agricultural Research, 58(2): 141–149.

Bakhetia, D.R.C. and Sidhu, A.S. 1977. Bioecology and control of dusky cotton bug, Oxycarenus laetus Kirby. Indian Journal of Entomology, 39(3): 244–252.

Fand, B.B., Sul, N.T., Bal, S.K. and Minhas, P.S. 2015. Temperature impacts the development and survival of the dusky cotton bug, *Oxycarenus laetus*, on cotton. Phytoparasitica, 43(1): 63–74.

Freed, S., Jin, F.L. and Naeem, A. 2018. Field efficacy of newer insecticides against sucking insect pest complex of cotton. Pakistan Journal of Zoology, 50(4): 1461–1468.

Gaur, N., and S. Mogalapu. (2018). Pests of soybean. Pests and their manage.5:137-162.

Gogi, M.D., Arif, M.J., Sarwar, G. and Bashir, M.H. 2013. Association of weather factors with population fluctuation of sucking insect pests infesting cotton. Pakistan Journal of Life and Social Sciences, 11(1): 66–72.

Government of Pakistan. 2025. Pakistan Economic Survey 2024–25. Finance Division, Islamabad, Pakistan. https://www.finance.gov.pk/survey 2025.html

Henderson, C. F. and E. W. Tilton. 1955. Tests with acaricides against the brown wheat mite. Journal of Economic Entomology, 48: 157–161. https://doi.org/10.1093/jee/48.2.157

Hussain, D., Saleem, M.A. and Younas, M. 2020. Chemical control of dusky cotton bug, Oxycarenus hyalinipennis Costa, and its effect on seed cotton yield and quality. Journal of Agricultural Research, 58(4): 279–286.

Iqbal, A., M. Iqbal, M. Alamzeb, D. Qiang,W. Xiangru, G. Huiping, Z. Hengheng, P. Nianchang, S. Fahad,and S. Anwar. 2022. Climate Change and Cotton Production, pp. 95-112, Improvement of Plant Production in the Era of Climate Change. CRC Press.

Iqbal, J., Ashfaq, M. and Ali, A. 2021. Seasonal incidence of sucking insect pest complex of cotton in relation to weather parameters in Punjab. Pakistan Journal of Agricultural Sciences, 58(3): 883–891.

Iqbal, N., Sarwar, M. and Nasir, S. 2023. Efficacy and economics of selected insecticides against dusky cotton bug (*Oxycarenus hyalinipennis*) infesting cotton. Journal of Innovative Sciences, 9(1): 112–120.

Jamil, M., Naeem, M. and Sahi, S.T. 2021. Impact of fipronil and other new chemistries on sucking insect pests and their natural enemies in Bt cotton. Journal of Innovative Sciences, 7(2): 209–216.

Jans, Y., W. von Bloh, S. Schaphoff, and C. Müller. 2021. Global cotton production under climate change–Implications for yield and water consumption. Hydrology and Earth System Sci. 25: 2027-2044.

Khalid, M., U. Hassan, M. Hanzala, I.Amjad, and A. Hassan. 2022.Current situation and prospects of cotton production in Pakistan. Bull. Biolog Allied Sci. Res. 2022: 27-27.

Khan, R.R., Ahmad, S. and Iqbal, M. 2020. Evaluation of spinetoram and other reduced-risk insecticides against sucking pests of cotton. Sarhad Journal of Agriculture, 36(3): 815–823.

Naeem, A., Freed, S. and Jin, F.L. 2018. Insecticide resistance monitoring in field populations of *Oxycarenus hyalinipennis* Costa (Hemiptera: Lygaeidae) from the cotton belt of Punjab, Pakistan. Crop Protection, 114: 118–124.

Naqvi, K.M. 1965. Dusky cotton bug, *Oxycarenus hyalinipennis* Costa, and its control in Pakistan. Agriculture Pakistan, 16(1): 45–54.

Nawaz, A., Ahmed, S. and Rasool, K.G. 2019. Comparative toxicity of neonicotinoid and organophosphate insecticides against cotton sucking pests. Journal of Animal and Plant Sciences, 29(2): 366–373.

Rafiq, M., Ghayyur, A. and Dasti, A.A. 2017. Effect of meteorological factors on the population

dynamics of insect pests of cotton in Multan district. Pakistan Journal of Agricultural Sciences, 54(3): 653–659.

Razaq, M., Aslam, M., Shad, S.A. and Naeem, A. 2019. Chemical control of sucking insect pests of Bt cotton and their impact on natural enemies. Journal of Animal and Plant Sciences, 29(5): 1234–1241.

Saeed, R., Razaq, M. and Hardy, I.C.W. 2015. The importance of alternative host plants as sources of the cotton bug, Oxycarenus hyalinipennis, in cotton-growing agro-ecosystems. Journal of Pest Science, 88(2): 517–531.

Saleem, M.A., Hussain, D. and Ghouse, G. 2018. Field evaluation of pyrethroid and organophosphate combination products against cotton sucking pest complex. Pakistan Entomologist, 40(1): 33–39.

Sattar, M., Abro, G.H. and Syed, T.S. 2011. Effect of weather factors on the population of sucking insect pests of cotton. Pakistan Journal of Zoology, 43(2): 271–277.

Shera, P.S. and Kumar, V. 2021. Bio-efficacy of newer insecticides, including spinetoram and fipronil, against dusky cotton bug, *Oxycarenus laetus* Kirby, on cotton. Indian Journal of Entomology, 83(3): 512–517.

Simon, S., Sundararaj, R. and Karuppaiah, V. 2020. Bioecology and management of dusky cotton bug, Oxycarenus hyalinipennis Costa (Hemiptera: Lygaeidae). Journal of Biological Control, 34(2): 89–99.

Tanwar, R.K., Jeyakumar, P. and Vennila, S. 2007. Dusky cotton bug and its management strategies. Technical Bulletin, National Centre for Integrated Pest Management, New Delhi.

Tariq, M., Khan, R.R. and Naz, F. 2022. Cost-benefit analysis of insecticidal management of cotton sucking pest complex in Punjab, Pakistan. Sarhad Journal of Agriculture, 38(2): 556–564.

Tausif, M., A. Jabbar, M. S. Naeem, A. Basit, F. Ahmad, and T. Cassidy. 2018. Cotton in the new millennium: advances, economics, perceptions and problems. Textile Progress 50: 1-66.

Ullah, F., Gul, H. and Desneux, N. 2019. Effectiveness and economics of newly introduced insecticides against sucking pest complex of cotton. Phytoparasitica, 47(4): 553–564.

Wakil, W., Ashfaq, M. and Ghazanfar, M.U. 2010. Influence of abiotic factors on population dynamics of sucking insect pests of cotton in Punjab, Pakistan. Pakistan Journal of Zoology, 42(6): 711–716.

Yousaf, S., Riaz, M.A. and Naeem, M. 2023. Comparative efficacy and cost-benefit ratio of newer insecticide combinations against sucking insect pests of Bt cotton. Journal of Innovative Sciences, 9(2): 233–241.

Zia, K., Hafeez, F. and Arif, M.J. 2013. Effect of weather variables on population buildup of jassid, whitefly and dusky cotton bug in cotton crop. Pakistan Entomologist, 35(2): 121–126.

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