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Seasonal and Crop-Stage Relationships Between Rice Pest Incidence and Final Yield: A Multi-Season Analysis

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Abstract: Rice yield is influenced by the occurrence and severity of insect pests and diseases, but their relationship with final yield can vary substantially with crop growth stage and season. The present study evaluated stage-wise associations between major insect pests, diseases and final yield using observations collected from 200 marked rice hills during five rice seasons, *viz*., *Rabi* 2003–04, *Kharif* 2004, *Rabi* 2004–05, *Kharif* 2005 and *Rabi* 2005–06. Pearson correlation and backward stepwise multiple regression analysis were performed after excluding hills that showed no recorded pest or disease incidence at the respective observation stage. The number of observations retained therefore varied according to the incidence of pests and diseases. Stepwise regression of identified significant pest variables associated with final yield at several crop stages in *Rabi* 2003–04 indicated that rodent damage was associated negatively with yield at 15 days after transplanting (DAT), while dead-heart and leaf-folder damage contributed negatively at 30 DAT. In *Kharif* 2004, planthoppers was retained at 10, 20, 30 and 80 DAT, whereas dead hearts/ white ears were retained at 50, 70 and 90 DAT. In *Rabi* 2004–05, white ears became the principal yield-associated variable from 75 DAT onwards. In *Kharif* 2005, planthoppers were retained at 70 and 80 DAT. In *Rabi* 2005–06, white eats were retained at 75 DAT and together with planthoppers at harvest. The strongest final models explained 15.98% and 16.48% of yield variation in *Rabi* 2004–05 and *Rabi* 2005–06, respectively. The results demonstrate that the pest yield relationship was strongly stage and season dependent and that late season yellow stem borer damage was particularly important in the *Rabi* seasons.

Keywords: Rice, insect pests, disease incidence, marked hills, yield, correlation, stepwise regression.

INTRODUCTION

Rice (*Oryza sativa* L.) is a major food crop, and insect pests and diseases remain important constraints to stable productivity. The major pest complex of rice includes yellow stem borer, planthoppers, leaf folder, gall midge, hispa, whorl maggot among the insects and sheath blight and blast among the diseases. The incidence of these pests and damage vary with crop growth stage, season, crop management and environmental conditions. An estimated annual yield loss of 10–30% was caused by these pest complex (Savary *et al*., 2019). Brown planthopper (*Nilaparvata lugens*) is an important rice pest whose population fluctuates among seasons and crop stages and can cause serious yield loss under high pressure (Kumar *et al*., 2022). Yellow stem borer (*Scirpophaga incertulas*) is particularly important because feeding injury produces dead hearts during vegetative growth and white ears during reproductive stage and are associated with yield loss (Subedi *et al*., 2024). Similarly, sheath blight and rice blast, particularly neck blast, are among the major fungal diseases causing substantial yield losses (Ghosh *et al*., 2025).

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Quantification of crop losses caused by pests is an important component of plant protection because the occurrence of an injury does not necessarily translate into a uniform yield reduction under all production situations. Recent reviews emphasize that rice insect pests can affect plants throughout the crop cycle and that their effects on productivity depend strongly on pest abundance, timing and crop susceptibility. The relationship between pest incidence and yield is not necessarily constant throughout crop development. A study on Basmati rice found that yield loss was closely related to stem-borer and leaf-folder damage during important crop growth stages, particularly around 50–65 DAT (Sarao *et al*., 2015). Similarly, a multi-location study in India demonstrated that stem borer, planthoppers and leaf-folder incidence differed with crop establishment and management practices and that lower pest incidence was associated with higher yield under SRI management (Chintalapati *et al*., 2023). Therefore, identifying which pest is most closely associated with yield at a particular crop stage is useful for developing stage-specific pest surveillance and integrated pest-management strategies.

Savary *et al.* (2000) demonstrated that pest injury can adversely affect crop growth and yield formation and emphasized the importance of the injury yield relationship through the concept of the damage function. They reported that different pest injuries may interact and exert cumulative effects on final crop yield and highlighted the importance of standardized assessment of pest injury and the application of multivariate analytical approaches to quantify the effects of multiple pest constraints on rice productivity. The relationship between pest incidence and crop yield may also vary with crop developmental stage. Consequently, stage-specific statistical analysis can provide greater insight into the timing and magnitude of pest effects and help identify the variables most closely associated with final yield (Savary *et al*., 2006).

Stepwise multiple regression offers a useful variable selection approach for simultaneously evaluating several pest and disease variables and identifying a parsimonious set of predictors that contribute significantly to yield variation (Savary *et al*., 1997). More recent agricultural studies have likewise employed stepwise regression and related variable selection techniques for stage specific crop modelling and identification of important yield determinants (Sharma *et al*., 2024; Bai *et al*., 2024). Hence. the present study aimed to quantify the stage wise association between pest and disease incidence and final rice yield across five rice seasons and to identify, through backward stepwise regression, the pest or disease variables that contributed most strongly to the observed variation in final yield.

MATERIALS AND METHODS

Experimental site and observations

Field experiments were conducted at Regional Agricultural Research Station, Maruteru, Andhra Pradesh, India to verify and monitor all *in situ* pest injuries throughout the season and to estimate their actual impact on grain yield under unprotected conditions. A total of 200 rice hills were selected from a one-acre experimental field. Fifty observation blocks, each consisting of four hills, were established systematically along a diagonal transect across the field to obtain representative observations. The blocks and individual hills were marked and labelled after transplanting, and the same hills were maintained throughout the crop season for repeated observations. All the agronomic practices except plant protection recommended were duly followed.

Observations recorded: The following observations were recorded at regular intervals on the marked hills for plant growth, insect pests, diseases and final grain yield during five

rice seasons i.e. *Rabi* 2003–04, *Kharif* 2004, *Rabi* 2004–05, *Kharif* 2005 and *Rabi* 2005–06.

1. Plant growth: Total number of tillers and leaves per hill.
2. Insect pest damage: Number of leaves showing <50% and >50% streaking or scraping damage due to hispa, whorl maggot, number of folded leaves due to leaf folder, galls per tiller due to gall midge, and dead hearts and white ear heads due to stem borer, number of planthoppers, rat cut tillers per marked hill.
3. Diseases: Incidence of major diseases, particularly sheath blight and neck blast.
4. Harvest observations: Number of panicle-bearing tillers, white ear heads and final grain yield in g per hill.

Incidence conditional data selection

A hill was considered to have recorded pest/disease incidence at a particular days after transplantation (DAT) when at least one of the pest/disease variables recorded a value greater than zero. Hills with zero values for all pest/disease variables at that DAT were excluded from the incidence conditional analysis.

Thus:

$$N_{\text{analysis}} = N_{\text{total}} - N_{\text{zero incidence}}$$

This procedure was applied separately to every DAT and every season.

Correlation analysis: Pearson's correlation coefficient was calculated between each pest/disease variable and final yield:

$$r = \frac{\text{Cov}(X, Y)}{\sqrt{\text{Var}(X)\text{Var}(Y)}}$$

where X represents pest/disease incidence and Y represents final yield per hill. Significance was evaluated at 5, 1 and 0.1% probability levels.

Stepwise multiple regression: Backward stepwise multiple linear regression after exclusion of zero-incidence observations was used to identify the pest/disease variables most strongly associated with final yield.

The general model was:

$$Y = b_0 + b_1X_1 + b_2X_2 + \cdots + b_iX_i$$

where:

Y = final yield (g hill^{-1})

b_0 = intercept

b_i = partial regression coefficient

X_i = pest/disease incidence variable.

Variables with P > 0.05 were sequentially removed from the model. The final model therefore contained only predictors meeting the selected significance criterion. The coefficient of determination (R^2), adjusted R^2, F statistic and model P-value were used to evaluate model performance.

RESULTS

***Rabi* 2003-04:** Correlation analysis during *Rabi* 2003–04 revealed significant associations between the incidence of major insect pests and final grain yield (Table 1a). The magnitude and direction of the correlation coefficients varied with the pest and crop growth stage, indicating that the effect of pest incidence on yield was dependent on both the type of pest and the timing of infestation. The percentage of dead hearts at 30 DAT ($r = -0.259$, $P < 0.001$) and white ears at 75 DAT ($r = -0.242$, $P < 0.001$) showed a significant negative correlation with final yield. Planthopper population exhibited a significant positive correlation with final yield at 45 DAT ($r = 0.260$, $P < 0.001$) and 75 DAT ($r = 0.263$, $P < 0.001$). Rodent damage recorded at 15 DAT had a relatively stronger negative correlation with final yield ($r = -0.512$, $P < 0.001$). The percentage of leaf folder damaged leaves at 30 DAT showed a significant negative correlation with final yield ($r = -0.194$, $P < 0.05$).

Backward stepwise regression analysis (Table 1b) demonstrated that the pest variables

Table 1a: Correlation (r) between insect pest incidence and final yield during *Rabi* 2003-04

Days after transplantation (DAT)	*N used*	*Pest variable*			
		PH	*% LFDL*	*% DH/WE*	*Rodent damage*
15	66	-	-	-	-0.512***
30	168	-	-0.194*	-0.259***	-
45	196	0.260***	-	-	-
75	195	0.263***	-	-0.242***	-

* P < 0.05; ** P < 0.01; *** P < 0.001; N= No. of hills with pest incidence; DH; Dead hearts; PH: Planthoppers/hill, LFDL: Leaf folder damaged leaves, WE: White ears

Table 1b: Backward stepwise regression equation after exclusion of zero-incidence observations during *Rabi* 2003-04

DAT	*N used*	*Regression equation*	*R^2 (%)*	*Adjusted R^2 (%)*	*F*	*Model P*
15 DAT	66	Y = 15.1571 - 0.1516(RD)	26.25	25.10	22.78	<0.001
30 DAT	168	Y = 12.5236 - 0.2301(%DH) - 0.6397(%LFDL)	15.85	14.31	10.30	<0.001
45 DAT	196	Y = 12.6381 + 0.0406(PH)	6.92	6.44	14.42	<0.001
60 DAT	195	Y = 14.4076 - 0.1315(%WE) + 0.6207(PH)	5.86	5.37	11.95	<0.001

N= No. of hills with pest incidence, RD: Rodent damage, DH; Dead hearts,
PH: Planthoppers/hill, LFDL: Leaf folder damaged leaves, WE: White ears

associated with yield varied with crop growth stage. Rodent damage at 15 DAT accounted for the highest proportion of yield variation (26.25 %), while combinations of dead hearts and leaf folder damage were important at 30 DAT and caused 15.85 per cent of the variation in yield. At 45 DAT, only planthopper population was retained in the model and accounted for 6.92 per cent of the variation in final yield. Planthopper population and white ear incidence were retained at 75 DAT, explained 5.86 per cent of the variation in final yield.

***Kharif* 2004:** During *Kharif* 2004, planthoppers showed significant positive correlations with yield at 10, 20, 30, 50 and 80 DAT, with the strongest association at 20 DAT ($r = 0.325$, $P < 0.001$). In contrast, hispa damage at 20 DAT and dead heart/white ear incidence at 50, 70 and 90 DAT were significantly negatively correlated with yield. The regression analysis showed that planthoppers was consistently retained at 10, 20 and 30 DAT, explaining 6.76, 10.55 and 8.11% of yield variation, respectively. At 50 DAT, both dead hearts and planthoppers were retained, and the model explained the highest proportion of yield variation for this season (12.16%). At 70 (4.47%) and 90 DAT (7.72%), white ears alone were retained and had a negative regression coefficient. Thus, the results suggest that pest-related variation in yield was most evident at 20 and 50 DAT, while yellow stem borer associated damage became more important during later crop stages.

***Rabi* 2004-05:** The *Rabi* 2004–05 season was characterized predominantly by negative relationships between pest/disease incidence and final yield. Silver-shoot incidence at 30 DAT was negatively correlated with yield ($r = -0.372$, $P = 0.006$). White ear incidence showed significant negative correlations at 75, 90 and 105 DAT, with the strongest association occurring at 105 DAT ($r = -0.405$, $P < 0.001$). Planthoppers at 90 DAT also showed a significant negative correlation, although the magnitude was relatively weak ($r = -0.162$, $P = 0.022$). Sheath blight at 105 DAT showed a weak but significant negative correlation ($r = -0.181$, $P = 0.011$) (Table 3a).

The regression analysis identified silver shoots at 30 DAT as the significant yield associated variable early in the season,

Table 2a: Correlation (r) between pest/disease incidence and final yield during *Kharif* 2004

Days after transplantation (DAT)	*N used*	*Insect pest variable*		
		PH	*% HDL*	*% DH/WE*
10	162	0.260***	-	-
20	127	0.325***	-0.249**	-
30	178	0.285***	-	-
50	172	0.301***	-	-0.208**
70	149	-	-	-0.211**
80	149	0.321***	-	-
90	198	-	-	-0.278***

** P < 0.01; *** P < 0.001; N: No. of hills with pest incidence; DH: Dead hearts,
PH: Planthoppers/hill, HDL: Hispa damaged leaves, WE: White ears

Table 2b: Backward stepwise regression models during *Kharif* 2004

DAT	*N used*	*Regression equation*	*R^2 (%)*	*Adjusted R^2 (%)*	*F*	*Model P*
10	162	Y = 14.3564 + 1.3172(PH)	6.76	6.18	11.60	<0.001
20	127	Y = 13.4215 + 1.7246(PH)	10.55	9.83	14.74	<0.001
30	178	Y = 11.4991 + 0.9690(PH)	8.11	7.59	15.53	<0.001
50	172	Y = 13.6606 − 0.0936 (%DH) + 0.3461(PH)	12.16	11.12	11.70	<0.001
70	149	Y = 16.4378 − 2.8476(%WE)	4.47	3.82	6.88	0.010
80	149	Y = 13.4302 + 0.5713(PH)	10.28	9.67	16.85	<0.001
90	198	Y = 16.2614 − 0.2114(%WE)	7.72	7.25	16.39	<0.001

N= No. of hills with pest incidence, DH; Dead hearts, PH: Planthoppers /hill, WE: White ears

explaining 13.87% of yield variation. From 75 DAT onwards, white ears were consistently retained and its explanatory power increased to 15.98% at 105 DAT. The progressively strong and consistent negative association of WE with yield during the later crop stages indicates the importance of stem borer associated damage during the reproductive and maturity stages. The models at 15, 45 and 60 DAT were intercept only models, indicating that no pest/disease variable was retained at these stages (table 3b).

***Kharif* 2005:** During *Kharif* 2005, significant relationships with yield were observed only for planthoppers at 70 and 80 DAT.

Table 3a: Correlation between pest/disease incidence and final yield during *Rabi* 2004–05

Days after transplantation (DAT)	*N used*	*Insect pest/disease variable*			
		%SS	*PH*	*% DH/WE*	*% Sheath blight*
30	53	-0.372**	-	-	-
75	186	-	-	-0.365***	-
90	199	-	-0.162*	-0.366***	-
105	199	-	-	-0.405***	-0.181*

*P < 0.05; ** P < 0.01; *** P < 0.001; N= No. of hills with pest incidence; SS: Silver shoots; DH; Dead hearts, PH: Planthoppers / hill, WE: White ears

Table 3b: Backward stepwise regression models during *Rabi* 2004–05

DAT	*N used*	*Regression equation*	*R^2 (%)*	*Adjusted R^2 (%)*	*F*	*Model P*
30	53	Y = 12.2336 − 0.4093(%SS)	13.87	12.19	8.22	0.006
75	186	Y = 11.4052 − 0.1454(%WE)	13.33	12.86	28.29	<0.001
90	199	Y = 11.4920 − 0.1239(%WE)	13.43	12.99	30.56	<0.001
105	199	Y = 11.6670 − 0.1098(%WE)	15.98	15.55	37.28	<0.001

N= No. of hills with pest incidence, *SS = Silver shoots; WE = white ears*

Table 4a: Correlation between pest/disease incidence and final yield during *Kharif* 2005

Days after transplantation (DAT)	*N used*	*Planthoppers/hill*
70	193	0.179*
80	191	0.170*

*P < 0.05; N= No. of hills with pest incidence

Table 4b: Backward stepwise regression models during *Kharif* 2005

DAT	*N used*	*Regression equation*	*R^2 (%)*	*Adjusted R^2 (%)*	*F*	*Model P*
70	193	Y = 8.9673 + 0.1415(PH)	3.21	2.70	6.33	0.013
80	191	Y = 8.9137 + 0.2106(PH)	2.89	2.37	5.62	0.019

N= No. of hills with pest incidence, PH: Planthoppers/hill

The correlations were positive but weak (r = 0.179 and 0.170, respectively) (Table 4a). Correspondingly, planthoppers were retained in the regression models at these two stages, but they explained only 3.21% and 2.89% of the variation in final yield (Table 4b). At all other observation stages, no pest variable was retained and the regression models explained essentially 0% of the yield variation.

***Rabi* 2005-06:** During *Rabi* 2005–06, white ears due to yellow stem borer was the principal pest variable associated with yield reduction. At 75 DAT, white ears showed a strong negative correlation with final yield (r = −0.401, P < 0.001) and was retained in the regression model, which explained 16.11% of yield variation. At harvest also white ears continued to show a significant negative relationship (r = −0.354, P < 0.001), whereas planthoppers showed a weak positive correlation (r = 0.189, P = 0.008). The harvest regression model included both white ears and planthoppers and explained 16.48% of yield variation (Table 5a & 5b)). The negative coefficient for white ears indicates its association with yield reduction, whereas the positive coefficient for planthoppers represents a statistical association rather than a beneficial pest effect. The models at 20, 40, 50 and 60 DAT were intercept-only models, with no pest variable retained.

From the above all season's data, it was observed that yellow stem borer (both dead hearts and white ears) and planthoppers incidence was commonly observed. The effect of yellow stem borer damage on yield loss across seasons based on the stage wise regression coefficients from 200 marked hills at different days after transplantation during different seasons from fig.1 indicated that yield loss increased with increase in dead hearts/ white ears in all seasons except in *Kharif* 2005. Among all seasons, *Rabi* 2004-05 showed the highest yield loss for a given level of damage, followed by *Kharif* 2004. The slopes indicate

Table 5a: Correlation between pest/disease incidence and final yield during *Rabi* 2005–06

Days after transplantation (DAT)	*N used*	*Planthoppers/hill*	*% White ears*
75	181	-	-0.401***
85	196	0.189**	-0.354***

** P < 0.01; *** P < 0.001; N= No. of hills with pest incidence

Table 5b: Backward stepwise regression models during *Rabi* 2005–06

DAT	*N used*	*Regression equation*	*R^2 (%)*	*Adjusted R^2 (%)*	*F*	*Model P*
75	181	Y = 13.7450 − 0.1507(%WE)	16.11	15.64	34.37	<0.001
85	196	Y = 11.9438 − 0.1252(%WE) + 0.1116(PH)	16.48	15.61	19.04	<0.001

N= No. of hills with pest incidence, PH: Planthoppers/hill, WE: White ears

that at higher crop stages, a unit increase in yellow stem borer damage causes greater yield loss. Similarly, in case of planthoppers also the yield loss increased with increase in planthopper population in all the seasons. *Rabi* 2003-04 showed the highest yield loss at all stages, indicating grater susceptibility of the crop, followed by *Kharif* 2004, *Rabi* 2004-05. Comparatively lower yield loss was observed during *Kharif* 2005 and *Rabi* 2005-06. The higher slopes at later stages indicated that the yield loss increased with crop age (Fig. 2).

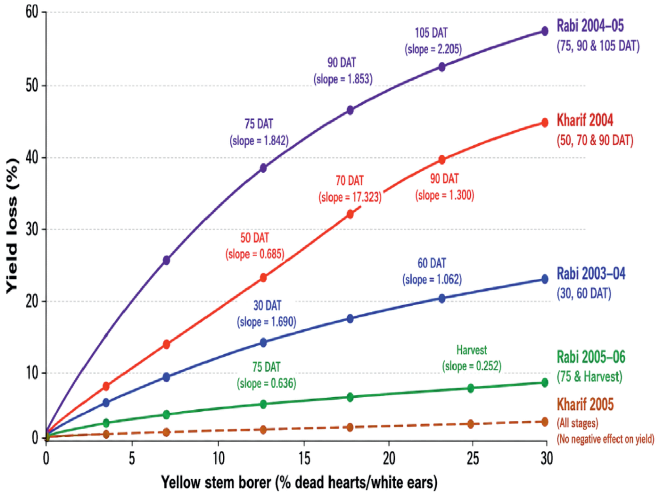


Fig. 1: Effect of Yellow stem borer damage on yield loss across seasons

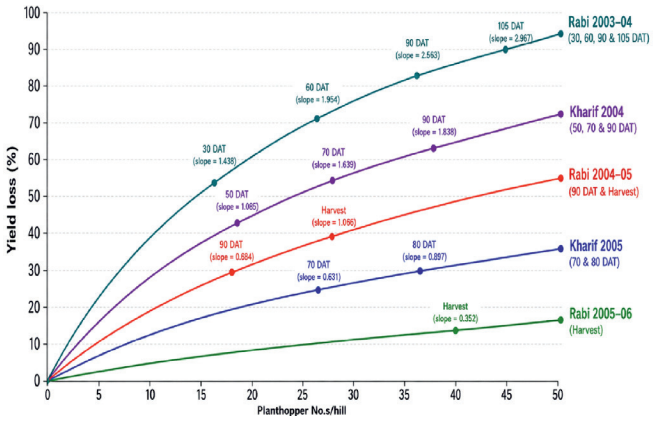


Fig. 2: Effect of Planthopper density on yield loss across seasons

DISCUSSION

The present analysis demonstrated that the relationship between pest incidence and rice yield was strongly dependent on season and crop growth stage. Rather than showing a uniform relationship throughout the crop period, the significant variables changed as the crop developed. This stage specific pattern is consistent with the concept of crop injury yield relationships, in which the effect of pest injury depends not only on the amount of injury but also on its timing, crop growth stage and production environment (Savary *et al.*, 2000).

A particularly important finding was the repeated selection of white ears in the regression models during later stages. The *Rabi* seasons showed particularly strong late season relationships. In *Rabi* 2004–05, the stepwise model explained 13.33, 13.43 and 15.98% of yield variation at 75, 90 and 105 DAT, respectively. Similarly, *Rabi* 2005–06 showed 16.11% explained variation at 75 DAT and 16.48% at harvest. The progressive strengthening of the white ears relationship toward maturity suggests that yellow stem borer injury occurring around the reproductive and grain development stages may have been more closely associated with final yield than early season incidence. Islam (2004) and Muralidharan and Pasalu (2006) also reported that yield loss was positively associated with dead heart and white head infestation across vegetative, reproductive and maturity phases.

Planthoppers were selected more frequently in the *Kharif* 2004, particularly at 10, 20, 30 and 80 DAT. In *Kharif 2005*, planthoppers were retained at 70 and 80 DAT. This seasonal difference may reflect differences in pest population development, crop condition and environmental conditions. Planthoppers population is known to fluctuate substantially among seasons and is influenced by crop growth and environmental conditions (Kumar *et al.*, 2022).

The positive coefficients obtained for planthoppers in several models require

careful interpretation. A positive regression coefficient does not demonstrate that planthoppers increases rice yield. Rather, it indicates a positive partial association within the selected incidence positive observations. Such associations may arise from differences in plant vigour, tillering, crop stage, pest distribution or other unmeasured variables. Previous studies have shown that rice plant vigour and resource availability can influence brown planthopper abundance and fitness, with well-developed and better-fertilised plants sometimes supporting greater BPH development and reproduction (Lu *et al*., 2017). Therefore, the positive coefficients observed in the present study should be interpreted as statistical associations rather than evidence of a beneficial effect of planthoppers on yield.

The analysis also demonstrated that many early-stage models were non-significant after zero-incidence hills were excluded. This was particularly evident in *Rabi* 2004–05 and *Rabi* 2005–06, where pest incidence was relatively limited at some early stages. Therefore, the absence of a significant regression model at a particular DAT should not be interpreted as evidence that the pest has no biological effect. It may instead indicate low pest pressure, insufficient variability or limited sample size.

Another important feature of the present analysis is that multiple pests were evaluated simultaneously. Rice yield is rarely determined by a single pest because several insects and diseases may occur concurrently and their effects can overlap. Savary *et al.* (2000) emphasized that rice production losses should be considered within the broader pest-complex and production-system context rather than by examining individual pests in isolation. Similarly, Sarao *et al.* (2015) demonstrated that simultaneous incidence of several insect pests can be associated with yield variation and that regression analysis can help identify important pest variables at particular crop stages.

The results have implications for integrated pest management (IPM). The repeated association of white ears with yield variation indicates the value of monitoring stem-borer damage during the reproductive stages, whereas the seasonal and stage-specific occurrence of planthoppers indicates the need for continued surveillance rather than assuming that pest pressure will be similar in every crop season.

CONCLUSION

The five-season marked-hill data demonstrated clear variation in pest yield associations with crop stage and season. White ears due to yellow stem borer were the most consistently retained late-season pest injury, particularly in the *Rabi* seasons, whereas planthoppers were more frequently selected in *Kharif*. The strongest models explained 15.98% and 16.48% of final yield variation in *Rabi* 2004–05 and *Rabi* 2005–06, respectively. The analysis therefore supports stage specific pest surveillance, especially for yellow stem borer injury during reproductive and late crop stages. Nevertheless, pest incidence alone accounted for only a modest proportion of yield variation, and the incidence-conditional exclusion of zero-incidence hills means that the results should be interpreted as statistical associations rather than direct causal yield-loss estimates.

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