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SEASONAL INCIDENCE, FIELD SCREENING OF LOCAL LANDRACES, AND BIOCHEMICAL BASIS OF RESISTANCE IN RICE AGAINST PADDY EARHEAD BUG, *LEPTOCORISA ORATORIUS* (FABRICIUS) (HEMIPTERA: ALYDIDAE)

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ABSTRACT

The paddy earhead bug, *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae), is a chronically destructive pest of rice (*Oryza sativa* L.) in India, with documented yield losses of 15–30% under moderate infestation and up to 80% under severe epidemics. A comprehensive investigation integrating seasonal population dynamics, large-scale varietal screening, and biochemical resistance characterisation was conducted at the College of Agriculture, V.C. Farm, Mandya, Karnataka, during Kharif 2021. Seasonal incidence studies recorded a peak population of 7.63 bugs/10 hills on the susceptible check Jaya during the last week of November, coinciding with the milky grain stage, and a substantially lower peak of 1.53 bugs/10 hills on IR 64. Pearson's correlation analysis identified maximum temperature as exerting a significant negative influence on bug density ($r = -0.78^{**}$ on Jaya; $r = -0.67^{**}$ on IR 64), while afternoon relative humidity ($r = +0.72^{**}$; $+0.68^{**}$) and sunshine hours ($r = +0.69^{**}$; $+0.72^{**}$) were significantly positive predictors, providing a meteorological basis for pest forewarning. Field screening of 50 local landraces categorised 15 as Resistant (R), 10 as Moderately Resistant (MR), 20 as Moderately Susceptible (MS), 3 as Susceptible (S), and 2 as Highly Susceptible (HS). Screening of 37 Advanced Varietal Trial (AVT) genotypes yielded 4 R, 11 MR, 14 MS, 5 S, and 3 HS entries. Biochemical analysis of 18 representative genotypes at the milky grain stage revealed that resistant accessions were characterized by elevated levels of total phenols (up to 1.49 mg g^{-1}), tannins (up to 4.85 mg g^{-1}), total free amino acids (TFA; up to 10.78 mg g^{-1}), and potassium (K; up to 3.54%) — all significantly and negatively correlated with grain damage ($r = -0.86^{**}$, -0.94^{**}, -0.95^{**}, -0.93^{**}, respectively). Susceptible genotypes accumulated higher total soluble sugars (TSS), total reducing sugars (TRS), crude proteins, nitrogen (N), and phosphorus (P), all of which showed highly significant positive correlations with grain damage ($r = +0.95^{**}$, $+0.97^{**}$, $+0.98^{**}$, $+0.95^{**}$, $+0.87^{**}$, respectively). The resistant landraces Kave kantak, Nagland paddy, and Narali, alongside their distinctive biochemical profiles, provide a robust scientific foundation for developing durable pest-resistant rice cultivars and implementing ecologically rational integrated pest management programmes.

KEYWORDS: *Leptocorisa oratorius*, Seasonal incidence, Meteorological variables, Landraces, Varietal screening, Biochemical resistance

1. INTRODUCTION

Rice (*Oryza sativa* L.) sustains the food security of more than 3.5 billion people globally and provides livelihoods for hundreds of millions of smallholder farmers across tropical and subtropical Asia. In India, the crop is cultivated on approximately 44 million hectares, contributing over 40% of total food grain production and occupying the central position in national agricultural policy. Despite remarkable advances in high-yielding variety development, fertilizer management, and irrigation infrastructure, insect pest pressure remains one of the most persistent and economically consequential biotic constraints limiting rice productivity. Among the arthropod pests that colonize the rice ecosystem, the paddy earhead bug (gundhi bug), *Leptocorisa oratorius* (Fabricius) (Hemiptera: Alydidae), commands particular attention owing to its capacity for sporadic yet devastating outbreaks precisely during the reproductive stages most critical for yield formation (Katti et al., 2023; Padmakumari et al., 2024).

The genus Leptocorisa constitutes a complex of closely related earhead bug species distributed across South, Southeast, and East Asia. In India, the species complex includes *L. oratorius*, *L. acuta*, *L. lepida*, and *L. varicornis*, with distributional variation across agro-ecological zones; L. oratorius predominates in South, West, and East India, while *L. acuta* is the dominant species in the Indo-Gangetic Plains (Lahari et al., 2024). Recent morphometric investigations have further documented intraspecific population-level variation in earhead bugs, underscoring the importance of precise taxonomic identification in regional pest management planning (Caburatan, 2025).

Both nymphs and adults of L. oratorius inflict damage by piercing the glumes of developing rice grains and extracting the milky endosperm during the grain-filling stage. Feeding produces characteristic yellowish-brown elliptical lesions with greyish necrotic centers, resulting in partial or complete grain chaff. Under severe infestations, yield losses range from 15 to 30%, with documented cases of up to 80% grain sterility during peak epidemics (Katti et al., 2023). Furthermore, the offensive pungent odour emitted by disturbed bugs imparts an objectionable flavour to harvested grain, adversely affecting market value.

The seasonal incidence of Leptocorisa spp. follows a characteristic build-up during the reproductive phase of rice, with peak densities typically coinciding with the milky grain stage between late September and November in tropical environments (Khare et al., 2020; Yadav et al., 2025). Population dynamics are shaped by a suite of abiotic factors, including temperature, relative humidity, rainfall, and sunshine duration. Maximum temperature has been reported to suppress population build-up, while high relative humidity and moderate sunshine hours favour pest proliferation (Arjun et al., 2017). Such quantitative weather-pest associations form the empirical basis for developing bio-meteorological forewarning models. Vinothkumar (2015) demonstrated that such models could predict pest incidence with reasonable accuracy in high-altitude rainfed rice agro-ecosystems, while weather-driven dynamics could guide surveillance timing and reduce unnecessary insecticide applications.

Host plant resistance (HPR) is globally recognised as the most ecologically rational, economically viable, and environmentally sustainable component of integrated pest management systems (Koch et al., 2016; Padmakumari et al., 2024). Resistance functions through three principal mechanisms: antixenosis, physical or chemical deterrence of pest colonisation and oviposition; antibiosis, adverse effects on pest biology, fecundity, and survival through plant metabolites; and tolerance, the plant's ability to sustain and recover from infestation-induced damage without proportionate yield loss. Earlier varietal screening studies by Girish et al. (2015), identified differential resistance responses among rice genotypes but were limited in geographic scope or in the number of entries evaluated.

The biochemical basis of host plant resistance to insect pests has received increasing scientific attention, as it provides mechanistic insight into plant-insect interactions and identifies molecular targets for precision breeding. Phenolic compounds, particularly tannins and hydroxycinnamic acid derivatives, are well-established as primary chemical defence barriers conferring antixenotic and antibiotic properties against sap-sucking pests (War et al., 2018; Singh et al., 2022). Elevated total free amino acids in resistant genotypes are associated with osmotic defence responses and inhibitory effects on pest development (Sahu et al., 2024). Conversely, higher concentrations of soluble sugars and nitrogenous compounds in susceptible varieties act as phagostimulants and nutritive substrates that promote pest colonization and reproduction (Pati et al., 2023). Potassium has been demonstrated to strengthen cell walls, stimulate secondary metabolite synthesis, and reduce carbohydrate accumulation in plant tissues, thereby reducing pest susceptibility (Amtmann et al., 2008; Mohapatra et al., 2017). Despite these broader findings, information specific to the biochemical resistance mechanisms of rice panicle tissue against *L. oratorius* in the context of local landraces adapted to the Cauvery command area of Karnataka remains conspicuously limited.

Against this background, the present investigation was designed to address this gap by: (i) documenting the seasonal population dynamics of *L. oratorius* in relation to prevailing meteorological parameters; (ii) conducting a large-scale field screening of local landraces and advanced breeding genotypes for varietal resistance; and (iii) elucidating the biochemical basis of resistance in representative genotypes from each resistance category, thereby establishing an integrated, multi-dimensional understanding of the host-pest relationship under the agro-climatic conditions of southern Karnataka.

2. MATERIALS AND METHODS

2.1 Experimental Location and Season

All field and laboratory experiments were conducted at the 'A' Block, College of Agriculture, V.C. Farm, Mandya, Karnataka (12°32' N latitude, 76°53' E longitude, 690 m above mean sea level) during Kharif 2021–22. The experimental site falls within the Southern Dry Zone (Agro-Climatic Zone VI) of Karnataka, which receives an average annual rainfall of 751 mm predominantly distributed from June to November. Mean maximum and minimum temperatures during the crop season ranged between 28–35°C and 24–26°C, respectively. Meteorological data including maximum and minimum temperatures, morning and afternoon relative humidity (RH), rainfall, number of rainy days (>2.5 mm), and sunshine hours were obtained from the Agro-Meteorological Observatory, V.C. Farm, Mandya.

2.2 Seasonal Incidence of Earhead Bug in Relation to Meteorological Variables

The susceptible check variety IR 64 and the popular variety Jaya were raised from 25-day-old seedlings transplanted in replicated field blocks measuring 8 × 9 m, maintaining an intra-row and inter-row spacing of 15 × 20 cm. Three blocks per variety were maintained following the recommended package of practices (UAS Bangalore, 2017), with plant protection measures deliberately excluded to allow natural pest colonization. Beginning from the flowering stage, earhead bug populations were recorded tri-daily from 10 randomly selected hills per block by counting all nymphal and adult individuals per hill. The mean population of three consecutive days was computed and correlated with the corresponding mean of seven meteorological variables using Pearson's correlation analysis (IBM SPSS version 2.0, $p \leq 0.05$).

2.3 Screening of Local Landraces and AVT Genotypes Against Earhead Bug

A total of 50 local landraces of rice (Table 1) and 37 Advanced Varietal Trial (AVT) genotypes (Table 2) were procured from the All India Coordinated Research Project (AICRP) on Rice, Zonal Agricultural Research Station (ZARS), V.C. Farm, Mandya. Twenty-five-day-old seedlings of each entry were transplanted in three rows of 25 hills at 20 × 15 cm spacing, without any plant protection measures applied. Observations on earhead bug density (nymphs and adults per hill) and percent grain damage were recorded from 20 representative hills per entry from flowering to harvest, following the Standard Evaluation System (SES) for Rice (IRRI, 2013). Percent grain damage was calculated as % Grain Damage = (No. of damaged grains per hill / Total grains per hill) × 100 and converted to a 0–9 damage score scale for resistance classification (Table 3).

Table 1. List of local rice landraces evaluated against paddy earhead bug, *Leptocorisa oratorius*

Sl. No.	Designation	Sl. No.	Designation
1	*Kave kantak*	26	*Nirga samba*
2	*GK-5*	27	*Bangara kale*
3	*Gangadale*	28	*Jenugudu*
4	*Talasiya*	29	*Kalakoli*
5	*Neermulka*	30	*Black sticky*
6	*Karimunduga*	31	*China ponni*
7	*Manjula sona*	32	*Vol bogsugandha*
8	*Naweli*	33	*Punkatt kodi-1*
9	*Jig madike*	34	*Punkatt kodi-2*
10	*Game*	35	*Murkanna sanna*
11	*Khushi adikshan*	36	*Dunda*
12	*Kalajeera*	37	*Mapilai samba-1*
13	*Rahodaya*	38	*GK-1*
14	*China ponno-2*	39	*Mapilai samba-2*
15	*Neermullare*	40	*Putta batta-2*
16	*Aishwarya*	41	*Nagland paddy*
17	*Mara batta-2*	42	*Narali*
18	*Krishna leela*	43	*Rajboga*
19	*Tagarhi*	44	*Nali batta*
20	*Malgudi sanna-2*	45	*Sanbog*
21	*Kaggali kearona*	46	*That jasmine*
22	*Bangara gandu*	47	*Navara*
23	*Kana kunja*	48	*Kyasare-1*
24	*Kundi pullan*	49	*Adri batta*
25	*PSB 87*	50	*Kari kagga*

Italicised names represent traditional landrace designations.

Table 2. List of Advanced Varietal Trial (AVT) genotypes evaluated against paddy earhead bug

Sl. No.	Variety	Sl. No.	Variety
1	AVT-IM-2	20	AVT-30
2	AVT-IM-16	21	AVT-8
3	AVT-IM-11	22	AVT-14
4	AVT-IM-15	23	AVT-25
5	AVT-IM-24	24	AVT-27

6	AVT-IM-19	25	AVT-12
7	AVT-IM-3	26	AVT-13
8	AVT-IM-6	27	Nattijaddu
9	AVT-IM-22	28	Hanasu
10	AVT-IM-5	29	BPT-5204
11	AVT-IM-20	30	Ative
12	AVT-IM-4	31	GMS-1
13	AVT-IM-17	32	Halaga
14	AVT-IM-18	33	Masali
15	AVT-IM-7	34	Kavame
16	AVT-IM-9	35	Kajejaya
17	AVT-IM-10	36	Bili halaga
18	AVT-28	37	MO-21
19	AVT-1 (IM-2)	38	MO-4

Table 3. Standard Evaluation System (SES) for rice against earhead bug (IRRI, 2013)

Scale	Grain Damage (%)	Resistance Category
0	No damage	Highly Resistant (HR)
1	<3%	Resistant (R)
3	4–7%	Moderately Resistant (MR)
5	8–15%	Moderately Susceptible (MS)
7	12–25%	Susceptible (S)
9	26–100%	Highly Susceptible (HS)

2.4 Biochemical Analysis of Rice Panicle Tissues

Based on resistance categorisation from field screening, 18 representative genotypes spanning all resistance categories were selected for biochemical analysis. Panicle samples were collected at the milky grain stage (80 days after transplanting), shade-dried, and subsequently oven-dried at 35°C for 24–48 h. The dried samples were ground to a fine powder and stored at 4°C in sealed containers until analysis. Alcoholic extracts were prepared by refluxing 10 g of sample in 150 mL of 80% ethanol for 30 min, filtering through Whatman No. 1 filter paper, and adjusting to a known volume. Nine biochemical and nutritional parameters were quantified using standard analytical protocols (Table 4). Data were subjected to one-way ANOVA; means were separated by Tukey's HSD test ($p = 0.05$). Biochemical parameters were subsequently correlated with per cent grain damage to establish resistance-biochemistry relationships.

Table 4. Standard procedures used for estimation of biochemical and mineral constituents in rice panicle (milky stage)

Biochemical Parameter	Method	Reference
Total Sugars (TSS)	Spectrophotometric (UV), alkaline copper reagent	Somogyi (1952)
Reducing Sugars (TRS)	Spectrophotometric (UV), arsenomolybdate method	Somogyi (1952)
Total Phenols	Folin-Ciocalteu spectrophotometric method	Bray & Thorpe (1954)
Tannins	Folin-Denis spectrophotometric method	Sadasivam & Manickam (1996)
Crude Proteins	Micro-Kjeldahl digestion and distillation	Sadasivam & Manickam (1996)
Total Free Amino Acids (TFA)	Ninhydrin method, spectrophotometry at 570 nm	Moore & Stein (1948)
Nitrogen (N)	Kjeldahl digestion method	AOAC (2016)

Phosphorus (P)	Vanadomolybdate spectrophotometric method, 420 nm	AOAC (2016)
Potassium (K)	Flame photometric method	AOAC (2016)

3. RESULTS

3.1 Seasonal Incidence of Paddy Earhead Bug on Jaya Variety

The seasonal incidence of *L. oratorius* on the susceptible Jaya variety during Kharif 2021 displayed a well-defined unimodal pattern tightly associated with the reproductive phase of the crop (Table 5). The first appearance of earhead bugs was recorded during the third week of November (12–14 November) at a very low density of 0.17 bugs/10 hills. The population then escalated rapidly over successive three-day observation intervals, reaching a peak of 7.63 bugs/10 hills during the last week of November (27–29 November). This peak density coincided precisely with the milky grain stage, when the endosperm is most nutritionally accessible to sap-sucking insects. Following the peak, populations declined progressively and steadily, falling to near-negligible levels of 0.17 bugs/10 hills by 22–26 December, concurrent with advancing grain hardening that rendered feeding sites increasingly unsuitable.

Pearson's correlation analysis between *L. oratorius* population density on Jaya and the seven meteorological variables is presented in Table 6. Maximum temperature exhibited a highly significant negative correlation with bug density ($r = -0.78^{**}$, $p \leq 0.01$), confirming that elevated daytime temperatures suppress earhead bug activity and population build-up. Afternoon relative humidity ($r = +0.72^{**}$) and sunshine hours ($r = +0.69^{**}$) were significantly and positively associated with bug incidence, indicating that warm, humid, and moderately sunny afternoons create favourable microclimatic conditions for pest foraging and colonisation. Minimum temperature ($r = -0.35$), morning relative humidity ($r = +0.19$), rainfall ($r = -0.36$), and number of rainy days ($r = -0.19$) demonstrated non-significant associations with bug density, suggesting these variables exert only secondary or indirect influence on population dynamics under the prevailing agroclimatic conditions at Mandya.

Table 5. Incidence of paddy earhead bug, *Leptocorisa oratorius*, on Jaya variety in relation to meteorological variables, Kharif 2021

Date (2021)	Bugs/ 10 hills	Max T (°C)	Min T (°C)	RH-Mor (%)	RH-Aft (%)	Rainfall (mm)	Rainy Days	Sunshine Hrs
Nov 12–14	0.17	29.7	19.2	90.1	64.0	3.6	0.3	0.5
Nov 15–17	1.10	28.3	19.5	91.2	49.1	5.3	0.7	1.5
Nov 18–20	2.50	28.3	19.3	88.7	67.1	0.0	0.0	5.3
Nov 21–23	3.70	28.7	18.3	92.2	61.6	0.0	0.0	3.7
Nov 24–26	6.63	28.0	17.7	90.7	76.3	0.7	0.0	3.0
Nov 27–29	7.63*	26.7	17.8	90.7	67.8	0.0	0.0	4.8
30 Nov–2 Dec	6.07	27.5	17.7	91.1	65.5	0.0	0.0	5.8
Dec 3–5	6.33	27.3	17.3	93.7	75.8	0.0	0.0	6.7
Dec 6–8	4.73	27.8	18.8	92.6	70.7	1.8	0.7	3.3
Dec 9–11	5.77	28.0	17.8	92.3	67.4	1.2	0.3	3.5
Dec 12–14	6.33	27.7	16.3	91.8	76.3	0.0	0.0	5.0
Dec 15–17	2.83	27.5	16.8	90.5	58.3	0.0	0.0	4.0
Dec 18–20	1.93	28.2	18.0	92.1	68.4	0.0	0.0	1.5
Dec 21–23	0.80	28.2	17.3	91.9	61.2	0.0	0.0	2.8
Dec 22–26	0.17	29.2	17.2	92.2	54.3	0.0	0.0	2.6

**Peak population; Mean of 3 days per observation period; N = 15*

Table 6. Pearson's correlation matrix between *Leptocorisa oratorius* population on Jaya and meteorological variables, Kharif 2021

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y – Bug population	–						
X_1 – Max. temp.	−0.78**	1.00					
X_2 – Min. temp.	−0.35	0.40	1.00				

X_3 – RH (Morning)	0.19	−0.15	−0.38	1.00			
X_4 – RH (Afternoon)	0.72**	−0.42	−0.29	0.16	1.00		
X_5 – Rainfall	−0.36	0.39	0.68	−0.14	−0.42	1.00	
X_6 – Rainy days	−0.19	0.16	0.62	0.11	−0.28	0.84	1.00
X_7 – Sunshine hrs	0.69**	−0.69	−0.41	0.11	0.47	−0.61	−0.43

*** Significant at $p \leq 0.01$; N = 15*

3.2 Seasonal Incidence on IR 64 Variety

On the IR 64 variety, the first appearance of *L. oratorius* occurred earlier, during the second week of November (5–7 November) at 0.23 bugs/10 hills. The population reached its peak of 1.53 bugs/10 hills during the fourth week of November (20–22 November) — approximately one week ahead of the Jaya peak, then declined progressively to 0.10 bugs/10 hills by the third week of December (11–13 December). The considerably lower peak density on IR 64 relative to Jaya reflects the inherent partial tolerance of IR 64 to earhead bug infestation, likely mediated by differences in panicle architecture, husk thickness, and constitutive secondary metabolite content. The earlier phenological milky stage of IR 64, which coincided with slightly higher ambient temperatures less conducive to mass bug activity, further contributed to the lower and earlier population peak. A heavy rainfall event in mid-November (12 mm on 6 November) appeared to temporarily suppress bug build-up on IR 64, consistent with previously reported mechanical disruption of feeding activity by precipitation.

The Pearson correlation pattern on IR 64 closely mirrored that observed on Jaya: maximum temperature yielded a significant negative association (r = −0.67**), while afternoon relative humidity (r = +0.68**) and sunshine hours (r = +0.72**) were significantly positive. The consistent directional agreement of these correlations across two varieties with contrasting susceptibility levels validates the robustness of these weather-pest relationships and confirms their potential utility for developing variety-independent meteorological forewarning models for L. oratorius in the region.

Table 7. Incidence of paddy earhead bug, *Leptocorisa oratorius.* on IR 64 in relation to meteorological variables, *Kharif* 2021

Month & Date	Population of earhead bugs/10hills*	Temperature (^{0}C)		Relative Humidity (%)		Rainfall (mm)	Rainy days (>2.5 mm)	Sunshine hours
		Max.	Min.	Morning	Afternoon			
Nov 5-7, 2021	0.23	31.3	20.8	89.7	60.7	12.0	0.3	3.7
Nov 8-10, 2021	0.57	28.7	18.8	90.6	60.5	0.0	0.0	3.3
Nov 11-13, 2021	0.53	31.0	18.3	90.1	61.6	0.0	0.0	4.0
Nov 14-16, 2021	1.03	27.8	19.3	91.2	75.0	4.6	0.7	4.5
Nov 17-19, 2021	1.13	27.3	19.5	90.0	67.9	4.3	0.3	4.7
Nov 20-22, 2021	1.53	27.2	16.5	91.1	65.8	0.0	0.0	6.3
Nov 23-25, 2021	1.20	27.3	18.2	90.5	79.9	0.7	0.0	5.3
Nov 26-28, 2021	1.03	27.0	17.3	90.7	67.5	0.0	0.0	8.2
29Nov-1Dec, 2021	0.70	28.0	17.5	91.1	66.0	0.0	0.0	4.0
Dec 2-4, 2021	0.87	27.7	18.0	93.9	72.6	0.0	0.0	3.8
Dec 5-7, 2021	0.50	27.2	18.3	91.0	71.3	0.9	0.3	0.5
Dec 8-10, 2021	0.43	30.5	18.3	94.0	64.7	2.1	0.7	4.0
Dec 11-13, 2021	0.10	29.0	16.7	91.4	56.8	0.0	0.0	2.0
Dec 14-16, 2021	0.23	28.5	18.7	89.2	51.9	0.0	0.0	1.8

* Mean population of 3 days; N=14

Table 8. Correlation matrix between the population of *Leptocorisa oratorius* on IR 64. and meteorological variables, *Kharif* 2021

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7
Y – Earhead bug population	-0.67**	-0.25	0.06	0.68**	-0.17	-0.05	0.72**
X_1 – Maximum temperature	1.00	0.40	-0.05	-0.52	0.44	0.22	-0.26
X_2 – Minimum temperature		1.00	-0.32	-0.00	0.81	0.48	-0.21
X_3 – Morning relative humidity			1.00	0.32	-0.23	0.32	0.03
X_4 – Afternoon relative humidity				1.00	0.00	0.25	0.35
X_5 – Rainfall					1.00	0.52	-0.00
X_6– Number of rainy days						1.00	-0.09
X_7- Sunshine hours							1.00

*** Significant at $p \leq 0.01$; N = 15*

3.3 Field Screening of Local Landraces

Field evaluation of 50 local landraces of rice during Kharif 2021 revealed highly significant genotypic variation in both earhead bug population density and percent grain damage (Table 7). Mean earhead bug density across entries ranged from 0.40 bugs/hill (Kave kantak) to 4.50 bugs/hill (Bangara kale), while percent grain damage ranged from 1.03% to 28.88%, indicating a broad and continuous spectrum of resistance response. Notably, no landrace was found to be completely immune (HR, Damage Score = 0), demonstrating that L. oratorius is capable of feeding on all tested genotypes to some degree.

Fifteen landraces were classified as Resistant (R) with less than 3% grain damage (Damage Score = 1): Kave kantak, Narali, Nagland paddy, Kundi pullan, Nali batta, Neermullare, Vol bogsugandha, Mapilai samba-2, Naweli, Kaggali kearona, Mara batta-2, Rajboga, Bangara gandu, Karimunduga, and PSB 87, with bug densities ranging from 0.40 to 1.00 bugs/hill. Ten landraces were categorised as Moderately Resistant (MR) with 4–7% grain damage: Krishna leela, GK-5, Sanbog, Adri batta, China ponni, Kari kagga, Malgudi sanna-2, Nirga samba, Kana kunja, and Dunda (1.10–1.40 bugs/hill). Twenty landraces were Moderately Susceptible (MS), three were Susceptible (S) — Aishwarya (15.60%), Kyasare-1 (19.64%), and Talasiya (22.60%) — and two were Highly Susceptible (HS): Punkatt kodi-1 (26.39%, 3.40 bugs/hill) and Bangara kale (28.88%, 4.50 bugs/hill).

Table 9. Summary of local landraces of rice under different resistance categories against *Leptocorisa oratorius*, Kharif 2021

Category	DS	Landraces	Bugs/hill	Total
HR	0	None	–	0
R	1	Kave kantak, Narali, Nagland paddy, Kundi pullan, Nali batta, Neermullare, Vol bogsugandha, Mapilai samba-2, Naweli, Kaggali kearona, Mara batta-2, Rajboga, Bangara gandu, Karimunduga, PSB 87	0.40–1.00	15
MR	3	Krishna leela, GK-5, Sanbog, Adri batta, China ponni, Kari kagga, Malgudi sanna-2, Nirga samba, Kana kunja, Dunda	1.10–1.40	10
MS	5	Putta batta-2, Navara, Tagarhi, Gangadale, Punkatt kodi-2, That jasmine, Khushi adikshan, Murkanna sanna, Mapilai samba-1, Kalajeera, Rahodaya, Kalakoli, Manjula sona, Game, Black sticky, GK-1, Neermulka, Jenugudu, Jig madike, China ponno-2	1.50–2.80	20
S	7	Aishwarya, Kyasare-1, Talasiya	3.00–3.30	3
HS	9	Punkatt kodi-1, Bangara kale	3.40–4.50	2

HR = Highly Resistant; R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; HS = Highly Susceptible; DS = Damage Score. Classification based on IRRI SES (2013).

3.4 Screening of AVT Genotypes

Among the 37 AVT genotypes evaluated under identical field conditions, none achieved complete immunity (HR, Damage Score = 0). Four genotypes were classified as Resistant (R): GMS-1 (1.86% grain damage, 0.50 bugs/hill), Kavame (2.40%, 0.80 bugs/hill), MO-4 (2.86%, 1.00 bugs/hill), and Ative (2.96%, 1.00 bugs/hill). Eleven genotypes — Bili halaga, BPT-5204, AVT-IM-2, Hanasu, AVT-12, Halaga, AVT-IM-22, AVT-13, Kajejaya, AVT-IM-17, and Nattijaddu — were

Moderately Resistant (MR), with grain damage between 4–7% and bug densities of 1.10–1.90 bugs/hill. Fourteen genotypes were Moderately Susceptible (MS), five were Susceptible (S): AVT-IM-11, AVT-30, AVT-IM-15, AVT-28, and AVT-8 (3.10–3.90 bugs/hill), and three were Highly Susceptible (HS): AVT-IM-3 (26.48%, 5.30 bugs/hill), AVT-IM-6 (26.07%, 4.80 bugs/hill), and AVT-IM-20 (25.79%, 4.10 bugs/hill) — which recorded the highest bug densities in the entire study.

Table 10. Summary of AVT genotypes under different resistance categories against *Leptocorisa oratorius*, Kharif 2021

Category	DS	AVT Genotypes	Bugs/hill	Total
HR	0	None	–	0
R	1	GMS-1, Kavame, MO-4, Ative	0.50–1.00	4
MR	3	Bili halaga, BPT-5204, AVT-IM-2, Hanasu, AVT-12, Halaga, AVT-IM-22, AVT-13, Kajejaya, AVT-IM-17, Nattijaddu	1.10–1.90	11
MS	5	AVT-IM-4, AVT-25, AVT-IM-18, MO-21, AVT-1(IM-2), AVT-IM-19, AVT-IM-5, AVT-IM-16, AVT-IM-24, AVT-27, AVT-14, AVT-IM-10, AVT-IM-7, AVT-IM-9	2.10–2.90	14
S	7	AVT-IM-11, AVT-30, AVT-IM-15, AVT-28, AVT-8	3.10–3.90	5
HS	9	AVT-IM-20, AVT-IM-6, AVT-IM-3	4.10–5.30	3

HR = Highly Resistant; R = Resistant; MR = Moderately Resistant; MS = Moderately Susceptible; S = Susceptible; HS = Highly Susceptible; DS = Damage Score. Classification based on IRRI SES (2013).

3.5 Biochemical Basis of Resistance in Rice Panicle Against *Leptocorisa oratorius*

3.5.1 Total Phenols

Total phenol content in rice panicles at the milky stage varied significantly across the resistance spectrum (Table 9). The highest phenol concentration was recorded in Kave kantak (1.49 mg g^{-1}, R category), followed closely by Rajboga (1.44 mg g^{-1}) and Nagland paddy (1.41 mg g^{-1}), while the lowest was observed in Bangara kale (0.76 mg g^{-1}, HS). A significant, monotonically decreasing gradient in total phenol content was evident from resistant to highly susceptible genotypes (R > MR > MS > S > HS). Total phenol content was highly significantly and negatively correlated with percent grain damage ($r = -0.86^{**}$, $p \leq 0.01$; Table 11), confirming that phenolic accumulation in panicle tissue is a key biochemical determinant of resistance against L. oratorius.

3.5.2 Tannins

Tannin content exhibited a particularly pronounced and statistically significant decreasing gradient from resistant to highly susceptible genotypes. Kave kantak recorded the highest tannin concentration (4.85 mg g^{-1}), followed by Nagland paddy (4.63 mg g^{-1}) and Neermullare (4.15 mg g^{-1}), while Bangara kale recorded the lowest (0.91 mg g^{-1}). The tannin contents of Punkatt kodi-1 (0.94 mg g^{-1}) and Bangara kale (0.91 mg g^{-1}) were not significantly different from each other, suggesting a threshold below which panicle tissue becomes chemically uninhibitory to earhead bug feeding. Among all biochemical parameters analysed, tannins yielded one of the strongest negative correlations with grain damage ($r = -0.94^{**}$, $p \leq 0.01$; Table 11).

3.5.3 Total Soluble Sugars (TSS) and Total Reducing Sugars (TRS)

TSS and TRS in rice panicles displayed a consistent increasing trend from resistant to highly susceptible genotypes (Table 9). TSS ranged from 0.91 mg g^{-1} (Kave kantak, R) to 3.94 mg g^{-1} (Bangara kale, HS), while TRS ranged from 3.22 mg g^{-1} (Kave kantak) to 8.89 mg g^{-1} (Bangara kale). Both parameters were highly significantly and positively correlated with grain damage: TSS ($r = +0.95^{**}$) and TRS ($r = +0.97^{**}$, $p \leq 0.01$; Table 11). The exceptionally high TRS in HS genotypes — Bangara kale (8.89 mg g^{-1}) and Punkatt kodi-1 (8.44 mg g^{-1}) — represents a nutritionally rich environment that coincides with the disproportionately high bug densities (4.50 and 3.40 bugs/hill, respectively) recorded on these genotypes during field screening.

3.5.4 Crude Proteins

Crude protein content increased consistently with increasing susceptibility, ranging from 9.31 mg g^{-1} (Kave kantak, R) to 16.20 mg g^{-1} (Bangara kale, HS). This parameter yielded the strongest individual bivariate correlation with grain damage in the entire biochemical dataset ($r = +0.98^{**}$, $p \leq 0.01$; Table 11), underscoring the paramount importance of nitrogen-based nutritional compounds as drivers of earhead bug host selection and performance. A clear and statistically significant step-wise increase in crude protein content was observed across resistance categories, with resistant genotypes consistently and significantly lower in protein content than susceptible or highly susceptible ones.

3.5.5 Total Free Amino Acids (TFA)

In contrast to crude proteins, TFA followed a markedly decreasing gradient from resistant to susceptible categories, ranging from 10.78 mg g^{-1} (Kave kantak, R) to 6.26 mg g^{-1} (Bangara kale, HS). TFA was highly significantly and negatively correlated with grain damage ($r = -0.95^{**}$, $p \leq 0.01$; Table 11), a value that matched the strongest resistance-negative correlations in the dataset alongside TRS. The inverse relationship between TFA and crude protein across the resistance spectrum suggests that nitrogen in resistant genotypes is preferentially channelled into free amino acid pools associated with secondary metabolite biosynthesis rather than structural protein accumulation.

3.5.6 Mineral Nutrients: Nitrogen (N), Phosphorus (P), and Potassium (K)

Nitrogen content in rice panicles increased from 1.21% (Kave kantak, R) to 2.34% (Bangara kale, HS), with a highly significant positive correlation with grain damage (r = +0.95**, $p \leq 0.01$; Table 11). Phosphorus followed a comparable trend, increasing from 0.14% (Kave kantak, R) to 0.52% (Bangara kale, HS), with a significant positive correlation (r = +0.87**; Table 11). Potassium exhibited a contrasting pattern: resistant genotypes accumulated significantly higher K content — Kave kantak (3.54%), Nali batta (3.11%), and Rajboga (3.04%) — relative to highly susceptible genotypes — Bangara kale (1.38%) and Punkatt kodi-1 (1.56%) — yielding a strong negative correlation with grain damage (r = −0.93**, $p \leq 0.01$; Table 11). The complete biochemical and mineral composition data for all 18 genotypes, along with the full correlation matrix, are presented in Tables 9, 10, and 11.

Table 11. Biochemical constituents in rice panicle (milky stage) of selected genotypes under different resistance categories against *Leptocorisa oratorius*, Kharif 2021

Genotype	Cat.	Grain dmg (%)	Phenols (mg g⁻¹)	TSS (mg g⁻¹)	TRS (mg g⁻¹)	Protein (mg g⁻¹)	TFA (mg g⁻¹)	Tannins (mg g⁻¹)
Kave kantak	R	1.03	1.49	0.91	3.22	9.31	10.78	4.85
Nagland paddy	R	1.22	1.41	0.99	3.80	9.63	10.56	4.63
Nali batta	R	1.46	1.38	1.13	4.29	10.13	10.32	3.92
Neermullare	R	1.52	1.32	1.30	3.96	10.53	9.71	4.15
Rajboga	R	2.23	1.44	2.13	5.15	10.97	8.85	2.98
PSB 87	R	2.96	1.12	2.25	4.92	11.60	9.49	3.56
Krishna leela	MR	4.01	1.14	1.87	4.24	11.90	8.98	3.83
GK 5	MR	4.27	0.96	2.04	5.15	12.10	9.06	3.36
Adri batta	MR	5.00	1.07	1.69	4.81	12.40	8.75	3.54
Nirga samba	MR	6.02	0.99	2.40	5.21	12.54	8.43	2.98
Murkanna sanna	MS	9.31	1.29	2.68	5.34	12.70	8.56	3.29
Manjula sona	MS	10.17	0.92	3.08	5.35	13.00	7.92	2.63
Game	MS	11.01	0.90	2.93	6.17	13.11	8.04	2.58
Black sticky	MS	11.64	0.87	2.99	6.22	13.70	7.53	1.86
Aishwarya	S	15.60	0.85	2.91	7.15	14.80	7.36	1.03
Talasiya	S	22.60	0.83	3.76	7.88	15.40	7.23	0.98
Punkatt kodi-1	HS	26.39	0.80	3.82	8.44	15.90	6.54	0.94
Bangara kale	HS	28.80	0.76	3.94	8.89	16.20	6.26	0.91

TSS = Total Soluble Sugar; TRS = Total Reducing Sugar; TFA = Total Free Amino Acids; Cat. = Resistance Category. All values are means; means within columns sharing common letters are non-significant at p = 0.05 (Tukey's HSD).

Table 12. Mineral constituents (%) in rice panicle (milky stage) of selected genotypes against *Leptocorisa oratorius*, Kharif 2021

Genotype	Category	Grain damage (%)	N (%)	P (%)	K (%)
Kave kantak	R	1.03	1.21	0.14	3.54
Nagland paddy	R	1.22	1.36	0.16	2.98
Nali batta	R	1.46	1.28	0.20	3.11
Neermullare	R	1.52	1.44	0.19	2.72
Rajboga	R	2.23	1.35	0.25	3.04
PSB 87	R	2.96	1.52	0.23	2.65
Krishna leela	MR	4.01	1.48	0.28	2.33

GK 5	MR	4.27	1.59	0.31	2.46
Adri batta	MR	5.00	1.63	0.26	2.42
Nirga samba	MR	6.02	1.78	0.28	2.58
Murkanna sanna	MS	9.31	1.43	0.45	2.33
Manjula sona	MS	10.17	1.86	0.33	2.21
Game	MS	11.01	1.91	0.35	2.29
Black sticky	MS	11.64	1.82	0.41	1.95
Aishwarya	S	15.60	1.99	0.49	1.74
Talasiya	S	22.60	2.04	0.35	1.83
Punkatt kodi-1	HS	26.39	2.25	0.41	1.56
Bangara kale	HS	28.80	2.34	0.52	1.38

Table 13. Correlation matrix between grain damage (%) and biochemical/mineral constituents of rice panicle against *Leptocorisa oratorius*, Kharif 2021

Parameters	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8	X_9
Y – Grain damage (%)	–								
X_1 – Total Phenols	−0.86**	1.00							
X_2 – TSS	+0.95**	−0.85	1.00						
X_3 – TRS	+0.97**	−0.83	0.94	1.00					
X_4 – Crude Proteins	+0.98**	−0.91	0.95	0.96	1.00				
X_5 – TFA	−0.95**	0.88	−0.96	−0.94	−0.98	1.00			
X_6 – Tannins	−0.94**	0.85	−0.94	−0.97	−0.96	0.96	1.00		
X_7 – Nitrogen	+0.95**	−0.93	0.91	0.93	0.95	−0.94	−0.92	1.00	
X_8 – Phosphorus	+0.87**	−0.76	0.86	0.84	0.89	−0.89	−0.85	0.78	1.00
X_9 – Potassium	−0.93**	0.90	−0.90	−0.90	−0.97	0.94	0.90	−0.92	−0.89

*** Significant at $p \leq 0.01$; N = 18; TSS = Total Soluble Sugar; TRS = Total Reducing Sugar; TFA = Total Free Amino Acids.*

4. DISCUSSION

4.1 Seasonal Incidence and Weather Relationships

The unimodal pattern of L. oratorius incidence on Jaya, with the pest appearing at flowering and reaching its peak at the milky grain stage before declining steeply during grain hardening, closely conforms to the ontogenetic feeding preference of the species for soft, carbohydrate-laden endosperm. This phenological synchrony between pest peak and crop milky stage has been widely reported across diverse rice-growing environments in India and is attributable to the maximal nutritional value and physical accessibility of the endosperm during this developmental window (Yadav et al., 2025). The attainment of peak density as late as the last week of November at Mandya reflects the relatively late Kharif season at this latitude and elevation, and distinguishes the present system from rice ecosystems in the eastern Indo-Gangetic plains where peak incidence typically occurs in September–October.

The highly significant negative correlation of bug density with maximum temperature (r = −0.78** on Jaya; r = −0.67** on IR 64) corroborates the established principle that elevated daytime temperatures reduce earhead bug foraging activity, egg-hatch rates, and nymphal survival. Arjun et al. (2017) similarly identified maximum temperature as the dominant negative abiotic driver of Leptocorisa population dynamics in rice ecosystems of North India. The partial divergence from Vinothkumar (2015), who reported a positive association of earhead bug damage with maximum temperature in high-altitude rainfed rice systems, is attributable to the fundamentally different thermal regimes of high-altitude (cool, sub-optimal temperatures where warming increases pest activity) versus lowland irrigated environments (warmer temperatures already approaching or exceeding thermal optima for the pest). This context-dependence of temperature effects underscores the importance of site-specific calibration in forewarning model development.

The significant positive associations of afternoon relative humidity (r = +0.72**; +0.68**) and sunshine hours (r = +0.69**; +0.72**) with bug density are mechanistically consistent with the known behavioural ecology of L. oratorius. High afternoon relative humidity promotes adult activity, dispersal, and oviposition by reducing desiccation stress, while adequate sunshine hours optimise panicle temperature for feeding. Roshan and Raju (2017) similarly reported dominant positive roles of relative humidity and sunshine hours in driving seasonal fluctuations of earhead bug populations. The non-significant associations of morning relative humidity, rainfall, and rainy days with bug density align with findings of Arjun et al. (2017) and suggest that while heavy rainfall may mechanically dislodge bugs from panicles, the overall population recovery is rapid and morning humidity conditions do not substantially constrain activity. Collectively, the three significant meteorological predictors identified, maximum temperature, afternoon relative humidity, and sunshine hours, across two varieties with different susceptibility levels provide a robust, variety-independent empirical foundation for developing a bio-meteorological forewarning model for L. oratorius in the southern Karnataka rice belt.

4.2 Field Screening of Local Landraces

The field screening of 50 local landraces under natural field infestation at Mandya revealed a broad, continuous distribution of resistance phenotypes, with 30% of entries qualifying as Resistant (15 R out of 50), confirming the rich diversity of resistance traits harboured in the traditional landrace diversity of the Cauvery command area. The complete absence of highly resistant or immune (HR) genotypes in the entire landrace panel is consistent with the broader literature on rice-earhead bug interactions, confirming that complete immunity to L. oratorius is rare or absent among currently available rice germplasm (Girish et al., 2015; Kakde & Patel, 2018). This finding implies that resistance to this pest is quantitative in genetic architecture, governed by multiple genes with additive and epistatic effects, rather than determined by a single major resistance gene capable of conferring immunity, a conclusion with direct implications for the design of breeding programmes that should prioritise pyramiding multiple resistance loci.

The identification of Punkatt kodi-1 and Bangara kale as Highly Susceptible, with grain damage exceeding 26% and bug densities of 3.40–4.50 bugs/hill, respectively, highlights the risk these landraces pose if grown at scale in earhead bug-endemic areas without integrated management. Their highly susceptible status warrants immediate advisory communication to farmers who may grow them for culinary or cultural reasons, recommending concurrent application of approved insecticides during the milky grain stage. Kakde and Patel (2018) reported IR-28 and Jaya as susceptible checks with 16–25% and >26% grain damage, respectively, values consistent with the susceptibility of Bangara kale observed in the present study and reinforcing the validity of the resistance categorisation adopted here.

4.3 Screening of AVT Genotypes

The screening of 37 AVT genotypes yielded four Resistant entries, GMS-1, Kavame, MO-4, and Ative, representing 10.8% of the genotypes evaluated, a proportion somewhat lower than the 30% resistant found among landraces. This difference is attributable to the breeding history of AVT entries, which have been selected primarily for agronomic performance, grain quality, and disease resistance, rather than for earhead bug resistance specifically. The higher proportion of resistant genotypes among landraces compared with AVT entries reflects the advantage of farmer selection under endemic pest pressure over many generations, a process that inadvertently enriched resistant alleles at frequencies exceeding those in formally bred germplasm.

GMS-1 and Kavame are particularly noteworthy among the resistant AVT entries: both combine low grain damage (1.86% and 2.40% respectively) with acceptable agronomic performance, making them immediately amenable to multi-location evaluation and eventual release as dual-purpose varieties, high yield with earhead bug resistance. BPT-5204, classified as MR in the present study, is already widely cultivated in Andhra Pradesh and Karnataka for its superior grain quality and cooking characteristics; confirmation of its intermediate resistance status adds a pest management dimension to its deployment rationale and supports its use as a background variety in earhead bug-resistant breeding crosses. The identification of three HS genotypes within the AVT series (AVT-IM-3, AVT-IM-6, AVT-IM-20, with grain damage of 25.79–26.48% and bug densities of 4.10–5.30 bugs/hill, warrants immediate attention from plant breeders and the AICRP on Rice to ensure these lines are not advanced toward commercial release in earhead bug-endemic regions without concurrent chemical management recommendations. These results are broadly consistent with Girish et al. (2015), who screened 231 genotypes and found resistance to be common but immunity absent.

4.4 Biochemical Basis of Resistance: Defence Compounds

The highly significant negative correlations of total phenols ($r = -0.86^{**}$), tannins ($r = -0.94^{**}$), total free amino acids ($r = -0.95^{**}$), and potassium ($r = -0.93^{**}$) with grain damage collectively establish these as the principal biochemical and mineral determinants of resistance against L. oratorius in rice panicle tissue. Together, these compounds form a synergistic, multi-layered defence system that operates through complementary but distinct mechanisms.

Total phenolic compounds, present at up to 1.49 mg g^{-1} in the most resistant landrace Kave kantak, confer resistance through several interacting mechanisms: (i) direct anti-feedant activity mediated by bitter taste perception in insect chemoreceptors; (ii) protein-complexing activity that reduces the digestibility of plant proteins by insect gut proteases; (iii) participation in oxidative defence responses through the formation of reactive quinones upon tissue disruption; and (iv) role as precursors in lignin biosynthesis, which physically hardens cell walls and increases tissue toughness against stylet penetration (War et al., 2018). Analogous negative associations of total phenols with pest damage have been reported across diverse rice-insect systems, including gall midge (Sahu et al., 2024), brown planthopper (Dharshini & Gowda, 2014; Pati et al., 2023), leaffolder (Singh et al., 2022), and yellow stem borer (Chavan & Patel, 2018), demonstrating the universality of phenolic-based resistance across feeding guilds and attesting to the mechanistic validity of the present findings.

Tannins yielded the second strongest negative correlation with grain damage ($r = -0.94^{**}$) among all parameters, underscoring their particular importance as resistance determinants against this hemipteran pest. As polyphenolic condensates, tannins operate primarily through anti-nutritional mechanisms: they form stable complexes with dietary proteins and digestive enzymes, particularly proteases, lipases, and amylases, in the insect midgut, precipitating these molecules and drastically reducing nutrient absorption efficiency. At sufficient concentrations, tannin-protein complexes also reduce the nitrogen utilisation efficiency of insects, slowing growth, delaying development, and reducing reproductive output. Dutta and Roy (2018) specifically reported significant negative associations between phenolic constituents, including tannins, and earhead bug incidence in rice, providing a direct precedent for the role of this compound class against L. oratorius. The threshold-like behaviour at the lower end of the tannin distribution, with no significant difference in tannin levels between the S and HS categories (approximately 0.91–1.03 mg g^{-1}), suggests that below a critical minimum tannin concentration, panicle tissues are effectively subinhibitory to earhead bug feeding, and further reductions in tannin content confer no additional susceptibility. This threshold effect has important implications for breeding, suggesting that achieving even moderate tannin elevation above the S-category baseline could substantially improve resistance.

Total free amino acids (TFA), despite belonging to the nitrogen fraction, exhibited a strongly negative relationship with grain damage (r = −0.95**), in apparent contrast to crude proteins, which were positively correlated. This seemingly paradoxical divergence is resolved by considering the differential physiological roles of these nitrogen fractions: free amino acids in resistant genotypes are predominantly associated with defensive nitrogen metabolism, serving as immediate precursors and nitrogen donors for the biosynthesis of phenolamides, alkaloids, proteinase inhibitors, and other nitrogen-containing secondary metabolites with established anti-herbivore activities, rather than serving as nutritional substrates available to feeding insects. The co-elevation of TFA and total phenols in resistant genotypes (Table 9) is consistent with metabolic channelling of free amino acids into phenylpropanoid and alkaloid biosynthesis pathways, representing a coordinated multi-layered chemical defence architecture. Dutta and Roy (2018) specifically reported a negative correlation of amino acids with L. acuta incidence in rice, and Sahu et al. (2024) documented higher total free amino acids in gall midge-resistant rice land races alongside elevated phenols, supporting the generality of this co-regulatory pattern.

Potassium content in panicle tissue was strongly negatively correlated with grain damage (r = −0.93**), with resistant genotypes accumulating substantially higher K, up to 3.54% in Kave kantak, compared to highly susceptible genotypes (1.38% in Bangara kale). The resistance-promoting role of K operates through multiple complementary pathways: (i) K-mediated turgor regulation and cell wall strengthening through the deposition of structural polysaccharides physically impedes stylet penetration and endosperm extraction by the piercing mouthparts of hemipteran earhead bugs; (ii) adequate K nutrition upregulates the synthesis of phenolic secondary metabolites and activates jasmonate-dependent defence signalling cascades; and (iii) K modulates carbohydrate partitioning in source tissues, reducing the accumulation of readily available soluble sugars that serve as primary phagostimulants (Amtmann et al., 2008; Mohapatra et al., 2017). These findings substantiate the integration of K nutrition parameters into resistance characterisation protocols and support the use of K fertilisation as a supplementary agronomic strategy for reducing earhead bug susceptibility in endemic areas.

4.5 Biochemical Basis of Resistance: Nutritional Phagostimulants

The positive associations of TSS (r = +0.95**), TRS (r = +0.97**), crude proteins (r = +0.98**), nitrogen (r = +0.95**), and phosphorus (r = +0.87**) with grain damage establish that susceptibility to L. oratorius is fundamentally determined by the nutritional richness and phago-stimulatory chemical environment of the panicle. Crude protein content emerged as the single strongest predictor of susceptibility (r = +0.98**, the highest bivariate correlation in the entire dataset), confirming that nitrogen-rich panicle tissue constitutes a superior nutritional host that supports faster nymphal development, higher adult longevity, and greater reproductive output of earhead bugs.

Soluble and reducing sugars serve as primary phagostimulants that trigger probing and sustained feeding behaviour in sap-sucking Hemiptera through chemoreceptor stimulation at the stylet tip. The extremely high TRS values in HS genotypes, Bangara kale (8.89 mg g^{-1}) and Punkatt kodi-1 (8.44 mg g^{-1}), representing approximately 2.8-fold and 2.6-fold higher concentrations than the most resistant genotype Kave kantak (3.22 mg g^{-1}), provide a mechanistic explanation for the disproportionately high bug densities recorded on these genotypes during field screening. Shi et al. (2023) reported higher total and reducing sugars in susceptible rice genotypes across multiple pest-host systems, while Sahu et al. (2024) confirmed a significant positive correlation of sugar content with gall midge infestation density, indicating that soluble sugar accumulation is a conserved susceptibility determinant across diverse rice insect-feeding guilds.

Nitrogen and phosphorus, as primary mineral nutrients supporting insect growth and reproduction through their roles in amino acid, nucleotide, and ATP metabolism, showed significant positive correlations with grain damage (r = +0.95** and +0.87** respectively). High plant tissue N has been well-documented to support superior insect growth rates in numerous herbivore systems, consistent with the nitrogen limitation hypothesis of insect herbivory. The lower but still significant positive correlation of P with grain damage (r = +0.87**) compared to N (r = +0.95**) suggests that while phosphorus availability in plant tissue supports earhead bug nutrition, its contribution to host suitability is somewhat secondary to nitrogen status. Pati et al. (2023), and Chavan and Patel (2018) confirmed significant positive correlations of N and P with susceptibility to diverse rice-insect pests, reinforcing the universality of these nutritional drivers across the rice pest complex.

Synthesising the complete biochemical dataset, it is evident that resistance in rice panicle tissue against L. oratorius is not determined by any single compound or mechanism but emerges from the aggregate balance between defence metabolites (phenols, tannins, TFA, & K) and nutritional phagostimulants (TSS, TRS, crude protein, N, P). Resistant genotypes present an environment that is simultaneously chemically repellent, physically resistant to stylet penetration, and nutritionally suboptimal for the pest, a tripartite defence architecture that is substantially more difficult for the pest to overcome than any single-compound resistance mechanism. This integrated view of resistance supports the concept that breeding for durable resistance should target the simultaneous elevation of multiple defence metabolites rather than optimising a single biochemical trait. The identified biochemical markers, particularly the ratio of tannin-to-TRS and phenol-to-crude-protein, show promise as rapid, cost-effective biochemical indices for pre-screening large germplasm collections in plant breeding programmes, complementing traditional field bioassay methods.

5. CONCLUSION

The present investigation constitutes the first comprehensive, multi-tiered analysis of the paddy earhead bug problem in the Cauvery command area of southern Karnataka, integrating seasonal population dynamics, large-scale varietal screening, and biochemical resistance characterisation within a unified experimental framework. The peak incidence of L. oratorius during the milky grain stage in the last week of November, with maximum temperature exerting a significant negative influence ($r = -0.78^{**}, -0.67^{**}$) and afternoon relative humidity and sunshine hours exerting significant positive associations, provides a robust empirical basis for the development of a regional, weather-driven forewarning model for L. oratorius. Extensive field screening identified 15 landraces (out of 50) and 4 AVT genotypes (out of 37) as Resistant, with none achieving complete immunity, underscoring the quantitative, polygenic nature of resistance to this pest in currently available rice germplasm. Landraces Kave kantak, Nagland paddy, Narali, and Kundi pullan, and AVT genotypes GMS-1 and Kavame are particularly recommended for further evaluation in multi-location trials and for utilisation as donor parents in resistance breeding programmes. Highly susceptible genotypes, particularly Bangara kale and Punkatt kodi-1 (landraces) and AVT-IM-3, AVT-IM-6, and AVT-IM-20 (AVT entries), should not be advanced for commercial cultivation in earhead bug-endemic areas without concurrent insecticide management recommendations. Biochemical analysis revealed that resistance in rice panicle tissue against L. oratorius is mediated by a synergistic combination of elevated defence compounds (total phenols, tannins, total free amino acids, and potassium) and reduced levels of nutritional phagostimulants (total soluble sugars, total reducing sugars, crude proteins, nitrogen, and phosphorus). These biochemical markers can serve as rapid, cost-effective tools for pre-screening germplasm in resistance breeding programmes. Future research should focus on: (i) molecular mapping of QTL governing phenolic and tannin biosynthesis in identified resistant landraces; (ii) transcriptomic profiling of earhead bug-challenged resistant versus susceptible panicle tissues; (iii) multi-season and multi-location validation of identified resistant genotypes; and (iv) development of an operational bio-meteorological forecasting model for L. oratorius to guide cost-effective IPM implementation across rice-growing areas of southern Karnataka and beyond.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

AUTHORS CONTRIBUTION

SBS, PK, DSP – Manuscript writing, reviewing, and data curation; **SD, PD & PP** – Manuscript Editing and Data analysis; **DC** – Data Analysis & Formal Editing; **VS & CK –** Reviewing and reference formatting

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