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Evaluation of biocontrol potential of *Euphlyctis adolfi* and *Duttaphrynus melanosticus* (Anura: Bufonidae) against rice insect pests under field conditions

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Abstract

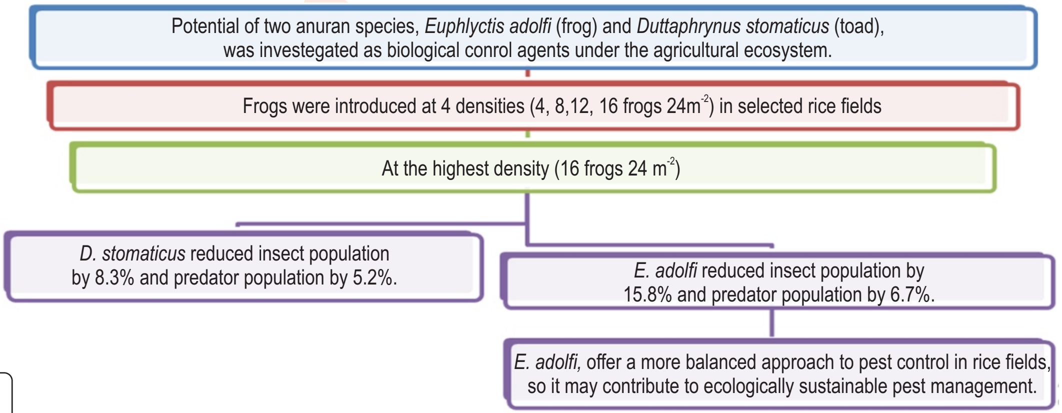
Aim: This study investigated the potential of two anuran species, *Euphlyctis adolfi* (frog) and *Duttaphrynus stomaticus* (toad), as biological control agents under the agricultural ecosystem of rice fields, using the varieties PR 121 and PR 122 during 2023.

Methodology: Frogs were introduced at four densities (4, 8, 12, and 16 frogs 24 m^{-2}) into selected rice plots, along with pesticide-treated and untreated control plots, each replicated thrice. Pest populations and crop damage were monitored weekly using standardized visual inspection and sweep net methods.

Results: Arthropod community in rice crop fields comprised of 22 species across six orders and 16 families, orthoptera being predominant. Results demonstrated an inverse relationship between anuran density and arthropod populations, where *E. adolfi* showed higher efficacy than *D. stomaticus*. At 16 frogs 24m^{-2} density, *E. adolfi* reduced insect population by 15.8% and predator populations by 6.7% as compared to controls, while *D. stomaticus* achieved 8.3% and 5.2% reductions, respectively. *E. adolfi* was particularly effective against white-backed planthoppers (35.6% reduction) and grasshoppers (15.4% reduction in crop damage) as compared to controls. Both anuran species had limited impact on rice stem borers due to it's endophytic lifecycle. Pesticide treatments, being more effective provide 70.7% reduction in pest populations, caused substantial decrease in predator populations (32% reduction).

Interpretation: The study revealed that anurans, especially *E. adolfi,* offer balanced approach to pest management as compared to pesticides potentially contributing to sustainable rice cultivation. Findings suggest that anuran integration into pest management strategies could maintain ecological balance while providing effective biological pest control in rice ecosystem.

Key words: Anurans, Biological control, Frog, Rice crop, Toad



Potential of two anuran species, *Euphlyctis adolfi* (frog) and *Duttaphrynus stomaticus* (toad), was investegated as biological conrol agents under the agricultural ecosystem.

Frogs were introduced at 4 densities (4, 8,12, 16 frogs 24m^{-2}) in selected rice fields

At the highest density (16 frogs 24 m^{-2})

D. stomaticus reduced insect population by 8.3% and predator population by 5.2%.

E. adolfi reduced insect population by 15.8% and predator population by 6.7%.

E. adolfi, offer a more balanced approach to pest control in rice fields, so it may contribute to ecologically sustainable pest management.

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Introduction

Frogs and toads are ecologically significant amphibians with diverse morphologies, behaviours and habitat preferences, with rice (*Oryza sativa* L.) ecosystems providing an important habitat for many species. In India, approximately 450 species of anurans exist, reflecting the country's varied ecosystems (Frost 2023; Dinesh *et al.,* 2021). Rice cultivation is crucial for global food security, with India being the second-largest producer, contributing about 21% of global rice production (FAO, 2023). However, rice ecosystems are threatened by a range of pests, including insects, resulting in significant yield losses, estimated at 10-15% annually (Prasad *et al.,* 2022). The overuse of chemical pesticides in rice farming has led to environmental degradation, including soil and water contamination, biodiversity loss and pesticide resistance (Zhang *et al.,* 2021). These concerns have raised interest in alternative pest management strategies, such as biological control. Anurans, due to their voracious predation on various agricultural pests, have been proposed as potential natural pest control agents in rice ecosystems (Khatiwada *et al.,* 2023).

Recent studies have highlighted the potential of frogs and toads in pest regulation, demonstrating their ability to reduce pest populations and contribute to higher crop yields (Hocking and Babbitt, 2014; Attademo *et al.,* 2022). A study by Liang *et al.* (2004) revealed that *Euphlyctis* species consumed large numbers of insect pests, including rice planthoppers (*Nilaparvata lugens*), with up to 150 planthoppers consumed per night by a single frog, significantly reducing rice crop damage up to 30%. Similarly, *Duttaphrynus melanosticus* has been observed to lower populations of pest species like grasshoppers (*Caelifera viridissima*) and leafhoppers (*Nephotettix virescens*) by approximately 25-40% in rice fields (Kumar *et al.,* 2023). *Euphlyctis adolfi* reduced the rice stem borer (*Scirpophaga excerptalis*) population by 35% and grasshopper damage by 22% after a 30-day observation period (Reddy *et al*., 2023; Liang *et al*, 2025). Furthermore, anuran predation has been linked to a 15-20% increase in crop yield in areas where amphibians were present compared to control plots without anurans (Hocking and Babbitt 2014). These findings underscore the importance of integrating anurans into sustainable pest management strategies, demonstrating their significant contribution to natural pest regulation in agricultural ecosystems.

Incorporating anurans into Integrated Pest Management (IPM) programs offer a promising, sustainable solution to reduce reliance on chemical pesticides while maintaining pest control (Peltzer *et al.,* 2019; Kumar *et al.,* 2023). However, the successful integration of anurans require a better understanding of their feeding preferences, habitat needs, and interactions within agroecosystems. This research aims to evaluate the biocontrol potential of *Euphlyctis adolfi* and *Duttaphrynus melanosticus* against rice insect pests, contributing to the development of sustainable and eco-friendly pest management practices in rice cultivation (Reddy *et al.,* 2023). The findings of this study may have broader implications for biodiversity conservation in agricultural landscapes and the advancement of agroecological approaches to food production.

Materials and Methods

Selection of rice varieties: After preparation of soil, different plots measuring 6×4 m were prepared using agricultural implements during 2023. There was a difference of 25 m distance between two plots. Rice plants of varieties PR 121 and PR 122 were transplanted in these plots. These rice varieties have been recommended by Punjab Agricultural University, Ludhiana for farmer cultivation in Punjab state. The rice plants were raised using agricultural practices (fertilizers, irrigation and plant protection measures) recommended by Punjab Agricultural University, Ludhiana on 25th June.

Selection of anuran species: To evaluate the predatory potential, two anuran species, *Duttaphrynus stomaticus* (having weight 12.0-19.05g) and *Euphlyctis adolfi* (weight 18.80-25.6g), were selected based on their abundance in local rice ecosystems of Punjab. To conduct this experiment, required number of anuran species were collected from various habitats including ponds at College of Fisheries, GADVASU, rice fields, and nearby residential areas using scoop nets. The frogs were introduced to the experimental plots just one-month post-rice transplantation. Each selected plot was enclosed with nylon netting along their periphery with height of 3 feet to check the escape of anurans from plots. The experiment comprised the following treatments:

Treatment 1-4: Plots having anuran density of 4, 8, 12, and 16 frogs 24 m^{-2}; Treatment 5: Plots having recommended pesticide application; Treatment 6:Plots having control (absence of frogs and pesticides).

The densities of 4, 8, 12 and 16 frogs 24 m^{-2} were selected for treatments 1-4 based on a combination of previous research findings (Khatiwada *et al.,* 2016) and ecological considerations, densities selected were within the range of natural anuran populations observed in similar agricultural landscapes, ensuring that the experimental treatments mimic real-world conditions. This density range provides a comprehensive evaluation of how anuran populations, varying in size, impact pest control, ensuring that the study results are both scientifically grounded and ecologically relevant. Each treatment was replicated thrice to ensure robust statistical analysis. In the anuran treated plots, pesticides and fertilizers were not used so as to prevent any adverse effect on anurans. The anuran species were counted from each field at monthly interval to maintain consistent population densities. Although predation by secondary predators such as snakes and birds was not directly observed in the study, the dead individuals were continuously replaced with new ones to maintain the anuran population.

Insect population and damage assessment: Population densities of different rice insect pests and their damage were assessed at weekly intervals throughout the cropping season during early morning hours (6:00-8:00 am). Insect population count and damage for brown planthopper, white-backed planthopper, grasshoppers, rice gundi bug and predators were conducted from 25 hills per plot (five randomly selected hills from each of the four quadrants and centre of each plot) using Atwal and Dhaliwal (2005) methodology. Visual inspection and sweep net method were used to assess the abundance of insect populations in the respective plots. For rice stem borer and leaf folder, ten randomly selected hills per plot were examined for population count and characteristic damage symptoms such as folded leaves, dead hearts (Atwal and Dhaliwal, 2005). Specimens were collected using scoop nets or hand-picking methods and identified using appropriate taxonomic keys and by the experts from Zoological Survey of India (ZSI), Pune and National Bureau of Agricultural Insect Resources (NBAIR), Bangalore. To assess crop damage, the following formulae were used:

Percent damage by rice stem borer:

$$\text{Percent damage} = \frac{\text{Number of damaged tillers}}{\text{Total number of tillers}} \text{x100}$$

Percent damage by rice leaf folder/grasshoppers:

$$\text{Percent damage} = \frac{\text{Number of damaged leaves}}{\text{Total number of leaves}} \text{x100}$$

Statistical analysis: The data on insect population count was analysed using Mean±S.D., One way ANOVA and was compared using Tukey's test with p value = 0.05 using SPSS software 2021.

Results and Discussion

During the study, a diverse arthropod community in the rice ecosystem was recorded, comprising 22 species belonging to six orders namely, Hemiptera, Coleoptera, Lepidoptera, Orthoptera, Odonata and Araneae belonging to 16 families from control plots (Table 1). Among herbivorous insects, Orthoptera was significantly ($p \leq 0.05$) the predominant order (44.4%), whereas order Araneae dominated significantly ($p \leq 0.05$) among predators (69.2%). This observation aligns with Kumar *et al.* (2024), who also reported Orthopterans as dominant in rice crop fields of Nepal and India. The dominance of Orthoptera among herbivores may be attributed to their greater mobility and ability to feed on a wide range of plant tissues, making them persistent pests in rice ecosystems (Singh *et al.,* 2025).

Establishment of this diverse arthropod community indicates healthy trophic structure essential for ecosystem stability, where high predator-to-prey ratios suggest natural regulatory mechanisms that can be enhanced through strategic biological control interventions (Gurr *et al.,* 2023). The predatory potential of *Euphlyctis adolfi* and *Duttaphrynus stomaticus* against rice insect pests revealed an inverse relationship between anuran density and arthropod populations. In all treated plots, as anuran density increased from 4 to 16 frogs 24 m^{-2}, insect pest and predator populations decreased, with a more pronounced effect on pest species. The mean reduction in populations of whitebacked planthopper and brown planthopper by *E. adolfi* increased from 7.71% at 4 frogs 24 m^{-2} to 25.44% at 16 frogs/24 m^2. Similarly, *D. stomaticus* showed an increase in reduction from 4.57% at 4 frogs 24 m^{-2} to 17.59% at 16 frogs 24 m^{-2} (Table 2). This density-dependent suppression of pests likely results from intensified predation pressure and greater prey encounter rates with increasing frog densities, consistent with previous findings that amphibian predation scales with population density (Valdez 2019; Peltzer *et al.,* 2022; Liang *et al.,* 2024). Peltzer *et al.* (2022) revealed that the mathematical relationship between anuran density and pest suppression follows optimal foraging theory; at densities of 8 to 16 frogs 24 m^{-2}, doubling the frog density led to a 2.8-fold increase in pest suppression efficiency, with prey capture rates rising by 47% and pest populations dropping by 31% over 10 days.

A similar density-dependent trend was observed in predator populations, with percentage reductions increasing from 1.09 to 6.95% for *E. adolfi* and from 1.30 to 5.79% for *D. stomaticus* as densities increased from 4 to 16 individuals 24 m^{-2} (Table 3). At the highest density of 16 frogs 24 m^{-2}, *E. adolfi* significantly ($p \leq 0.05$) reduced insect pest populations by 18.79% and beneficial predator populations by 6.95% compared to control plots. In contrast, *D. stomaticus* achieved reduction of 9.69% in pest populations and 5.79% in predator populations at same density. These findings demonstrate a positive correlation between anuran density and pest suppression, suggesting that increasing frog populations can enhance biological pest control in agroecosystems (Smith *et al.,* 2021; Chen and Ramirez, 2024). Liang *et al.* (2024) reported that individual *E. adolfi* can consume up to 150 planthoppers (*Nilaparvata lugens*) per night approximately, resulting in 30% reduction in rice field pest densities. This high predation capacity highlights the efficacy of *E. adolfi* as a potent biocontrol agent, particularly against soft-bodied insect pests vulnerable to amphibian predation (Gurr *et al.,* 2023).

The use of anurans in Integrated Pest Management (IPM) represents an environmentally sustainable alternative to chemical pesticides. Unlike chemical pesticides, which broadly reduces both pest and beneficial predator populations, anuran predation is more selective, maintaining ecosystem balance and preventing problems such as biodiversity loss and pesticide resistance (Zhang *et al.,* 2021). Pesticide treatments caused a mean reduction of 63.86% in overall pest populations but also resulted in a 32.53% decline in predator populations, indicating a non-selective impact (Kumar *et al.,* 2023). In contrast, anuran predation a density of 16 frogs 24 m^{-2} reduced pest populations by 18.79%, while limiting reduction in beneficial predator populations to a maximum of 6.95% (*E. adolfi*) and 5.79% (*D. stomaticus*) (Table 2). Species-specific differences in predation effectiveness, likely influenced by prey size and capture ability, aligns with the results of Valdez (2019), who reported predation rates ranging from 50 to 150 prey items per night per individual. This selective predation helps in preserving natural enemy complexes, supporting long-term pest suppression (Gurr *et al.,*

Table 1: Inventory of pests (herbivores) and predators (carnivores) in rice crop

Scientific name	Common name	Family	Order
Scientific name	Common name	Family	Order
Nilaparvata lugens (Stål 1854)	Brown planthopper		
Sogatella furcifera (Horváth 1899)	White backed planthopper	Delphacidae	Hemiptera
Leptocorisa acuta (Thunberg 1783)	Rice gundi bug	Alydidae	
Cnaphalocrocis medinalis (Guenée 1854)	Rice leaf flder	Crambidae	Lepidoptera
Scirpophaga incertulas (Walker 1863)	Yellow stem borer	Pyralidae	
Oxya hyla (Serville 1831)	Rice grasshopper		
Trilophidia annulata (Thunberg 1815)	Band-winged grasshopper	Acrididae	
Eucriotettix tricarinatus (Bolivar 1887)	Ground hopper	Tetrigidae	Orthoptera
Atractomorpha crenulata (Fabricius 1793)	Tobacco grasshopper	Pyrgomorphidae	
Predators (carnivores)			
Cheilomenes septempunctata (Linnaeus 1758)	Lady bird beetle	Coccinellidae	Coleoptera
Cheilomenes sexmaculata (Fabricius 1781)			
Crocothemis servilia (Drury 1773)	Dragonfly	Libelluidae	Odonata
Ischnura hastata (Say 1839)	Damselfly	Coenagrionidae	
Tetragnatha javana (Thorell 1890)	Stretch spider		
Leucauge venusta (Walckenaer 1842)	Chard orbweaver spider	Tetragnathidae	
Leucauge argyra (Walckenaer 1842)	Orchard Orbweavers		
Dolomedes fimbriatus (Clerck 1757)	Raft spider	Pisauridae	
Neoscona adianta (Walckenaer 1802)	Bordered orb-weaver	Araneidae	Araneae
Oxyopes salticus (Hentz 1845)	Striped lynx spider	Oxyopidae	
Philodromu spraelustris (Keyserling 1880)	Running crab spider	Philodromidae	
Pardosa milvina (Hentz 1844)	Shore spider	Lycosidae	
Trochosa terricola (Thorell 1856)	Ground wolf spider		

2023). Among herbivorous insect pests and predators, *E. adolfi* at a density of 16 frogs 24 m^{-2} recorded the higher percent reduction against whitebacked planthopper at 35.62%, followed by rice gundi bug at 22.58%, grasshopper at 20.73% and rice leaf folder at 12.35% (Table 2). At same density, *D. stomaticus* showed higher efficacy against the whitebacked planthopper with a 27.25% reduction, while reduction by *E. adolfi* in other pests were comparatively lower (rice gundi bug: 22.58%, grasshopper: 20.73% and rice leaf folder: 12.35%) (Table 2).

These prey-specific preferences likely reflect evolutionary adaptations in anuran feeding behavior, where morphological constraints such as gape size, tongue projection speed, and visual prey detection capabilities determine selective predation patterns. Toledo *et al.* (2007) revealed that gape size directly limits the maximum prey size anuran species can consume, with gape widths ranging approximately 8 mm in small species to over 20 mm in larger species, thereby influencing prey selection and feeding efficiency. Schwenk (2000) highlighted that tongue projection mechanics vary significantly across frog species, with tongue projection speeds ranging 2 to 5 meters per second, which affects capture success on different prey types by enabling rapid prey capture within milliseconds. These morphological and functional traits can be strategically utilized for targeted pest management to maximize biocontrol efficiency, as selective predation reduces non-target impacts and enhances pest suppression sustainability (Valdez, 2019). Pesticide-treated plots exhibited an overall 63.86% reduction in herbivorous insect populations and a 32.53% reduction in predator populations, underscoring the broad-spectrum impact of chemical treatments. The most significant pest reductions were observed in brown planthoppers at 71.19%, rice leaf folders at 70.75%, and whitebacked planthoppers at 66.02%, confirming their effectiveness against major rice pests. Notably, both anuran species had limited impact on rice stem borers, with population reductions of only 6.25% by *E. adolfi* and 2.50% by *D. stomaticus*.

This low efficacy is likely due to the larval stage of stem borers residing inside rice stems, rendering them less accessible to surface-feeding predators (Hocking and Babbitt, 2014; Gurr *et al.* 2023). This limitation underscores the need for complementary pest control strategies within Integrated Pest Management (IPM) programs, wherein anurans effectively target surface-feeding pests while other biological control agents (parasitoids, entomopathogenic fungi) or selective chemical treatments are employed to manage cryptic pest species, thereby ensuring comprehensive pest suppression (Khan *et al.,* 2019; Zhao *et al.,* 2021). *E. adolfi,* semi-aquatic and adapted to flooded rice fields, efficiently navigates submerged vegetation, enabling it to reduce soft-bodied pests like planthoppers and gundi bugs by up to 25.44% and 22.58%, respectively (Table 2). Its ground-level foraging likely explain higher reductions in Orthopterans such as

Table 2: Per cent reduction in population of insect pests of rice crop under different anuran treatments

Treatment	BPH	WBPH	Mean (BPH+ WBPH)	Rice gundi bug	Grasshoppers	Rice Stemborer	Rice leaf folder	Percent reduction over control
Control	-	-	-	-	-	-	-	
Pesticide	71.1 ±0.40^{c}	66.0±0.10^{c}	68.6±0.10^{c}	60.9±0.40^{c}	48.7±0.60^{c}	65.6±0.20^{b}	70.7±0.01^{c}	63.8±0.20
E. adolfi 4	2.7±0.10^{a}	12.7±0.96^{a}	7.7±0.40^{a}	5.1±0.20^{a}	2.5±0.96^{a}	1.2±0.10^{a}	4.0±0.10^{a}	4.7±0.40
8	4.9±0.40^{a}	23.1±0.80^{a}	14.0±0.10^{a}	10.2±0.40^{a}	12.5±0.80^{a}	2.5±0.40^{a}	8.0±0.10^{a}	10.2±0.40
12	7.7±0.40^{a}	30.5±0.10^{a}	19.1±0.20^{a}	18.8±0.60^{a}	16.7±0.56^{a}	5.0±0.20^{a}	10.0±0.20^{a}	14.8±0.36
16	15.2±0.10^{b}	35.6±0.04^{b}	25.4±0.04^{b}	22.5±0.20^{b}	20.7±0.40^{b}	6.2±0.10^{a}	12.3±0.96^{b}	18.7±0.26
D. stomaticus 4	2.7±0.60^{a}	6.4±0.60^{a}	4.5±0.96^{a}	0.6±0.10^{a}	1.2±0.10^{a}	-	1.2±0.20^{a}	2.0±0.10
8	3.3±0.10^{a}	11.7±0.53^{a}	7.5±0.40^{a}	1.2±0.04^{a}	3.7±0.20^{a}	-	3.2±0.56^{a}	3.8±0.40
12	5.3±0.04^{a}	21.6±0.40^{a}	13.4±0.60^{a}	3.8±0.56^{a}	5.0±0.40^{a}	1.2±0.96^{a}	5.0±0.20^{a}	7.0±0.20
16	7.9±0.20^{a}	27.2±0.60^{b}	17.5±0.10^{b}	6.2±0.40^{a}	7.0±0.40^{a}	2.5±0.80^{a}	7.2±0.10^{a}	9.6±0.10

*BPH- Brown plant hopper; *WBPH - White backed plant hopper; *Statistical analysis (ANOVA) showed significant result with p value = 0.05; *Mean value followed by same letter (a,b,c) in the given table above are not significantly different as per Tukey' Test

Table 3: Per cent reduction in population of different predator species under different anuran treatments

Treatments	Dragonfly	Damselfly	Beetles	Spiders	Percent reduction over control
Control	-	-	-	-	-
Pesticide	15.7±0.10^{b}	12.5±0.10^{b}	54.6±0.20^{b}	47.2±0.40^{b}	32.5±0.40
E. adolfi 4	1.1±0.20^{a}	-	2.2±0.40^{a}	0.9±0.40^{a}	1.0±0.50
8	4.7±0.04^{a}	-	2.2±0.10^{a}	3.2±0.20^{a}	2.5±0.10
12	5.9±0.10^{a}	1.2±0.40^{a}	6.2±0.60^{a}	6.6±0.56^{a}	5.0±0.60
16	7.0±0.01^{a}	2.5±0.96^{a}	10.3±0.56^{a}	7.4±0.10^{a}	6.9±0.40
D. stomaticus 4	1.1±0.20^{a}	-	3.1±0.96^{a}	0.9±0.40^{a}	1.3±0.10
8	2.3±0.40^{a}	-	4.6±0.10^{a}	3.2±0.96^{a}	2.5±0.40
12	3.5±0.10^{a}	1.2±0.10^{a}	7.2±0.40^{a}	5.4±0.10^{a}	4.3±0.20
16	5.0±0.10^{a}	2.5±0.20^{a}	9.3±0.20^{a}	6.2±0.10^{a}	5.7±0.20

*Statistical analysis (ANOVA) showed significant result with p value = 0.05; *Mean value followed by same letter (a,b,c) in the given table above are not significantly different as per Tukey' Test

grasshoppers (20.7%) (Liang *et al.,* 2025). In contrast, the more terrestrial *D. stomaticus* showed lower reductions—planthoppers (17.59%) and gundi bugs (6.25%), likely due to limited access to semi-aquatic pests (Singh *et al.,* 2024). These habitat-specific adaptations imply that manipulating water levels and vegetation could optimize biocontrol efficiency in rice systems without compromising yield (Chen and Ramirez, 2024). *E. adolfi,* at 16 frogs 24 m^{-2}, significantly reduced predatory arthropod populations (beetles by 10.93%, spiders by 7.40% and dragonflies by 7.00%), while *D. stomaticus* showed similar but lower reductions of approximately 9.37%, 6.25% and 5.05% for beetles, spiders and dragonflies. In comparison, pesticide treatments caused much larger declines, reducing beetle and spider populations by 54.68% and 47.22%, respectively. The comparatively lower impact of anurans on these beneficial predators likely results from selective feeding preferences and habitat partitioning, as well as behavioral and ecological differences; for example, dragonflies are primarily aerial predators, spending much of their time flying or perched away from the ground, which reduces their vulnerability to ground-foraging frogs (McPeek 2008; Samways, 2011). This selective predation helps conserve natural enemies essential for ecosystem health (Gurr *et al.,* 2023). This differential effect highlights opportunities for temporal and spatial management strategies to minimize predator–predator conflicts during peak pest outbreaks while maintaining year-round biological control services (Gurr *et al.,* 2023).

Insect order analysis revealed that *E. adolfi* was most effective against Orthoptera (20.73% reduction) and Hemiptera (15.76%), while *D. stomaticus* showed its highest efficacy against Coleoptera (9.37%) and Hemiptera (8.41%). These species-specific predation patterns likely stem from differences in prey handling ability, gape size (approximately 18 mm for *E. adolfi* vs. 14 mm for *D. stomaticus*), and foraging behavior. Zhang *et al.* (2023), revealed that larger gape size correlates with increased predation on larger, more mobile prey. Khan *et al.* (2019) reported that anuran predation rates in rice fields vary by insect order, with

Table 4: Mean per cent damage/hill by insect pests during rice crop period

Treatment	Rice stem borer		Rice leaf folder		Grasshopper	
	Percent damage/hill	**Percent reduction over control**	**Percent damaged leaves/hill**	**Percent reduction over control**	**Percent damaged leaves/hill**	**Percent reduction over control**
Control	5.9±0.10^{a}	-	3.5±0.40^{a}	-	4.9±0.10^{a}	-
Pesticide	1.6±0.20^{b}	72.5±0.10	2.1±0.30^{b}	38.1±0.10	2.4±0.10^{c}	51.8±0.04
E. adolfi 4	5.9±0.10^{a}	1.1±0.10	3.4±0.20^{a}	3.1±0.20	4.8±0.20^{a}	1.8±0.40
8	5.8±0.40^{a}	1.8±0.20	3.3±0.10^{a}	5.2±0.20	4.6±0.10^{a}	6.9±0.20
12	5.8±0.96^{a}	2.5±0.40	3.2±0.20^{a}	7.3±0.40	4.4±0.40^{a}	10.4±0.56
16	5.7±0.40^{a}	4.6±0.56	3.2±0.40^{a}	9.3±0.20	4.2±0.60^{b}	15.4 ±0.96
D. stomaticus 4	5.9±0.20^{a}	0.6±0.40	3.4±0.56^{a}	3.3±0.10	4.9±0.01^{a}	1.4±0.40
8	5.9±0.01^{a}	0.8±0.20	3.4±0.10^{a}	4.0±0.60	4.8±0.10^{a}	2.5±0.10
12	5.8±0.10^{a}	1.5±0.20	3.3±0.20^{a}	5.3±0.56	4.7±0.10^{a}	4.6±0.20
16	5.8±0.40^{a}	2.1±0.10	3.3±0.10^{a}	5.9±0.40	4.7±0.40^{a}	5.0 ±0.20

*Statistical analysis (ANOVA) showed significant result with p value = 0.05; *Mean value followed by same letter (a,b,c) in the given table above are not significantly different as per Tukey' Test

Orthoptera and Hemiptera being the most susceptible to amphibian predation due to their relatively slower movement and surface dwelling habits. Understanding these selective feeding patterns enables the development of tailored release strategies that optimize pest suppression by matching anuran species with dominant pest communities in different rice production environments (Gurr *et al.,* 2023).

Crop damage assessments demonstrated both anuran species reduced pest damage, with *E. adolfi* showing greater efficacy (4.68–15.46% reduction) than *D. stomaticus* (2.17–5.93% reduction) (Table 4). Notably, *E. adolfi* significantly reduced grasshopper damage by 15.46% at 16 frogs 24 m^{-2}. Pesticide treatments resulted in higher damage reductions (72.57% for rice stem borer and 51.80% for grasshopper). Although pesticides provide rapid and large scale reductions, the significant, albeit modest, damage suppression by anurans support their role as sustainable long term pest control agents without environmental harm (Valdez, 2019; Kumar *et al.,* 2024). The economic threshold analysis suggests that while anuran mediated damage reduction may not match chemical control in magnitude, the cumulative benefits including reduced input costs, enhanced ecosystem services, and improved long term sustainability may provide superior cost benefit ratios over multiple cropping cycles (Smith *et al.,* 2025). These quantitative damage assessments provide essential baseline data for developing economic injury levels and action thresholds specific to anuran biocontrol programs, enabling farmers to make informed decisions about intervention timing and intensity.

Both species exhibited density dependent effects, with *E. adolfi* consistently more efficient. This suggests that increasing anuran densities can enhance pest control without adversely impacting beneficial predator populations, balancing pest suppression and conservation in rice ecosystems (Gurr *et al.,* 2023). Recent studies also highlight the rising importance of amphibians in agroecosystems as multifunctional agents, contributing to ecosystem resilience and biodiversity conservation (Smith *et al.,* 2025). Incorporating anurans in IPM thus aligns with sustainable agricultural practices promoting ecological balance and pest regulation. However, optimal density thresholds must be carefully determined to avoid potential negative effects such as increased competition for resources, territorial conflicts, or excessive predation pressure that could destabilize existing ecological relationships (Peltzer *et al.,* 2022).

Our study reveals the potential of anurans, particularly *E. adolfi,* as effective biological control agents in rice ecosystems. While not as immediately impactful as chemical pesticides, anurans offer a more balanced approach to pest management, reducing pest populations without severely affecting beneficial predators and environment and can be used in Integrated Pest Management strategies thus, could contribute to sustainable and ecologically sound rice cultivation, potentially reducing reliance on chemical pesticides.

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