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Research Article

Comparative predatory potential of frog, *Euphlyctis adolfi* (Anura: Dicroglossidae) and toad, *Duttaphrynus stomaticus* (Anura: Bufonidae) against major insect pests of rice crop

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Abstract: Present study covers comparative feeding potential and functional response of frog (*Euphlyctis adolfi*) and toad (*Duttaphrynus stomaticus*) (Amphibia: Anura) against major rice insect pests (*Nilaparvata lugens*, *Sogatella furcifera, Oxya hyla, Trilophidia annulata* and *Conocephalus longipennis*) during 2022 and 2023 under laboratory conditions. *Euphlyctis adolfi* demonstrated the highest feeding potential, consuming 3.00 to 27.33 insects across all prey species under investigation, while that of *D. stomaticus* was invariably lower as a consequence of poor capture success on larger and more evasive grasshopper species. Functional response analysis showed a Type II, hyperbolic response for both anuran species, although *E. adolfi* displayed significantly higher values of attack rate (0.723–0.981 h^{-1}) and lower handling time (0.032–0.045 h^{-1}) as compared to *D. stomaticus*. *E. adolfi* was 14.29-98.54% more efficient for attaining the theoretical maximum rate of predation. Species-specific variability in predatory performance was attributed to differences in morphological adaptations, hunting strategies and ecological preferences. These findings further underscore the value of conserving diverse anuran communities within rice agroecosystems to support sustainable Integrated Pest Management practices. From the present study, *E. adolfi* emerged as an effective and eco-friendly predator having the potential to act as a biological control agent in managing insect pests of rice crop and reduce usage of pesticides.

Keywords: Biocontrol, frog, predation, rice, sustainability

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INTRODUCTION

Anurans, which include toads and frogs, are members of the order Anura within the class Amphibia and are classified into approximately 50 families. They are the most diverse and ecologically significant amphibians worldwide, with more than 7,600 species adapted to diverse environments from tropical rainforests to arid deserts. India, a biodiversity hotspot, harbours approximately 447 anuran species, representing about 5.9% of global diversity (Dinesh *et al.,*2023). Anurans inhabit a wide range of ecosystems across India, from the Western Ghats and the Himalayas to the northeastern plains.

In rice agroecosystems, anurans play a crucial role in pest control and maintaining ecological balance. The 21st century has introduced significant challenges to global agriculture, including the need to feed a growing population while minimising environmental impact. Rice, a staple food crop, faces substantial losses due to insect pests, which account for 10-20% of annual rice loss worldwide (Heong & Hardy, 2009). There is an urgent need for sustainable pest management strategies that protect crop yields with minimal environmental harm.

Traditional Asian farming systems have long recognized the role of frogs in natural pest control. Recent research has begun to quantify how frogs contribute to pest management in rice fields (Ma *et al.,*2024). This interest is timely, as concerns about the environmental and health impacts of chemical pesticides drive the search for alternative pest control methods (Lou *et al.,*2014). Studies have demonstrated that some frog species can consume up to 200 insects per day (Hocking & Babbitt, 2014).

Frogs possess unique adaptations that enhance their predatory efficiency. Their adhesive tongues and varied hunting techniques allow them to capture a wide range of prey sizes, both in water and on land, making them versatile predators in rice fields (Jolly *et al.,*2015). Temporal overlap between predator and prey populations is crucial for effective biological control. Research in Nepal indicates that frogs in rice fields are associated with reduced populations of pests

like planthoppers and leafhoppers (Khatiwada *et al.,*2016). Frogs act as mesopredators, regulating both pest and beneficial insect populations, which contributes to a more stable agroecosystem (Weterings *et al.,*2018). Unlike broad-spectrum chemical pesticides, frog predation is selective, targeting only pest species and helping to maintain ecological balance.

However, practices such as chemical pesticide use and intensive tillage can reduce frog populations in rice fields. A holistic agricultural approach is needed to integrate crop production with biodiversity conservation. For instance, the Japanese tree frog (*Hyla japonica*) has been identified as an effective biocontrol agent against planthoppers in rice fields due to its ability to climb plants and capture prey (Ohba & Nakasuji, 2006). Anurans also contribute to nutrient cycling, water quality regulation, and carbon sequestration (Hocking & Babbitt, 2014). As global agriculture faces challenges in food security and environmental sustainability, the natural pest control services provided by frogs and other beneficial organisms will be increasingly important. Future research should focus on integrating frog-friendly practices into agricultural systems and exploring the economic benefits of frog-mediated pest control. The present study aims to evaluate the predatory potential of frogs and toads against major rice insect pests, to enhance Integrated Pest Management (IPM) strategies for sustainable agriculture.

MATERIALS AND METHODS

Rearing of insects

Brown plant hopper (*Nilaparvata lugens*), white backed plant hopper (*Sogatella furcifera*) and grasshoppers (*Trilophidia annulata*, *Oxya hyla* and *Conocephalus longipennis*) were selected due to their significance as important rice insect pests at the global level (Plate 1). These insects were collected from nearby rice crop fields using an aspirator (30 × 0.9 cm) and a scoop net (90 cm rod length and 40 cm loop diameter with a collapsible nylon bag). They were further reared under laboratory conditions at the Entomology Research Farm, Department of Entomology, Punjab Agricultural University, Ludhiana.

The insects were housed in rectangular iron bar cages (0.68 x 0.50 x 0.50 m) covered with nylon mesh (40 mesh size) on all sides and open at the top. The cages were tied with cotton thread at the top to prevent escape. Pots (8 inches in diameter) with 30-day-old TN1 (Taichung Native 1) rice plants were placed inside the cages, which were set in concrete troughs (410 × 60 × 15 cm) filled with water to deter ants. Water in the troughs was changed regularly (Singh *et al.,*2022). For grasshoppers, plastic trays (40 × 35 × 8 cm) with 30-day-old rice plants were used (Harchli *et al.,*2015). Freshly emerged adults from these cultures were selected for further experiments.

Anurans as predators of insect pests in rice crop

Adult anurans, *Duttaphrynus stomaticus* and *Euphlyctis adolfi*, weighing 12.0-19.05 g and 18.80-25.6 g, respectively, were used in the study. Anurans were collected using a scoop net (90 cm rod length and 40 cm loop diameter with a collapsible nylon bag) from ponds at the College of Fisheries, Guru Angad Dev Veterinary and Animal Science University (GADVASU), Ludhiana, rice fields and nearby residential areas.

Assessment of Anurans predatory potential

The anurans were placed in split cages (60.5 × 41 × 42.5 cm) containing plastic trays (40 × 35 × 8 cm) with 30-day-old TN1 rice plants under laboratory conditions at Entomology Research Farm, Department of Entomology, Punjab Agricultural University, Ludhiana.

The experiment was conducted over two years (2022 and 2023) with different predator-prey ratios of 1:4, 1:9, 1:16, 1:25 and 1:36. The number of insects offered as prey was counted before release into the split cage and again after 24 hours to determine prey consumption. Each anuran species was starved for 24 h prior to the experiment and allowed to feed on prey insects for 24 h at different predator-prey ratios. Prey consumption, attack time, handling time and maximum predation rate were recorded using Rogers' equation. Each treatment was replicated six times, and the experiment was conducted twice per year.

Statistical analysis

Thedata on functional responsewere subjected to logistic regression analysis to determine the type of functional response (Type I, Type II, or Type III) exhibited by the predator-prey interaction between the consumed prey and the offered prey density. The logistic regression equation was calculated using the following formula:

$$Na/N = \exp(p0 + p1N + p2N^2 + p3N^3) / (1 + \exp(p0 + p1N + p2N^2 + p3N^3)$$

where:
Na = Number of prey consumed
N = Prey density
p0 = Intercept or constant
p1 = Linear coefficient
p2 = Quadratic coefficient
p3 = Cubic coefficient

Exhibiting a Type I functional response implies that the predator's handling time against the prey is zero, and the predator does not have a satiation point for predation on the



Nilaparvata lugens



Sogatella furcifera



Trilophidia annulata



Oxya hyla



Conocephalus longipennis

Plate 1. Species of insects reared.

prey. However, this is considered highly unrealistic and can only be explained theoretically, as it is challenging to observe in real-time experiments.

After fitting the predation data to the logistic regression model, if the linear coefficient (p1) is found to be significantly negative, it indicates a Type II or Type III functional response. The data were subjected to Rogers' Random Predator Equation (Rogers,1972) for Type II functional response to estimate the parameters of the functional response. The equation is as follows:

$$Na = N[1 - \exp(aThNa - aT)]$$

where:
Na = Number of prey consumed per predator
N = Prey density offered to one predator
T = Total time (duration of the experiment)
Th = Handling time (time required by one predator to pursue, kill and digest prey)
a = Attack rate

RESULTS

Feeding potential of anurans

The feeding potential of two anuran species, *Euphlyctis adolfi* and *Duttaphrynus stomaticus*, was assessed against major rice insect pest species (*Nilaparvata lugens*, *Sogatella furcifera*, *Oxya hyla*, *Trilophidia annulata* and *Conocephalus longipennis*) during 2022 and 2023 (Plate 2).

For *N. lugens* and *S. furcifera*, prey consumption increased as prey density rose from 4 to 36 individuals. For *E. adolfi*, consumption rates for *N. lugens* ranged from 3.33 ± 0.25 to 27.33 ± 0.34 and for *S. furcifera* from 3.00 ± 0.18 to 17.33 ± 0.40 in 2022, and from 3.17 ± 0.23 to 23.83 ± 4.95 and from 3.33 ± 0.23 to 20.67 ± 0.47 in 2023, respectively. The proportion of prey consumed decreased as prey density increased, from 0.83 to 0.76 for *N. lugens* and from 0.75 to 0.48 for *S. furcifera* during 2022 and 2023 (Figures 1 and 2).

For *D. stomaticus*, prey consumption ranged from 3.00 ± 0.18 to 23.00 ± 1.07 and from 3.00 ± 0.01 to 20.67 ± 3.30 for



Plate 2. *E. adolfi* approaching and feeding on *O. hyla.*

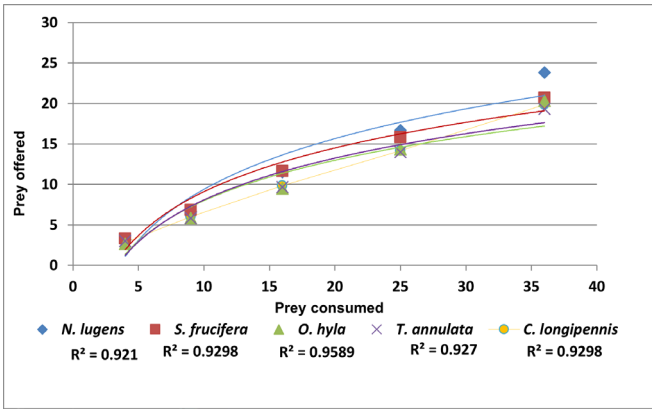


Figure 1. Functional response of *E. adolfi* against different insect pests during 2022.

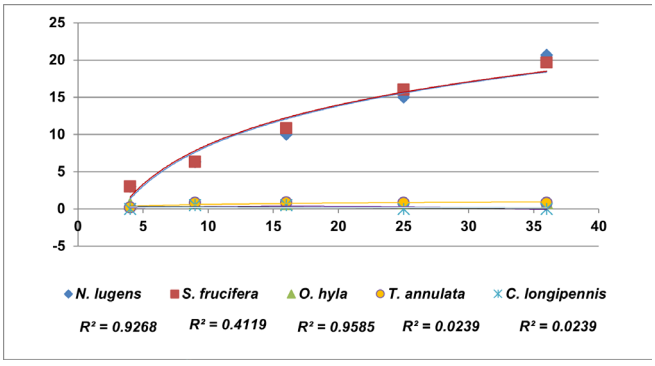


Figure 2. Functional response of *E. adolfi* against different insect pests during 2023.

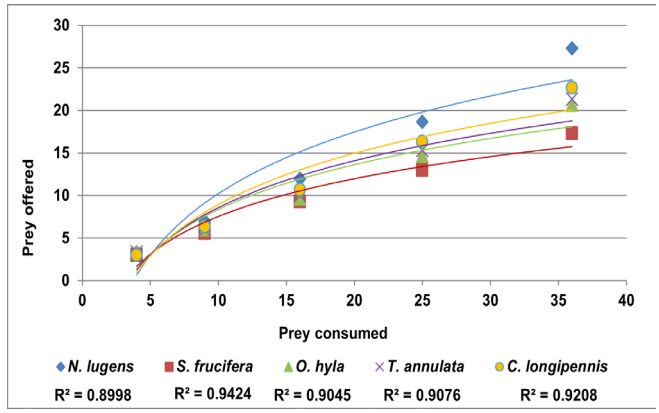


Figure 3. Functional response of *D. stomaticus* against different insect pestsduring 2022.

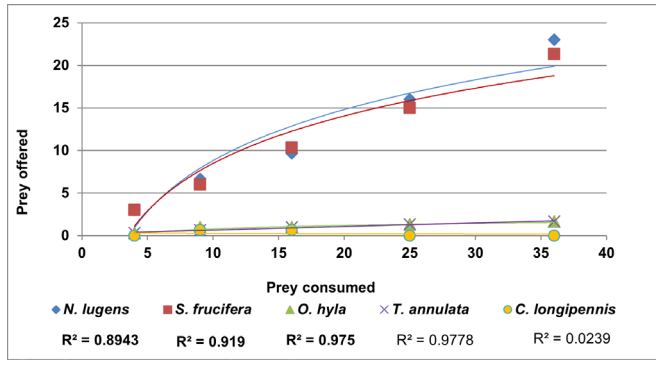


Figure 4. Functional response of *D. stomaticus* against different insect pestsduring 2023.

N. lugens and from 3.00 ± 1.12 to 21.33 ± 0.18 and from 3.00 ± 0.01 to 19.67 ± 2.35 for *S. furcifera* during 2022 and 2023. The proportion of prey consumed decreased from 0.75 to 0.63 for *N. lugens* and from 0.75 to 0.59 for *S. furcifera* over the same period.

For *O. hyla*, *E. adolfi* consumed more prey as density increased, from 3.33 ± 1.11 to 20.67 ± 0.98 and from 2.67 ± 0.47 to 20.34 ± 0.47. The proportion of prey consumed decreased from 0.83 to 0.57 and from 0.66 to 0.56 during 2022 and 2023, respectively. Conversely, *D. stomaticus* consumed very few *O. hyla* individuals, showing proportions of 0.08 to 0.04 and 0.16 to 0.02 in 2022 and 2023, respectively.

For *T. annulata* and *C. longipennis*, *E. adolfi* exhibited higher consumption rates compared to *D. stomaticus*. Consumption of *T. annulata* ranged from 3.33 ± 0.50 to 21.33 ± 0.45 and from 3.00 ± 0.47 to 19.33 ± 2.83. For *C. longipennis*, it ranged from 3.00 ± 0.50 to 22.67 ± 1.21 and from 2.83 ± 0.24 to 19.84 ± 4.01. In contrast, *D. stomaticus* consumed fewer *T. annulata* and *C. longipennis* individuals, with very low proportions of prey consumed (0.08 to 0.04 and 0.07 to 0.00 for *T. annulata* and *C. longipennis*, respectively (Figures 3 and 4).

Regression coefficients of functional response

To determine the type of functional response (Type I, II, or III), logistic regression was performed on the proportion of prey consumed by *E. adolfi* and *D.stomaticus* at various prey densities.

A Type I functional response, characterised by a linear increase in consumption with prey density, is rare and usually observed in filter feeders. A Type II response featured an initial rapid increase in consumption, which then levels off due to constraints such as handling time or satiation. Type III response shows a sigmoid curve with slow initial consumption, rapid increase at intermediate densities and levelling off at high densities.

The logistic regression analysis indicated that both anuran species exhibited a Type II functional response, as evidenced by significantly negative linear coefficients for both species across all prey types in 2022 and 2023. For *E. adolfi*, the linear coefficients ranged from -0.11 (for *S. furcifera*) to -0.25 (for *T. annulata*) in 2022 and from -0.32 (for *C. longipennis*) to -21.66 (for *T. annulata*) in 2023.

For *D. stomaticus*, linear coefficients were negative and significant for *N. lugens*, *S. furcifera* and *O. hyla* but non-significant for *T. annulata* and *C. longipennis*. The coefficients ranged from -3.99 to -28.10 during 2022 and from -2.19 to -17.70 during 2023.

Functional response parameters

In 2022, *E. adolfi* had the highest attack rate of 0.953 h^{-1} for *N. lugens*, compared to 0.876 h^{-1} for *D. stomaticus*. The handling time was lowest for *E. adolfi* (0.032 h^{-1}), resulting in the highest theoretical maximum predation rate of 31.25 h^{-1}. *E. adolfi* exhibited a 15.77% higher theoretical maximum predation rate than *D. stomaticus*. For *S. furcifera*, *E. adolfi* also demonstrated a higher attack rate (0.912 h^{-1}) and theoretical maximum predation rate (24.39 h^{-1}), with a 19.59% increase over *D. stomaticus*.

Against *O. hyla*, *T. annulata*, and *C. longipennis*, *E. adolfi* consistently showed superior results, with attack rates ranging from 0.785 to 0.912 h^{-1} and lower handling times (0.039 to 0.041 h^{-1}), leading to higher maximum predation rates (23.81 to 25.64 h^{-1}). In contrast, *D. stomaticus* had lower attack rates and higher handling times, resulting in lower maximum predation rates. *E. adolfi* showed a 93.02% to 98.71% higher theoretical maximum predation rate than *D. stomaticus*.

In 2023, similar trends were observed, with *E. adolfi* having the highest attack rate (0.894 h^{-1}) and the lowest handling time (0.036 h^{-1}) for *N. lugens*, resulting in a 14.29% higher theoretical maximum predation rate than *D. stomaticus*. For *S. furcifera*, *E. adolfi* also had the highest attack rate (0.981 h^{-1}) and theoretical maximum predation rate (23.81 h^{-1}), showing a 4.53% increase over *D. stomaticus*. Against *O. hyla*, *T. annulata*, and *C. longipennis*, *E. adolfi* maintained better performance with higher attack rates (0.723 to 0.796 h^{-1}), lower handling times (0.043 to 0.045 h^{-1}) and higher theoretical maximum predation rates (22.22 to 23.26 h^{-1}). *D. stomaticus* showed reduced efficiency, with lower attack rates and higher handling times (Table 1).

DISCUSSION

In this study, *E. adolfi* demonstrated a high feeding potential, consuming between 3.00 and 27.33 insects across all prey types. In comparison, *D. stomaticus* showed variable consumption rates, ranging from 0 to 23.00 insects. *D. stomaticus* was more effective at consuming *N. lugens* and *S. furcifera* (3.00 to 23.00 insects) but less efficient with *O. hyla*, *T. annulata* and *C. longipennis* (0 to 1.66 insects). These differences are linked to anatomical and behavioural traits. Toads, like *D. stomaticus*, have smaller mouths and weaker jaws, making it challenging for them to capture and subdue agile prey such as grasshoppers. Their ambush strategy works well for sedentary insects but is less effective for more mobile grasshoppers (Blaustein *et al.,*2012). Conversely, frogs like *E. adolfi* have larger mouths and stronger jaws, allowing them to capture a wider range of prey. They are also active hunters, which enhances their ability to capture both plant hoppers and grasshoppers (Duellman & Trueb, 1994; Vitt & Caldwell, 2014). Grasshoppers are more challenging to catch due to their agility and escape mechanisms (Grillo, 2011; Pough *et al.,*2004). Previous studies have shown that some anurans, such as the European green toad (*B. tesviridis*),

Table1. Parameters of functional response of two anuran species against different insect pests of rice crop during the years 2022 and 2023

S.no	Prey species	*E. adolfi*			*D. stomaticus*		
		Attack rate (a)(h^{-1})	Handling time (Th) (h^{-1})	Maximum predation rate (T/Th)	Attack rate (a)(h^{-1})	Handling time (Th)(h^{-1})	Maximum predation rate (T/Th)
2022							
1	*N. lugens*	0.953	0.032	31.25	0.876	0.038	26.32
2	*S. furcifera*	0.912	0.041	24.39	0.792	0.050	19.61
3	*O. hyla*	0.785	0.040	23.81	0.142	0.603	1.66
4	*T. annulata*	0.889	0.041	24.39	0.123	0.601	1.66
5	*C. longipennis*	0.912	0.039	25.64	0.087	1.515	0.66
2023							
6	*N. lugens*	0.894	0.036	27.78	0.832	0.045	23.81
7	*S. furcifera*	0.981	0.042	23.81	0.876	0.044	22.73
8	*O. hyla*	0.723	0.043	23.26	0.189	0.936	1.05
9	*T. annulata*	0.796	0.045	22.22	0.110	1.135	0.88
10	*C. longipennis*	0.761	0.044	22.73	0.08	2.00	0.50

Overall, *E. adolfi* demonstrated consistently higher predatory potential compared to *D. stomaticus*, particularly against grasshopper species.

are effective at controlling grasshopper populations (Pope, 2008). Similarly, Japanese brown frogs (*R. rugosa*) consume a significant number of grasshoppers, particularly during their breeding season (Hirai & Matsui, 2000). Research by Hopkins (2007) highlights the role of anurans in pest control by consuming various insect pests.

As prey density increased from 4 to 36, the proportion of prey consumed decreased for all anuran species. This is due to the anurans' limited feeding capacity. As they consume more prey, their appetite, stomach capacity and digestion rate reach a threshold, reducing their consumption rate despite increased prey availability (Falaschi *et al.,*2020). Fatigue and slower digestion can further limit consumption, leading to a lower proportion of prey consumed. Logistic regression analysis of prey consumption relative to prey density revealed a significant negative linear coefficient for both *E. adolfi* and *D. stomaticus*, confirming a Type II functional response. This finding is consistent with studies by Ananjeva *et al.*(2015) and Corn (2005), who reported Type II responses in other anuran species.

E. adolfi showed higher attack rates (0.785 to 0.953 h^{-1} in 2022 and 0.723 to 0.981 h^{-1} in 2023), lower handling times (0.032 to 0.041 h^{-1} in 2022 and 0.036 to 0.045 h^{-1} in 2023) and higher theoretical maximum predation rates (23.81 to 31.25 prey/h in 2022 and 22.22 to 27.78 prey/h in 2023) compared to *D. stomaticus*. *E. adolfi* had a 14.29 to 31.90% higher theoretical maximum predation rate for *N. lugens* and *S. furcifera* compared to *D. stomaticus*. *D. stomaticus* displayed lower efficiency against grasshoppers (*O. hyla*, *T. annulata* and *C. longipennis*), with attack rates as low as 0.087 h^{-1}, handling times up to 1.51 h^{-1}, and theoretical maximum predation rates as low as 0.66 h^{-1}. In contrast, *E. adolfi* demonstrated 93.02-98.71% higher theoretical maximum predation rates against these grasshopper species. These findings support the concept of size-dependent predation in amphibians (Solé & Rödder, 2010). Similar trends in attack rates and handling times have been observed in other predatory species (Egea-Serrano, 2012; Zakaria *et al.,*2016). Singh (2022) also found Type II functional responses in syrphid species, aligning with the results of this study. Utilising the natural predatory abilities of species like *E. adolfi* can contribute to more sustainable and environmentally friendly agricultural practices.

CONCLUSION

The study revealed that the anurans, frogs and toads also contribute to the biological control of insect pests in rice crop**.** *Euphlyctis adolfi* emerged as an effective and eco-friendly predator anuran species having the potential to serve as a biological control agent against major insect pests of rice crop, which further helps to reduce usage of pesticides and may be integrated as a component in organic farming. Studies on field validation of these anurans as biocontrol agents against rice pests is to be carried out to further support their potential in as an effective biocontrol agents against rice insect pests.

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