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A novel nesting behaviour of a treefrog, *Rhacophorus lateralis* in the Western Ghats, India

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Nest building by leaf folding is a rare behaviour in anuran amphibians, with previous reports for only two genera, the Sub-Saharan African *Afrixalus*, and Central and South American *Phyllomedusa*. This communication reports a specialized nest building behaviour of an Indian treefrog *Rhacophorus lateralis*, which was observed in natural habitat at Kalpetta in Wayanad District, Kerala. This behaviour of leaf folding is the first report in the family Rhacophoridae, and in the Asiatic amphibians. Nesting behaviour of *R. lateralis* is

unique among *Rhacophorus* – a purse-like nest is made over water by folding a single leaf around the egg mass (embryos and translucent foam) by the female alone after oviposition. The function of this parental investment is to prevent desiccation of eggs in open sunlight. This paper also documents the multiple leaf nesting behaviour of other two species of this genus, *R. calcadensis* and *R. pseudomalabaricus*, and the previously documented nesting behaviour of *R. malabaricus* using more than one leaf.

Keywords: Leaf folding, leaf nesting, *Rhacophorus lateralis*, treefrog, Western Ghats.

IN addition to typical aquatic habitats, anuran amphibians deposit eggs in a wide range of places including underground¹, arboreal foam nests², tree holes³ and stream banks⁴. Among the 262 anuran amphibians reported from India⁵, above-ground nest construction using multiple leaf is known only in *Rhacophorus malabaricus*⁶.

Rhacophorus lateralis is a small sized Rhacophoridae treefrog (snout to vent size-male: 28.6–30.1 mm, $N = 5$; female: 33.5–34.8 mm, $N = 3$) having bright green or light reddish-green dorsal colour with a prominent golden yellowish streak from snout along the side of head to near the vent. Scientific knowledge on *R. lateralis* is sparse other than the original description based on a sole preserved animal⁷, followed by rediscovery after a gap of more than 100 years from the Western Ghats of Kerala⁸ and Karnataka⁹. *Rhacophorus lateralis* is an endangered species¹⁰, thus a better understanding of the breeding biology of this frog is critical for its conservation management.

A breeding population of *R. lateralis* was observed over two breeding seasons during which courtship, mating and leaf nesting behaviour were studied. The primary objective of this communication is to document leaf nest construction behaviour of *R. lateralis* and determine the possible function of this behaviour based on field observations and laboratory studies. The complete sequence of courtship and mating behaviour of this species is beyond the scope of this communication. This study is based on observation of 65 nests, including nine sequences from pair detachment after oviposition to completion of leaf nesting.

The study was conducted during 2000 and 2005 breeding seasons (June–September) at Kalpetta (11°36'N, 76°05'E; 980 m asl), Wayanad District, Kerala. Amplexed pairs were located by active searching guided by choruses or by making repeated observations of single females until they mated. Amplexus is axillary and duration of egg laying varies from 35 to 50 min ($N = 9$). Fieldwork was undertaken at a natural breeding pool between 19:00 and 23:00 h using a dim or red flashlight. The pool was 3.2 m wide and had a maximum depth of 0.9 m. Grasses, low herbs (*Ludwigia* sp., *Lantana* sp., *Chromolaena* sp., etc.).

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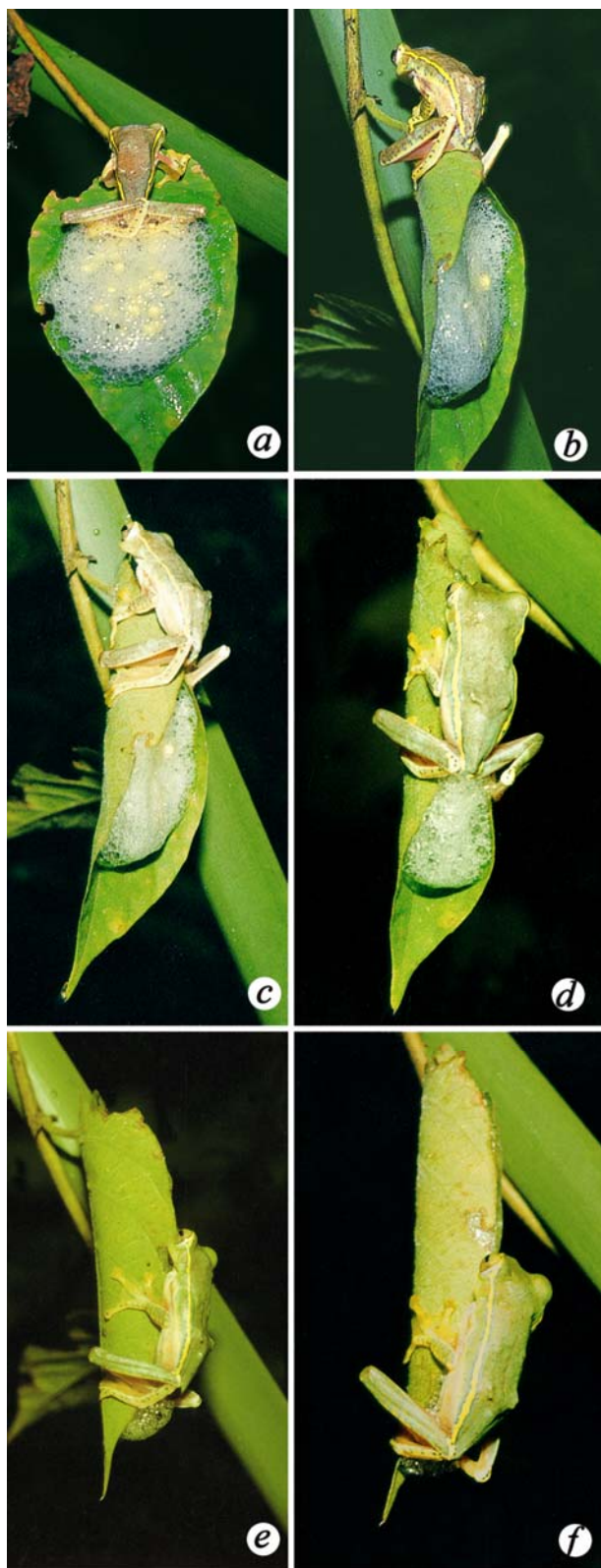


Figure 1. Arboreal nesting sequence of a female *Rhacophorus lateralis*. *a, b*, Stage 1: *a*, Female after detachment from male on the foam nest tugging at leaf margins using fore limbs; *b*, Folding and holding the petiole end of the leaf using both limbs; *c, d*, Stage 2: *c*, Moving down and folding the leaf using both limbs; *d*, Completing half of the leaf nest; *e-f*, Stage 3: *e*, Finishing leaf folding to the leaf tip; *f*, Completed leaf nest and female just before moving away from the nest.

and climbers (*Merremia umbellata*) were found in and around the pool.

The spawning behaviour of nine pairs of *R. lateralis* was observed beginning with amplexus and continuing until separation of the male following spawning, and female leaving the oviposition site after nest construction. Oviposition and fertilization occurs on a single leaf, after which the male leaves the female alone to roll the leaf containing foam and eggs into a purse-like nest (Figure 1). Nest building can be divided into three stages based on the major events and female resting periods, and these are shown in Figures 1 and 2. In stage 1, female tugs at the petiole end of the leaf margins using her forelimbs (Figure 1 *a*) and fastens their edges with viscous foam (Figure 1 *b*). While the female was firmly tugging at the leaf margins, its thighs were at right angle to its body and there were contractions of its abdominal wall (Figure 1 *a*). The female was in this position for about 3 min (Figure 1 *b*). In stage 2, the female descends and sticks the leaf margins using both limbs (Figure 1 *c* and *d*) and holds the folded leaf for 1 min. In stage 3, female moves further down towards the distal end, folds the remaining leaf

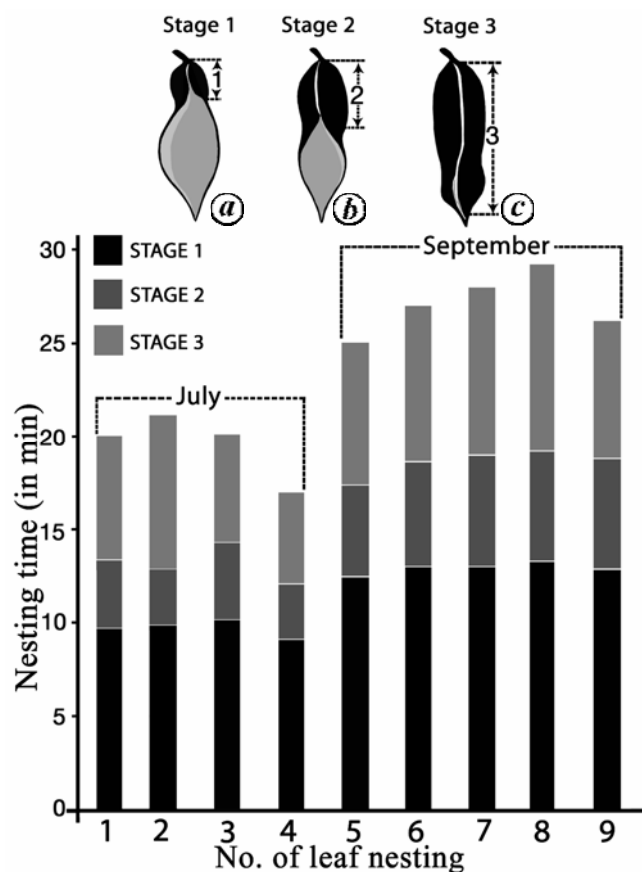


Figure 2. Leaf nesting duration in three stages of nine episodes of *Rhacophorus lateralis* at Kalpetta in July and September. *a-c*, Schematic sketches of leaf folding stages: *a*, Stage 1: Initial sealing of leaf margins just below the petiole; *b*, Stage 2: Leaf folding almost at half leaf length; *c*, Leaf folding completed to leaf tip.

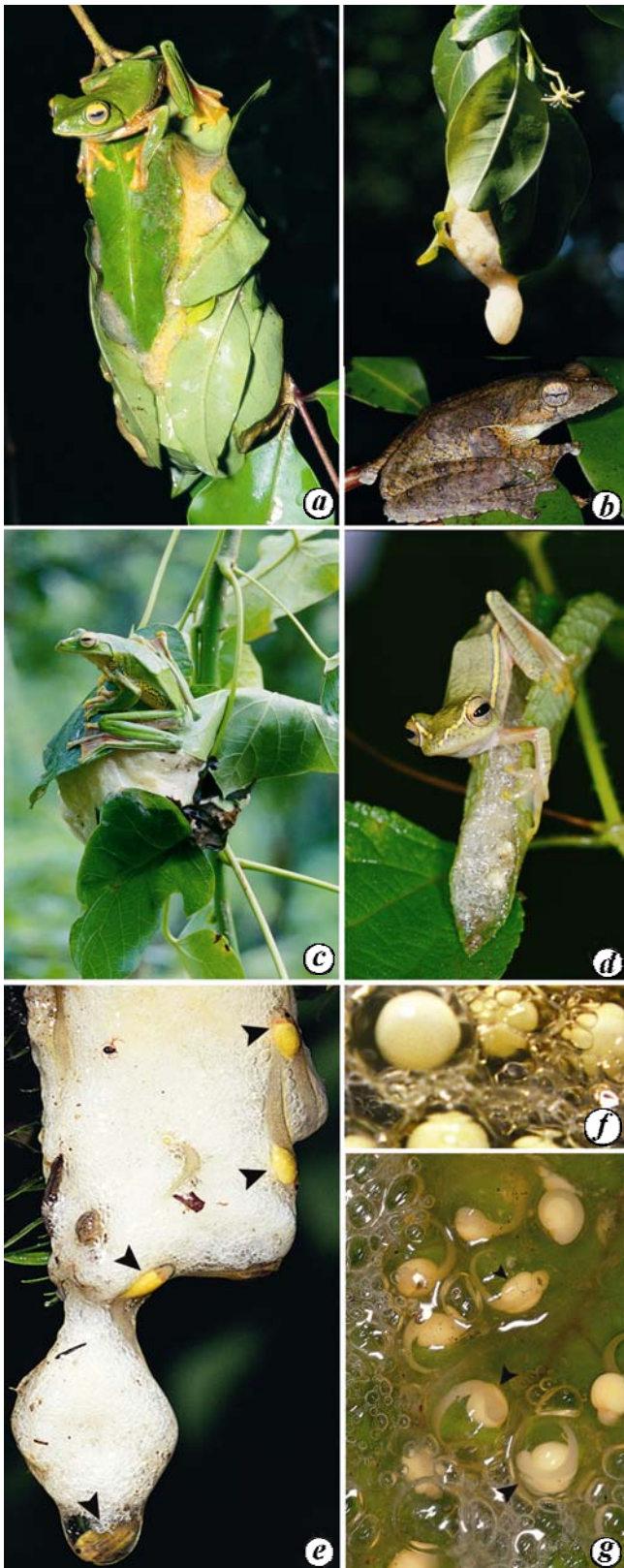


Figure 3. *a–d*, Leaf nesting of four members of the genus *Rhacophorus*. *a–c*, Multiple leaf nests. *a*, *R. pseudomalabaricus*; *b*, *R. calcadensis*; *c*, *R. malabaricus*; *d*, *R. lateralis* single leaf nest; *e–g*, Eggs inside the foam. *e*, *R. malabaricus* (thick foam with arrow marks showing developed embryos after 40 h); *f*, *R. lateralis* (fresh eggs and loose foam); *g*, *R. lateralis* (loose foam with arrow marks showing embryo development after 40 h).

edges right up to the tip, and firmly holds the folded leaf for about 2 min (Figure 1 *e* and *f*). In general, just after completion of nest construction the female jumped into nearby vegetation from the lower end of the rolled leaf, except on one occasion, when the female ascended the folded leaf nest and repeatedly pressed the leaf margins once again before jumping into nearby vegetation ($N = 9$). No further evidence of parental care was observed after leaf rolling. Depending on the size of the leaf used, leaf nest size varied, however those measured were 53–80 mm long and 28–64 mm in diameter ($N = 23$). The number of eggs varied from 43 to 72 (mean (\bar{X}) = 57.6, SD = 10.4 mm; $N = 23$). Individual eggs measured between 2.6 and 3.1 (mean = 2.8, SD = 0.5 mm, $N = 53$, single egg clutch). Freshly laid eggs were yellowish-cream in colour (Figure 3 *f*).

Duration of nest construction ranged from 17 to 29 min (\bar{X}) = 23.7, SD = 4.2 min, $N = 9$; Figure 2). Nest building was observed between 20:00 and 22:00 h, except one nest, which was constructed after 23:00 h ($N = 9$). There is a probable relationship between rainfall and nest construction duration. In the study area, July (southwest monsoon) receives more rain than September. In the period of study, rainfall varied between July ($\bar{X}_{\text{July}} = 17.47$ mm, SD = 37.0 mm) and September ($\bar{X}_{\text{September}} = 8.63$ mm, SD = 11.48 mm), and the difference was found to be significant when tested by one way ANOVA ($F = 14.03$, $P < 0.001$). Nest building time in July ranged between 17 and 21 min ($\bar{X} = 19.5$, SD = 1.7 min; $N = 4$). Duration of the three stages of nest construction in July is as follows: stage one 9–10 min (mean = 9.5, SD = 0.6 min, $N = 4$); stage two 3–4 min (mean = 3.5, SD = 0.6 min, $N = 4$); stage three 5–8 min (mean = 6.5, SD = 1.3 min, $N = 4$). However, in September, nest construction time is significantly longer, between 25 and 29 min (mean = 27, SD = 1.6 min, $N = 5$). Duration of the three stages of nest construction in September is as follows: stage one 12–14 minutes (mean = 13.0, SD = 0.7 min, $N = 5$); stage two 4–6 min (mean = 5, SD = 0.7 min, $N = 5$); stage three 8–10 min (mean = 9.0, SD = 0.7 min, $N = 5$). Nest construction was rarely observed during heavy downpours, usually only between showers. In July, the interval between two rains was shorter than in September. In the single nesting event observed during a downpour, the female had great difficulty in closing the leaf and finally made an imperfect nest.

Nest construction in anurans with aquatic larvae has been interpreted as a method to protect early developmental stages against a high diversity of aquatic predators^{11–13}. Foam nesting is a widespread reproductive mode among anuran families¹⁴ but arboreal leaf nest construction in frogs is known only in the genera *Rhacophorus*⁶, *Phyllomedusa*^{15,16} and *Afraxalus*^{17,18}. The habit of laying eggs on vegetation or other objects hanging over water is not uncommon among species of Rhacophoridae, but

construction of an above-ground nest using leaves has presently been reported only in *Rhacophorus malabaricus*⁶. In addition to the unique leaf nesting behaviour of *R. lateralis*, this study also documents multiple leaf nesting in *R. pseudomalabaricus* in Valparai ($N = 12$) and *R. calcadensis* ($N = 3$) in Agasthyamalai. Oviposition height above water on overhanging bush was 2–4 m in *R. pseudomalabaricus* and 1–4 m in *R. calcadensis*. In *R. pseudomalabaricus*, nest construction involved 4–10 leaves and in *R. calcadensis*, 3–7 (Figure 3 a, b). The basic sequence and pattern in both *R. calcadensis* and *R. pseudomalabaricus* are exactly the same as in *R. malabaricus*⁶. However, the present study did not witness any nesting on the ground as reported for *R. malabaricus*⁶. The closed, purse-like leaf nest of *R. lateralis* differs from those of other members of *Rhacophorus* from the Western Ghats. *R. lateralis* invariably uses only one leaf for completely enclosing the egg mass, whereas *R. malabaricus*⁶, *R. calcadensis* and *R. pseudomalabaricus* (present study) always use more than one leaf (3–10) for nest construction.

The single leaf nest of *R. lateralis* is similar to that of the south American *Phyllomedusa*^{15,16} and Sub-Saharan African *Afraxalus*^{17,18}. However, in both *Phyllomedusa* and *Afraxalus*, both male(s) and female in amplexus close the leaf using their hind limbs^{18,19}. Additionally, in *Phyllomedusa*, the female hydrates the eggs during nest construction or releases eggless capsules inside the leaf nest to provide moisture for the entire clutch^{20,21}, while no such behaviour was observed in *R. lateralis*.

Comparison of the foam texture of *R. lateralis* with seven other members of Rhacophoridae in India clearly differentiates the former from the latter (Figure 3 a–g). In *R. lateralis*, foam is far more translucent than that of *R. calcadensis* (Figure 3 b), *R. malabaricus* (Figure 3 e), *R. pseudomalabaricus* (Figure 3 a), *R. maximus* (personal observation), *Ghatixalus variabilis*²², *Polypedates leucomystax* (personal observations) and *P. maculatus*²³.

On 22 September 2002, five *R. lateralis* nesting events were observed in a single spot within 6 m radius, all exposed to open sunlight. On two of these nesting occasions, the females were removed before closing the leaf and the nests kept open. A transparent polythene roof was erected on top of the bush to avoid direct rain on the nests (both opened and unopened). On the subsequent three days, daytime average maximum air temperature was 30°C and minimum 25°C, with intermittent showers. On the fourth day, eggs in both the opened and closed nests were examined to confirm the effect of direct sunlight on embryo development. The number of eggs developed in closed leaf nests was 27 (out of 29), 34 (out of 38) and 42 (out of 47), a mean of 90.3%. In open nests, embryo development was observed in 16 (out of 31) and 19 (out of 43), a mean of 47.3%. In open nests, eggs located immediately below the exposed outer region of foam became dehydrated and aborted. Two open leaf nests kept

in laboratory conditions at 19–20°C for four days had embryonic development and hatching from almost 90% of eggs reaffirming the effect of sunlight on developing embryos.

The leaf folding behaviour of *R. lateralis* may have evolved as an adaptive advantage since its loose foam needs the best protection possible. This can be compared with the foam nest of other predominantly arboreal breeders among Indian Rhacophoridae members. The members of the genus *Polypedates* construct nest in the same way as their African counter part *Chiromantis* without folding a leaf or multiple leaves². These nests have thick foam outside. The foam subsequently dries and hardens to afford protection to eggs and developed tadpoles from desiccation (Biju, pers. obs.). Sympatric members of the genus *Philautus* from this study area have an individual thick jelly layer outside the embryos, rather than a foam nest, which moisten the eggs and developing embryos, protecting them from desiccation²⁴.

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