

# Sexual Dimorphism in the Hindlimb Muscles of the Asiatic Toad (*Bufo gargarizans*) in Relation to Male Reproductive Success

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**Abstract** In many anurans, the forelimb muscles of males are used to grasp females and are often heavier than those of females despite the larger female body size. Such sexual dimorphism in forelimb musculature is thought to result from sexual selection. In addition, the hindlimbs of frogs and toads play an important role in the reproductive process as amplexant males can expel rivals with robust hindlimbs through kicking. In this study, the sexual dimorphism in dry mass for six hindlimb muscles of the Asiatic toad (*Bufo gargarizans*) was investigated. The results showed that, when controlled for body size, the hindlimb muscle mass of males significantly exceeded that of females for every muscle. The hindlimb muscle mass of amplexant males was also significantly larger than that of non-amplexant males. These results suggested that if strong hindlimb muscles could improve mating success of males, sexual selection would promote the evolution of dimorphism in this character.

**Keywords** *Bufo gargarizans*, hindlimb muscle, sexual dimorphism, sexual selection

## 1. Introduction

Shine (1979) found that female-biased size dimorphism (in which males are smaller than females) occurs in 90% of anuran species. Differences in body size are generally believed to result from sex-specific differences in either natural or sexual selection (Shine, 1990; Herrel *et al.*, 2012). The cause of this phenomenon is often attributed to fecundity selection based on a positive correlation between fecundity and body size of females (Crump, 1974; Andersson, 1994; Liao and Lu, 2009a, b; Liao and Lu, 2010a, b, c; Yu and Lu, 2010; Liao and Chen, 2012; Liao and Lu, 2012a) and greater age in females (Monnet and Cherry, 2002; Zhang and Lu, 2012).

In many anuran species, the forelimb muscles of males are heavier than those of females, even though females are larger in body size and mass (Kirby, 1983; Oka *et al.*, 1984; Yekta and Blackburn, 1992; Peters and Aulner, 2000; Lee, 2001; Clark and Peters, 2006; Navas and James, 2007; Liao *et al.*, 2012b; Mi, 2012). This sexual dimorphism in forelimb muscle mass may relate to the function used by the males during amplexus and

male-male aggression, which has been regarded as the result of sexual selection and intrasexual sexual selection, expressed as male-male competition (Lee, 1986; Peters and Aulner, 2000; Lee, 2001; Liao *et al.*, 2012b; Mi, 2012). The hindlimbs of frogs and toads are involved in hopping, kicking and swimming. During amplexus, amplexant males can expel competing males with robust hindlimb kicking (Andersson, 1994; Gillis and Biewener, 2000; Liao *et al.*, 2012a). Relatively strong hindlimb muscles may evolve in some species where scramble competition is common among males (the already grasped male kicks the rival that attempts to displace him). Lee and Corrales (2002) found that the plantaris longus, sartorius and triceps femoris muscles in *Bufo marinus* exhibit significant sexual dimorphism in mass, with the male values exceeding those of females. On the contrary, *B. andrewsi* female musculature is significantly greater than that of males (Liao *et al.*, 2012a). Therefore, there are obvious differences in sexual dimorphism of hindlimb muscles of the two studied species of toads, and sexual dimorphism of hindlimb muscles needs to be investigated extensively among anuran species.

The Asiatic toad (*Bufo gargarizans*) is a species endemic to East Asia, including China, Russia and Korea. It is referred to as an explosive breeder. Information on its habitat selection (Yu and Guo, 2010), diet (Yu *et al.*,

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2009) and mating behaviour (Yu and Lu, 2010; Yu and Sharma, 2012) is available. Moreover, Mi (2012) found that the forelimb muscles (i.e., deltoideus, pectoralis, coraco-humeralis longus, coraco-humeralis brevis, sterno-radialis, flexor carpi radialis, extensor carpi radialis, abductor indicus longus, extensor digitorum communis longus and flexor digitorum communis) used in axillary amplexus, and those (i.e., infraspinalis, latissimus dorsi and triceps branchii) not used in axillary amplexus are all sexually dimorphic, with muscle mass of males exceeding that of females. The forelimb muscles used in axillary amplexus are significantly larger in amplexant males than those in non-amplexant males, but those not used in axillary amplexus do not exhibit significant difference between amplexant and non-amplexant males. However, there are currently no reports on sexual dimorphism of hindlimb muscle mass in *B. gargarizans*. This study aims to explore the intersexual difference in the hindlimb muscle mass and compare the masses of amplexant and non-amplexant males of this toad.

## 2. Materials and Methods

The specimens of *B. gargarizans* were collected during evening hours between 24 January and 12 February 2011 from a breeding congregation in Shunqing County of Nanchong, Sichuan, China (30°49' N, 106°03' E; 251 m a.s.l.), which included 16 males and 16 females collected in amplexus, and 18 non-amplexant males. Each individual was killed by pithing, and its snout-vent length (SVL) was measured to the nearest 0.1 mm using a digital vernier caliper. Subsequently, all the specimens were stored in 10% neutral buffered formalin for later dissection.

All samples were dissected in the laboratory from 19 to 31 July 2011. Six hindlimb muscles (sartorius, triceps femoris, adductor longus, plantaris longus, tibialis anticus longus and peroneus) were dissected from the right side of each specimen. The hindlimb muscles were dried to constant mass using a thermostat drier at 60°C (Liao *et al.*, 2012a) with each dried hindlimb muscle being weighed using an electronic balance to the nearest 0.1 mg.

One-way ANOVA analysis was used to test for the differences in SVL between males and females, and between amplexant and non-amplexant males. The data were tested for normal distribution by the Kolmogorov-Smirnov procedure before proceeding with the ANOVA. I regressed the muscle mass on SVL for each muscle, and compared regression coefficients between two groups

(males *vs.* females, and amplexant *vs.* non-amplexant males) with regression analysis for homogeneity. According to the regression equation, I calculated asymptotic muscle mass. The significance of differences of the adjusted means was tested by the analyses of covariance (ANCOVA), with SVL as a covariate (Lee, 2001). Means  $\pm$  SD are given.

## 3. Results

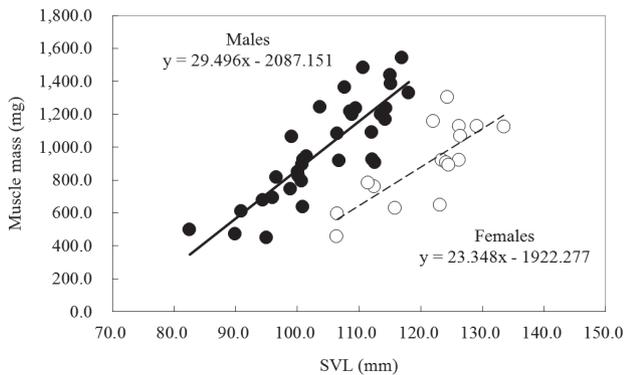
SVL ranged from 82.5 to 118.0 mm ( $n = 34$ , mean =  $104.5 \pm 8.7$  mm) for males, and from 106.4 to 133.5 mm ( $n = 16$ , mean =  $121 \pm 8.0$  mm) for females. On average, females were significantly larger than males in body size (ANOVA,  $F_{1,49} = 40.70$ ,  $P < 0.001$ ). Linear regression statistics of muscle mass on SVL for males and females, the adjusted means, and results of ANCOVA comparing the muscles of males with those of females are shown in Table 1. In every muscle, linear regression of muscle mass on SVL was very significant for both sexes ( $P < 0.01$ ), and 43.8%–72.5% of variation in muscle mass was statistically explained by regression on SVL (Table 1). For all comparisons between males and females, the slopes were homogeneous ( $P > 0.05$ ), except for the triceps femoris ( $P = 0.027$ ). In every case, the adjusted means differed significantly between the sexes by ANCOVA (Table 1). Independent of body size, hindlimb muscle mass of males was significantly heavier than that of females, and all hindlimb muscles examined were male-biased sexual dimorphism. Total mass of hindlimb muscles regressed significantly on SVL for both sexes (Figure 1; males:  $R^2 = 0.725$ ,  $n = 34$ ,  $P < 0.001$ ; females:  $R^2 = 0.607$ ,  $n = 16$ ,  $P < 0.001$ ), and the slopes were homogenous ( $P = 0.313$ ). By ANCOVA, the differences in the adjusted means between the sexes were highly significant for total mass of hindlimb muscles ( $F_{2,49} = 3179.779$ ,  $P < 0.001$ ).

Average body size of amplexant males was significantly larger than non-amplexant males (ANOVA,  $F_{1,33} = 9.29$ ,  $P = 0.005$ ). SVL ranged from 99.1 to 118.0 mm ( $n = 16$ , mean =  $108.8 \pm 6.5$  mm) for amplexant males and from 82.5 to 114.2 mm ( $n = 18$ , mean =  $100.7 \pm 8.7$  mm) for non-amplexant males. Linear regression analysis statistics, adjusted means, and results of ANCOVA comparing the muscles of amplexant males with those of non-amplexant males are shown in Table 2. In each case, linear regression analysis of muscle mass on SVL was highly significant ( $P < 0.01$ ) for both amplexant and non-amplexant males, and 46.1%–72.1% of variation in muscle mass was statistically explained by

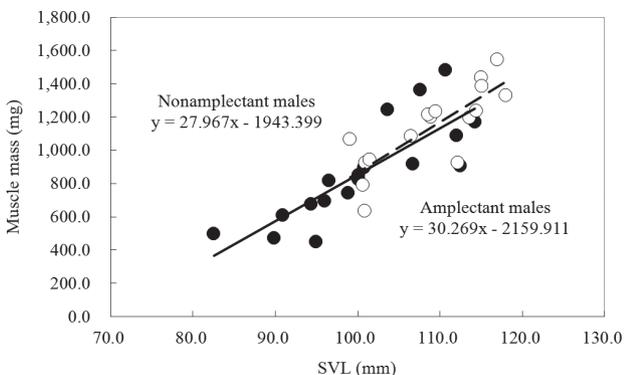
regression on SVL. For each comparison of amplexant vs. non-amplexant males, the regression coefficients were homogeneous ( $P > 0.05$ ). When the effect of SVL was removed, the adjusted means of muscle mass in amplexant males were significantly larger than those in non-amplexant males, but the sartorius muscle failed to satisfy conventional statistical significance ( $P = 0.315$ ; Table 2). Linear regression of total mass of hindlimb muscles on SVL was highly significant in amplexant and non-amplexant males (Figure 2; amplexant males:  $R^2 = 0.658$ ,  $n = 16$ ,  $P < 0.001$ ; non-amplexant males:  $R^2 = 0.665$ ,  $n = 18$ ,  $P < 0.001$ ), and the slopes were homogenous ( $P = 0.775$ ). Independent of body size, total mass of hindlimb muscles of amplexant males was significantly larger than that of non-amplexant males (ANCOVA,  $F_{2,34} = 69.418$ ,  $P < 0.001$ ).

#### 4. Discussion

Sexual selection theory predicts that large males may have a mating advantage in some populations or species



**Figure 1** Linear regression of the total mass of hindlimb muscles on SVL for males (closed circles, solid line) and females (open circles, broken line) of *Bufo gargarizans*.



**Figure 2** Linear regression of the total mass of hindlimb muscles on SVL for non-amplexant males (closed circles, solid line) and amplexant males (open circles, broken line) of *Bufo gargarizans*.

(Lee, 1986; Lee, 2001; Liao and Lu, 2011; Liao and Lu, 2012b). Amplexant males of *B. gargarizans* are significantly larger in body size than non-amplexant males (Yu and Lu, 2010; this study), suggesting that mating success was non-random with respect to male body size. Moreover, this large male-mating advantage may depend on absolute mass of forelimb muscles used in amplexus, because successful mating males have much larger forelimb muscles and greater mate-holding capacity than unsuccessful males (Lee, 2001; Liao *et al.*, 2012b; Mi, 2012).

The hindlimb muscles of *B. marinus* (Lee and Corrales, 2002) and *B. gargarizans* (this study) are all sexually dimorphic, with males exceeding females in muscle mass and also amplexant males exceeding non-amplexant males. However, hindlimb muscle mass of *B. andrewsi* for females significantly exceeds that of males, and there is no significant difference between amplexant and non-amplexant males (Liao *et al.*, 2012a). As noted above, the interspecific difference in sexual dimorphism in muscles is common (Oka *et al.*, 1984; Yekta and Blackburn, 1992; Navas and James, 2007) and the significance of these differences probably relates to a diverse aspect of anuran reproductive biology. Based on current data, however, there is no general pattern about this variability. The phenomenon should be investigated extensively.

Sex steroid hormones affect skeletal muscle size, dry mass and fiber type (Lyons *et al.*, 1986; Sassoon and Kelley, 1986; Itoh and Ishii, 1990; Kim *et al.*, 1998; Gobbetti and Zerani, 1999). The dimorphic muscles are sensitive to androgens and have high level of androgen receptors, which presumably triggers specific genes regulating muscle size (Girgenrath and Marsh, 2003). Seasonal changes in levels of androgens cause variation in the degree of sexual dimorphism (Licht *et al.*, 1983). However, there is little information about the influences of steroids on the dimorphism muscles in *B. gargarizans*.

In explosive breeding anurans, males attempting to take-over a male that is already in amplexus are common. The prevalence of take-over attempts has brought about the evolution of sexual dimorphism in the forelimb muscles (Oka *et al.*, 1984; Lee, 2001; Clark and Peters, 2006; Navas and James, 2007). Those forelimb muscles used in amplexus (i.e., the muscles that adduct the forearm, flex the elbow, flex the wrist, and abduct the first digit) have been found to be sexually dimorphic in mass, with males significantly exceeding females in some explosive breeding species (Oka *et al.*, 1984; Yekta and Blackburn, 1992; Peters and Aulner, 2000; Lee, 2001; Clark and Peters, 2006; Navas and James, 2007; Mi,

**Table 1** Linear regression of muscle mass on SVL and results of ANCOVA comparing the males and females of *Bufo gargarizans*.

Muscle	Males (n = 34)			Females (n = 16)			F	P
	Equation	R <sup>2</sup>	Adj. mean	Equation	R <sup>2</sup>	Adj. mean		
Triceps femoris	y = 13.150x - 934.436	0.707	440.10 ± 114.59	y = 9.967x - 804.068	0.530	401.74 ± 80.08	2255.443	0.000
Sartorius	y = 1.497x - 100.715	0.664	55.76 ± 13.05	y = 1.135x - 89.938	0.545	47.38 ± 9.13	2993.203	0.000
Adductor longus	y = 0.777x - 48.242	0.513	32.98 ± 6.77	y = 0.593x - 46.903	0.438	24.84 ± 4.75	4654.527	0.000
Tibialis anticus longus	y = 3.714x - 259.274	0.680	128.95 ± 32.36	y = 3.528x - 303.694	0.724	123.12 ± 28.35	50343.612	0.000
Plantaris longus	y = 8.948x - 643.949	0.725	291.36 ± 77.97	y = 6.931x - 576.475	0.637	262.04 ± 55.69	2726.195	0.000
Peroneus	y = 1.410x - 100.535	0.710	46.85 ± 12.29	y = 1.194x - 101.198	0.592	43.24 ± 9.60	5677.900	0.000

**Table 2** Linear regression of muscle mass on SVL and results of ANCOVA comparing amplexant and non-amplexant males of *Bufo gargarizans*.

Muscle	Non-amplexant males (n = 18)			Amplexant males (n = 16)			F	P
	Equation	R <sup>2</sup>	Adj. mean	Equation	R <sup>2</sup>	Adj. mean		
Triceps femoris	y = 11.776x - 803.113	0.626	382.61 ± 103.03	y = 14.333x - 1055.336	0.665	504.74 ± 93.67	26.733	0.000
Sartorius	y = 1.304x - 81.510	0.558	49.78 ± 11.41	y = 1.820x - 135.530	0.687	62.57 ± 11.88	1.045	0.315
Adductor longus	y = 0.792x - 49.078	0.461	30.67 ± 6.92	y = 0.895x - 61.883	0.529	35.55 ± 5.85	147.675	0.000
Tibialis anticus longus	y = 3.677x - 257.568	0.633	112.68 ± 32.18	y = 3.341x - 216.526	0.552	147.13 ± 21.83	118.213	0.000
Plantaris longus	y = 9.069x - 656.986	0.721	256.16 ± 79.34	y = 8.507x - 595.083	0.572	330.88 ± 55.60	7.596	0.010
Peroneus	y = 1.350x - 95.143	0.680	40.78 ± 11.80	y = 1.372x - 95.554	0.574	53.78 ± 8.97	2850.878	0.000

2012) and in an elongated breeding species (Liao *et al.*, 2012b). Peters and Aulner (2000) suggested that more massive muscles can produce larger isometric forces, and thus more massive forelimb muscles used in amplexus may enable males to grasp a female more firmly during amplexus and to resist competing males. Generally, this size dimorphism in forelimb muscle mass has been attributed to sexual selection (Lee, 1986; Lee, 2001; Liao *et al.*, 2012b). According to this explanation, the hindlimb muscles not involved in the axillary amplexus should not differ in mass between the sexes or between amplexant and non-amplexant males. However, the results from this study are inconsistent with the above theoretic prediction. The six kinds of hindlimb muscles are heavier in males than in females. In addition, the muscle mass of amplexant males exceeds that of non-amplexant males though the sartorius muscle does not reach statistical significance. Similar results have been reported in *B. marinus* (also being an explosive breeding species; Lee and Corrales, 2002). The triceps femoris, tibialis anticus longus and peroneus all can extend the knee joint, and the plantaris longus can extend the ankle joint (Feng, 1990; Lee and Corrales, 2002). These four extensor muscles are involved in kicking actions. If rivals approach an amplexant pair from behind, strong kicking motions produced by the amplexant male might resist attempted take-overs (Lee and Corrales, 2002). The

sartorius and adductor longus can flex the knee joint and hip joint respectively, and pulls the femur ventrally (Feng, 1990; Lee and Corrales, 2002). These two flexor muscles can pull the hindlimbs of amplexant male against its mate female tightly, and so they probably help the forelimbs of amplexant male to maintain clasping posture. If robust hindlimbs offer a locomotor advantage in swimming, kicking and hopping, then males with more massive hindlimb muscles might reach females first. These findings suggested that more massive hindlimb muscles might provide selective advantages for allowing males to faster clasp females and better prevent the interference from non-amplexant males in explosive breeding species. So, differences in hindlimb muscle mass between the sexes, and between amplexant and non-amplexant males may be interpreted by sexual selection on hindlimb muscle traits. It is clear that perfect understanding of sexual selection and mating success of *B. gargarizans* would benefit from additional comparative studies of the physiology, biomechanics and ecology related to appendicular muscles.

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## References

- Andersson M.** 1994. Sexual selection. Princeton, NJ: Princeton University Press
- Clark D. L., Peters S. E.** 2006. Isometric contractile properties of sexually dimorphic forelimb muscles in the marine toad *Bufo marinus* Linnaeus 1758: Functional analysis and implications for amplexus. *J Exp Biol*, 209: 3448–3456
- Crump M. L.** 1974. Reproductive strategies in a tropical anuran community. *Misc Publ Mus Nat Hist Univ Kans*, 61: 1–68
- Feng X. Y.** 1990. The systematic dissection of *Bufo gargarizans*. Beijing, China: Higher Education Press (In Chinese)
- Gillis G. B., Biewener A. A.** 2000. Musculoskeletal mechanisms for accommodating locomotion in different environments: Hind limb extensor muscle function during hopping and swimming in the toad (*Bufo marinus*). *J Exp Biol*, 203: 3547–3563
- Girgenrath M., Marsh R. L.** 2003. Season and testosterone affect contractile properties of fast calling muscles in the gray tree frog *Hyla chrysoscelis*. *Am J Physiol Regul Integr Comp Physiol*, 284: R1513–R1520
- Gobbetti A., Zerani M.** 1999. Hormonal and cellular brain mechanisms regulating the amplexus of male and female water frog (*Rana esculenta*). *J Neuroendocrinol*, 11: 589–596
- Herrel A., Gonwouo L. N., Fokam E. B., Ngundu W. I., Bonneaud C.** 2012. Intersexual differences in body shape and locomotor performance in the aquatic frog, *Xenopus tropicalis*. *J Zool*, 287: 311–316
- Itoh M., Ishii S.** 1990. Changes in plasma levels of gonadotropins and sex steroids in the toad, *Bufo japonicus*, in association with behavior during the breeding season. *Gen Comp Endocrinol*, 80: 451–464
- Kim J. W., Im W. B., Choi H. H., Ishii S., Kwon H. B.** 1998. Seasonal fluctuations in pituitary gland and plasma levels of gonadotropic hormones in *Rana*. *Gen Comp Endocrinol*, 109: 13–23
- Kirby A. C.** 1983. Physiology of the sternoradialis muscle: Sexual dimorphism and role in amplexus in the leopard frog (*Rana pipiens*). *Comp Biochem Physiol*, 74: 705–709
- Lee J. C.** 1986. Is the large-male mating advantage in anurans an epiphenomenon? *Oecologia*, 69: 207–212
- Lee J. C.** 2001. Evolution of a secondary sexual dimorphism in the toad, *Bufo marinus*. *Copeia*, 2001: 928–935
- Lee J. C., Corrales A. D.** 2002. Sexual dimorphism in hind-limb muscle mass is associated with male reproductive success in *Bufo marinus*. *J Herpetol*, 36: 502–505
- Liao W. B., Chen W.** 2012. Inverse Rensch-rule in a frog with female-biased sexual size dimorphism. *Naturwissenschaften*, 99: 427–431
- Liao W. B., Lu X.** 2009a. Male mate choice in the Andrew's toad *Bufo andrewsi*: A preference for larger females. *J Ethol*, 27: 413–417
- Liao W. B., Lu X.** 2009b. Sex recognition by male Andrew's toad *Bufo andrewsi* in a subtropical montane region. *Behav Proc*, 82: 100–103
- Liao W. B., Lu X.** 2010a. Age structure and body size of the Chuanxi tree toad *Hyla annectans chuanxiensis* from two different elevations (China). *Zool Anz*, 248: 255–263
- Liao W. B., Lu X.** 2010b. A skeletochronological estimation of age and body size by the Sichuan torrent frog (*Amolops mantzorum*) between two populations at different altitudes. *Anim Biol*, 60: 479–489
- Liao W. B., Lu X.** 2010c. Age and growth of a subtropical high-elevation torrent frog, *Amolops mantzorum*, in western China. *J Herpetol*, 44: 172–176
- Liao W. B., Lu X.** 2011. Proximate mechanisms leading to the large male-mating advantage in the Andrew's toad *Bufo andrewsi*. *Behaviour*, 148: 1087–1102
- Liao W. B., Lu X.** 2012a. Adult body size =  $f(\text{initial size} + \text{growth rate} \times \text{age})$ : Explaining the proximate cause of Bergman's cline in a toad along altitudinal gradients. *Evol Ecol*, 26: 579–590
- Liao W. B., Lu X.** 2012b. Variation in mating patterns in the Andrew's toad *Bufo andrewsi* along an elevational gradient in southwestern China. *Ethol Ecol Evol*, 24: 174–186
- Liao W. B., Liao Y. M., Xiao W. M., Chen W., Mi Z. P., Li C.** 2012a. Sexual dimorphism in hind limb muscle mass of the Andrew's toad (*Bufo andrewsi*) in relation to sexual selection. *NW J Zool*, 8: 252–256
- Liao W. B., Wu Q. G., Barret K.** 2012b. Evolution of sexual dimorphism in the forelimb muscles of Andrew's toad (*Bufo andrewsi*) in response to putative sexual selection. *Anim Biol*, 62: 83–93
- Licht P., McCreery B. R., Barnes R., Pang R.** 1983. Seasonal and stress related changes in plasma gonadotropins, sex steroids, and corticosterone in the bull frog, *Rana catesbeiana*. *Gen Comp Endocrinol*, 50: 124–145
- Lyons G. E., Kelly A. M., Rubinstein N. A.** 1986. Testosterone-induced changes in contractile protein isoforms in the sexually dimorphic temporalis muscle of the guinea pig. *J Biol Chem*, 261: 13278–13284
- Mi Z. P.** 2012. Sexual dimorphism in the forelimb muscles of the Asiatic toad *Bufo gargarizans*. *Herpetol J*, 22: 219–224
- Monnet J. M., Cherry M. I.** 2002. Sexual size dimorphism in anurans. *Proc Roy Soc B*, 269: 2301–2307
- Navas C. A., James R. S.** 2007. Sexual dimorphism of extensor carpi radialis muscle size, isometric force, relaxation rate and stamina during the breeding season of the frog *Rana temporaria* Linnaeus 1758. *J Exp Biol*, 210: 715–721
- Oka Y., Ohtani R., Satou M., Ueda K.** 1984. Sexually dimorphic muscles in the forelimb of the Japanese toad, *Bufo japonicus*. *J Morph*, 180: 297–308
- Peters S. E., Aulner D. A.** 2000. Sexual dimorphism in forelimb muscles of the bullfrog, *Rana catesbeiana*: A functional analysis of isometric contractile properties. *J Exp Biol*, 203: 3639–3654
- Sassoon D., Kelley D. B.** 1986. The sexually dimorphic larynx of *Xenopus laevis*: Development and androgen regulation. *Am J Anat*, 177: 457–472
- Shine R.** 1979. Sexual selection and sexual dimorphism in the Amphibia. *Copeia*, 1979: 297–306

- Shine R.** 1990. Proximate determinants of sexual differences in adult body size. *Am Nat*, 135: 278–283
- Yekta N., Blackburn D.** 1992. Sexual dimorphism in mass and protein content of the forelimb muscles of the northern leopard frog *Rana pipiens*. *Can J Zool*, 70: 670–674
- Yu T. L., Gu Y. S., Du J., Lu X.** 2009. Seasonal variation and ontogenetic change in the diet of a population of *Bufo gargarizans* from the farmland, Sichuan, China. *Biha Biol*, 3: 99–104
- Yu T. L., Guo Y. S.** 2010. Overwintering habitat selection of Asiatic toad, *Bufo gargarizans* in southwestern China. *Biha Biol*, 4: 15–18
- Yu T. L., Lu X.** 2010. Sex recognition and mate choice lacking in male Asiatic toads (*Bufo gargarizans*). *Ital J Zool*, 77: 476–480
- Yu T. L., Sharma M. D.** 2012. Sex recognition and mate choice by male *Bufo gargarizans* in central China. *Zool Sci*, 29: 347–350
- Zhang L. X., Lu X.** 2012. Sexual size dimorphism in anurans: Ontogenetic determination revealed by an across-species comparison. *Evol Biol* (In press)