黑斑侧褶蛙消化道重量及长度的性别和季节差异

金晨晨[①] 张志强[②*]

① 安徽农业大学生命科学学院 合肥 230036; ② 安徽农业大学动物科技学院 合肥 230036

摘要: 消化道是联系脊椎动物能量摄入和能量支出之间关系的纽带, 其重量和长度对外界环境具有高度的敏感性和弹性(flexibility)。以黑斑侧褶蛙(*Pelophylax nigromaculata*)为研究对象, 测定了山东聊城地区 2012 年夏季(16 只, 8♀/8♂)、秋季(19 只, 9♀/10♂)及翌年春季(17 只, 8♀/9♂)其体重、体长、胴体湿重和干重系数、总消化道及各段(食道、胃、小肠和大肠)的湿重、干重和长度系数的性别和季节差异(双因素方差分析), 对有性别差异的指标, 用单因素方差分析分别比较了雌、雄蛙的季节差异。结果显示, 1)雌蛙的体重、体长均高于雄蛙, 都在秋季最高, 春季或夏季最低; 雄蛙的胴体湿重系数高于雌蛙, 夏季高于秋季; 胴体干重系数既无性别差异, 也无季节差异。2)除食道湿重系数无性别差异外, 雌蛙总消化道及各段的湿重系数均高于雄蛙; 除胃湿重系数无季节差异外, 春季或秋季的总消化道及各段的湿重系数都高于夏季; 雌蛙的总消化道干重和胃干重系数高于雄蛙, 食道、小肠和大肠的干重系数无性别差异, 所有的干重系数均无季节性差异。3)除雌蛙的大肠长系数高于雄蛙外, 总消化道及各段的长度系数均无性别差异, 春季和秋季的总消化道长、食道长及胃长系数均高于夏季, 小肠长和大肠长系数均无季节性差异。结果表明, 随着季节更替, 黑斑侧褶蛙消化道各段的重量和长度表现出一定的弹性特征, 这与各器官的功能及其生活环境的多样性是相适应的。

关键词:黑斑侧褶蛙; 表型弹性; 消化道; 季节; 性别

中图分类号:Q954.3 **文献标识码**:A **文章编号**:0250-3263(2014)02-207-08

Sexual and Seasonal Differences of Digestive Tract Mass and Length in *Pelophylax nigromaculata*

JIN Chen-Chen[①] ZHANG Zhi-Qiang[②*]

① *School of Life Sciences, Anhui Agricultural University, Hefei* 230036;

② *School of Animal Sciences and Technology, Anhui Agricultural University, Hefei* 230036, *China*

Abstract: The digestive tract represents a functional link between energy intake and energy allocation in vertebrates. Its mass and length are highly sensitive to environmental adaption, and is of flexibility. In this paper, sexual and seasonal differences in body mass, snout-vent length (SVL), wet and dry carcass mass indices, as well as wet and dry mass indices, and length indices of total digestive tract and different portions (oesophagus, stomach, small intestine, and large intestine) of digestive tract (Two way ANOVA) were measured in black-spotted pond frog *Pelophylax nigromaculata* captured in summer (8 males, 8 females, n =

基金项目 国家自然科学基金面上项目(No. 31170379);

* 通讯作者, E-mail: zzq-003@163.com;

第一作者介绍 金晨晨, 女, 硕士研究生; 研究方向: 水生生物学; E-mail: jcchz123@163.com。

收稿日期: 2013-07-08, 修回日期: 2013-11-18

16) and autumn (10 males, 9 females, n = 19) 2012, and in spring (9 males, 8 females, n = 17) 2013, respectively from Liaocheng city, Shandong province, China. If some indices showed significant sexual differences, seasonal variations of those indices for any gender were further analyzed by one way ANOVA. The results were as follows: 1) Body mass and SVL in females were higher than in males, and both were higher in autumn than in spring or summer for both sexes. Wet carcass mass index in males was higher than in females, and was greater in summer than in autumn for both sexes. No sexual and seasonal differences were found for dry carcass mass index. 2) All the wet mass indices of total digestive tract and different portions of digestive tract except for oesophagus wet mass index in females were higher than in males. All the wet mass indices of total digestive tract and different portions of digestive tract except for the stomach wet mass index in spring or autumn were greater than in summer. Both total digestive tract and stomach dry mass indices in females were higher than in males, but not for the oesophagus, small intestine and large intestine dry mass indices. All the dry mass indices did not show seasonal differences. 3) No sexual differences were found for the length indices of total digestive tract and different portions of digestive tract except that large intestine length index in females was higher than in males. The length indices of total digestive tract, oesophagus and stomach in spring and autumn were higher than in summer, but not for small and large intestine length indices. These results indicate that the mass and length of different portions of digestive tract in *Pelophylax nigromaculata* change with seasons, and display some flexibility characters, which may be related to the functions of digestive organs and diversities of life environments.

Key words: *Pelophylax nigromaculata*; Phenotypic flexibility; Digestive tract; Season; Gender

表型弹性(phenotypic flexibility)是自然界中普遍存在的一种现象，是指当环境条件发生变化时，生物体能做出可逆性的调整，以适应多变的环境条件(Piersma et al. 2003)。近年来，随着全球变暖的加剧，作为变温动物的两栖动物面临着比以往任何时候都更为严峻的生存威胁。器官水平上，动物体多种脏器的大小会随着季节的波动而出现适应性改变(Naya et al. 2007, 2008)。消化道是联系脊椎动物能量摄入和能量支出之间关系的纽带，具有弹性(Naya et al. 2009a, b)。例如，林蛙(*Rana temporaria*)消化道重量及其组织具有季节动态，并与年取食周期相关(Juszczyk et al. 1966)；禁食和重喂食条件下，安第斯刺蟾(*Bufo spinulosus*)消化道在整体水平、组织学水平和生理学水平都表现出弹性(Naya et al. 2005, 2009b)，其重量和长度也会随着纬度(Naya et al. 2009a)的变化而波动。然而，关于两栖动物消化道表型弹性的野外证据仍十分缺乏，有继续扩大研究范围的必要(Naya et al. 2004, Secor 2005a, b, Naya et al. 2009a, b, Seliverstova et al. 2012)。

黑斑侧褶蛙(*Pelophylax nigromaculata*)属两栖纲(Amphibians)无尾目(Anura)蛙科(Ranidae)侧褶蛙属，分布范围广泛、数量多、适应性强。吴云龙(1965)和曹玉萍等(2000)曾分别比较分析过北京和保定郊区秋季和春季黑斑侧褶蛙的肥满度、脂肪体系数、肝系数和生殖腺系数等的差异，Pan 等(2009)测定过禁食处理对黑斑侧褶蛙消化道内分泌细胞分布密度和形态学特征的影响，但尚无关于黑斑侧褶蛙消化道季节动态的系统研究。本文以分布于山东聊城地区的黑斑侧褶蛙为研究对象，测定了夏、秋、春三季黑斑侧褶蛙消化道重量和长度的变化，旨在从器官水平上为表型弹性理论提供实验证据，为两栖动物进化和比较生理学研究提供基础资料。

1 材料与方法

1.1 实验动物 分别于 2012 年 7 月中旬(夏季)、2012 年 10 月初(秋季)和 2013 年 5 月中旬(春季)，在山东省聊城市聊城大学东校区校

园内(36.43°N, 116.00°E)池塘中捕捉成体黑斑侧褶蛙,共捕获25只雌蛙,27只雄蛙,三个季节捕获的样本数分别为8♀/8♂、9♀/10♂和8♀/9♂。

1.2 取材 电子天平(精度为0.001 g,上海菁海仪器有限公司,型号:JA2003N)称量动物体重,直尺(精度为0.1 cm)测量体长后,用双毁髓法处死动物,立即解剖取出消化道,剔除肠系膜和其他结缔组织后,分离出消化道各段(食道、胃、小肠和大肠),保持消化道各段处于自然状态,不拉伸,用电子数显卡尺(精度为0.01 mm,上海恒量量具有限公司,型号:12887)测量消化道各段的长度,胃长按胃弯曲的角度段与段之间呈垂直状态累加测量。总消化道长(mm) = 食道长(mm) + 胃长(mm) + 小肠长(mm) + 大肠长(mm)。纵剖开消化道各段,用任氏液冲洗干净,并用滤纸吸干附着于表面的液体,电子天平称量总消化道及各段的湿重。称量干重时,先称量包裹胴体和消化道各段的锡箔纸的纸重,之后置于65℃电热恒温鼓风干燥箱(精度为0.5℃,江苏省金坛市杰瑞尔电子有限公司,型号:DHG-9000A)烘至恒重,称量含有锡箔纸的胴体和消化道各段的总重量(精确到0.001 g)。胴体干重(g) = 烘干后的胴体和锡箔纸的总重量(g) - 包裹胴体的锡箔纸的纸重(g);消化道各段的干重(g) = 烘干后的消化道各段和锡箔纸的总重量(g) - 包裹消化道各段的锡箔纸的纸重(g)。胴体湿重(或干重)系数(%) = 胴体湿重(或干重) × 100/体重;总消化道(或消化道各段)湿重系数(%) = 总消化道(或消化道各段)湿重 × 100/体重;总消化道(或消化道各段)干重系数(%) = 总消化道(或消化道各段)干重 × 100/胴体干重;总消化道(或消化道各段)长系数(%) = 总消化道(或消化道各段)长 × 100/体长。

1.3 统计分析 用SPSS 13.0对实验数据进行分析。所有数据经Kolmogorov-Simirov检验均符合正态分布($P > 0.05$);Levene's检验发现一些数据方差不齐($P < 0.05$),对胴体湿重和干重系数及胃长系数进行了自然对数转换,直肠湿重系数及食道和直肠干重系数进行了反正弦转换。用双因素方差分析(Two-way ANOVA)比较体重、体长、胴体湿重和干重系数、总消化道(或消化道各段)的湿重、干重及长度系数的性别和季节差异。对有性别差异的参数,用单因素方差分析(One-way ANOVA)分别比较雌、雄蛙的季节差异。数值均以平均值 ± 标准误(Mean ± SE)表示,$P < 0.05$ 为差异显著。

2 结　果

2.1 黑斑侧褶蛙体重、体长、胴体湿重及干重系数的性别和季节差异 双因素方差分析表明,雌、雄黑斑侧褶蛙的平均体重分别为(45.027 ± 3.069) g 和(29.832 ± 2.037) g,雌蛙显著高于雄蛙;雄蛙的体重秋季最高,春季最低(单因素方差分析:$F_{2,24} = 9.892$, $P < 0.05$),雌蛙秋季高于夏季和春季(单因素方差分析:$F_{2,22} = 8.194$, $P < 0.05$)(表1)。黑斑侧褶蛙胴体湿重系数雄蛙(79.226 ± 1.832)显著高于雌蛙(72.899 ± 1.558);雄蛙夏季和春季高于秋季,雌蛙夏季最高,春季其次,秋季最低(单因素方差分析,雄蛙:$F_{2,24} = 5.390$, $P < 0.05$;雌蛙:$F_{2,22} = 31.551$, $P < 0.05$);胴体干重系数既无性别差异,也无季节差异(表1)。雌、雄蛙的平均体长分别为(8.2 ± 0.2) cm 和(7.1 ± 0.1) cm,雌蛙显著长于雄蛙,均秋季最长,春季或夏季最短(单因素方差分析,雄蛙:$F_{2,24} = 5.284$, $P < 0.05$;雌蛙:$F_{2,22} = 5.353$, $P < 0.05$)(表1)。

2.2 黑斑侧褶蛙总消化道及各段湿重系数的性别和季节差异 总消化道湿重系数雌蛙(4.406 ± 0.206)显著高于雄蛙(3.569 ± 0.143);雄蛙秋季高于夏季,雌蛙春季最高,夏季最低(单因素方差分析,雄蛙:$F_{2,24} = 4.833$, $P < 0.05$;雌蛙:$F_{2,22} = 5.866$, $P < 0.05$)(表2)。食道湿重系数无性别差异,秋季高于夏季(表2)。胃、小肠和大肠湿重系数雌蛙(胃:1.961 ± 0.126;小肠:1.464 ± 0.100;

表 1 黑斑侧褶蛙体重、体长、胴体湿重及干重系数的性别和季节差异

Table 1 Sexual and seasonal differences in body mass, snout-vent length, wet and dry carcass mass indices in *Pelophylax nigromaculata*

	性别 Gender	夏季 Summer	秋季 Autumn	春季 Spring	*F* 值和 *P* 值 *F* and *P* values		
样本数 Sample size	♂	8	10	9	季节 Season	性别 Gender	季节 × 性别 Season × Gender
	♀	8	9	8			
体重(g)	♂	29.705 ± 2.625^{ab}	37.780 ± 3.470^{a}	21.114 ± 1.768^{b}	$F_{2,46}$ = 16.070	$F_{1,46}$ = 27.441	$F_{2,46}$ = 1.806
Body mass	♀	37.156 ± 3.455^{b}	58.115 ± 5.302^{a}	38.174 ± 3.125^{b}	P < 0.05	P < 0.05	P > 0.05
体长(cm)	♂	7.2 ± 0.1^{ab}	7.6 ± 0.3^{a}	6.6 ± 0.2^{b}	$F_{2,46}$ = 7.917	$F_{1,46}$ = 32.251	$F_{2,46}$ = 2.673
Snout-vent length	♀	7.7 ± 0.3^{b}	8.8 ± 0.3^{a}	8.2 ± 0.2^{ab}	P < 0.05	P < 0.05	P > 0.05
胴体湿重系数(%)	♂	83.827 ± 2.780^{a}	72.473 ± 3.567^{b}	82.640 ± 0.816^{a}	$F_{2,46}$ = 19.519	$F_{1,46}$ = 12.271	$F_{2,46}$ = 1.231
Wet carcass mass index	♀	81.308 ± 0.860^{a}	65.340 ± 0.686^{c}	72.994 ± 2.319^{b}	P < 0.05	P < 0.05	P > 0.05
胴体干重系数(%)	♂	20.389 ± 0.524	18.968 ± 0.710	20.760 ± 0.340	$F_{2,46}$ = 2.222	$F_{1,46}$ = 3.530	$F_{2,46}$ = 0.020
Dry carcass mass index	♀	18.752 ± 0.654	17.505 ± 0.251	19.504 ± 2.143	P > 0.05	P > 0.05	P > 0.05

双因素方差分析比较各项指标的性别和季节差异；单因素方差分析比较除胴体干重系数外的雌、雄蛙的季节差异。同一行中不同字母代表季节间的差异显著。

Sexual and seasonal differences-two way ANOVA. Seasonal differences of other parameters except for dry carcass mass index for any gender-one way ANOVA. The different letters in the same line represent significant seasonal difference.

表 2 黑斑侧褶蛙总消化道及各段湿重系数的性别和季节差异

Table 2 Sexual and seasonal differences in wet mass indices of total digestive tract and different portions of digestive tract in *Pelophylax nigromaculata*

	性别 Gender	夏季 Summer	秋季 Autumn	春季 Spring	*F* 值和 *P* 值 *F* and *P* values		
样本数 Sample size	♂	8	10	9	季节 Season	性别 Gender	季节 × 性别 Season × Gender
	♀	8	9	8			
总消化道湿重系数(%)	♂	3.123 ± 0.298^{b}	4.055 ± 0.145^{a}	3.424 ± 0.218^{ab}	$F_{2,46}$ = 6.106	$F_{1,46}$ = 17.083	$F_{2,46}$ = 5.168
Total digestive tract wet mass index	♀	3.767 ± 0.209^{b}	4.248 ± 0.275^{ab}	5.223 ± 0.393^{a}	P < 0.05	P < 0.05	P < 0.05
食道湿重系数(%)	♂	0.383 ± 0.092^{b}	0.578 ± 0.064^{a}	0.514 ± 0.055^{ab}	$F_{2,46}$ = 3.925	$F_{1,46}$ = 1.579	$F_{2,46}$ = 0.043
Oesophagus wet mass index	♀	0.465 ± 0.072	0.663 ± 0.045	0.563 ± 0.091	P < 0.05	P > 0.05	P > 0.05
胃湿重系数(%)	♂	1.651 ± 0.161	1.638 ± 0.062	1.481 ± 0.076	$F_{2,46}$ = 2.712	$F_{1,46}$ = 10.007	$F_{2,46}$ = 5.380
Stomach wet mass index	♀	2.032 ± 0.165^{ab}	1.546 ± 0.211^{b}	2.355 ± 0.188^{a}	P > 0.05	P < 0.05	P < 0.05
小肠湿重系数(%)	♂	0.856 ± 0.119^{b}	1.470 ± 0.084^{a}	1.150 ± 0.110^{ab}	$F_{2,46}$ = 20.693	$F_{1,46}$ = 11.005	$F_{2,46}$ = 4.071
Small intestine wet mass index	♀	0.932 ± 0.092^{b}	1.627 ± 0.128^{a}	1.813 ± 0.125^{a}	P < 0.05	P < 0.05	P < 0.05
大肠湿重系数(%)	♂	0.234 ± 0.025^{b}	0.369 ± 0.041^{a}	0.278 ± 0.016^{ab}	$F_{2,46}$ = 6.149	$F_{1,46}$ = 19.602	$F_{2,46}$ = 3.553
Large intestine wet mass index	♀	0.337 ± 0.022^{b}	0.412 ± 0.016^{ab}	0.492 ± 0.058^{a}	P < 0.05	P < 0.05	P < 0.05

双因素方差分析比较各项指标的性别和季节差异；单因素方差分析比较除食道湿重系数外的雌、雄蛙的季节差异。同一行中不同字母代表季节间的差异显著。

Sexual and seasonal differences-two way ANOVA. Seasonal differences of other indices except for oesophagus wet mass index for any gender-one way ANOVA. The different letters in the same line represent significant seasonal difference.

大肠:0.413 ± 0.023)均显著高于雄蛙(胃:1.590 ± 0.058;小肠:1.182 ± 0.075;大肠:0.299 ± 0.020);胃湿重系数无季节性差异,小肠湿重系数雄蛙秋季高于夏季,雌蛙秋季和春季都高于夏季(单因素方差分析,雄蛙:$F_{2,24}$ = 8.806, P < 0.05;雌蛙:$F_{2,22}$ = 15.196, P < 0.05),大肠湿重系数雄蛙秋季高于夏季,雌蛙春季高于夏季(单因素方差分析,雄蛙:$F_{2,24}$ = 5.187, P < 0.05;雌蛙:$F_{2,22}$ = 4.542, P < 0.05)(表 2)。性别和季节对食道湿重系数无交互作用,对其他各段湿重系数有交互作用(表 2)。

2.3　黑斑侧褶蛙总消化道及各段干重系数的性别和季节差异　双因素方差分析表明,总消化道干重系数和胃干重系数雌蛙(消化道干重系数:5.113 ± 0.216;胃干重系数:2.224 ± 0.101)均大于雄蛙(消化道干重系数:4.050 ± 0.225;胃干重系数:1.625 ± 0.072),但均无季节性差异(表 3)。食道、小肠和大肠干重系数均无性别差异,也无明显的季节性差异(表 3)。除胃干重系数外,性别和季节对总消化道干重及各段干重系数均无交互作用(表 3)。

2.4　黑斑侧褶蛙总消化道长及各段长度系数的性别和季节差异　双因素方差分析表明,雌蛙(20.1 ± 1.2)的大肠长系数大于雄蛙(16.9 ± 0.8),但无季节性差异(表 4)。总消化道长及其余各段的长度系数均无性别差异;总消化道长、食道长及胃长系数秋季和春季都高于夏季,小肠长系数无季节性差异(表 4)。性别和季节对总消化道长、小肠长和大肠长系数无交互作用,但对食道长和胃长系数有交互作用(表 4)。

表 3　黑斑侧褶蛙总消化道及各段干重系数的性别和季节差异

Table 3　Sexual and seasonal differences in dry mass indices of total digestive tract and different portions of digestive tract in *Pelophylax nigromaculata*

	性别 Gender	夏季 Summer	秋季 Autumn	春季 Spring	F 值和 P 值 F and P values		
样本数 Sample size	♂	8	10	9	季节 Season	性别 Gender	季节 × 性别 Season × Gender
	♀	8	9	8			
总消化道干重系数(%)	♂	3.818 ± 0.480	4.615 ± 0.379	3.628 ± 0.247	$F_{2,46}$ = 1.645	$F_{1,46}$ = 12.136	$F_{2,46}$ = 0.582
Total digestive tract dry mass index	♀	4.916 ± 0.473	5.291 ± 0.321	5.109 ± 0.363	P > 0.05	P < 0.05	P > 0.05
食道干重系数(%)	♂	0.612 ± 0.162	0.730 ± 0.118	0.539 ± 0.051	$F_{2,46}$ = 2.345	$F_{1,46}$ = 2.363	$F_{2,46}$ = 0.031
Oesophagus dry mass index	♀	0.750 ± 0.116	0.877 ± 0.050	0.638 ± 0.071	P > 0.05	P > 0.05	P > 0.05
胃干重系数(%)	♂	1.585 ± 0.168	1.778 ± 0.107	1.491 ± 0.094	$F_{2,46}$ = 0.275	$F_{1,46}$ = 27.246	$F_{2,46}$ = 3.958
Stomach dry mass index	♀	2.287 ± 0.177	1.962 ± 0.193	2.457 ± 0.105	P > 0.05	P < 0.05	P < 0.05
小肠干重系数(%)	♂	1.211 ± 0.273	1.720 ± 0.240	1.255 ± 0.192	$F_{2,46}$ = 3.127	$F_{1,46}$ = 2.064	$F_{2,46}$ = 0.065
Small intestine dry mass index	♀	1.399 ± 0.229	2.003 ± 0.153	1.618 ± 0.315	P > 0.05	P > 0.05	P > 0.05
大肠干重系数(%)	♂	0.410 ± 0.089	0.386 ± 0.061	0.343 ± 0.052	$F_{2,46}$ = 0.548	$F_{1,46}$ = 1.098	$F_{2,46}$ = 0.006
Large intestine dry mass index	♀	0.480 ± 0.116	0.448 ± 0.027	0.396 ± 0.071	P > 0.05	P > 0.05	P > 0.05

双因素方差分析比较各项指标的性别和季节差异;单因素方差分析比较总消化道及胃干重系数雌、雄蛙的季节差异。同一行中不同字母代表季节间的差异显著。

Sexual and seasonal differences-two way ANOVA. Seasonal differences of total digestive tract and stomach dry mass indices for any gender-one way ANOVA. The different letters in the same line represent significant seasonal difference.

表 4 黑斑侧褶蛙总消化道及各段长度系数的性别和季节差异

Table 4 Sexual and seasonal differences in length indices of total digestive tract and different portions of digestive tract in *Pelophylax nigromaculata*

	性别 Gender	夏季 Summer	秋季 Autumn	春季 Spring	*F* 值和 *P* 值 *F* and *P* values		
样本数 Sample size	♂	8	10	9	季节 Season	性别 Gender	季节 × 性别 Season × Gender
	♀	8	9	8			
总消化道长系数(%)	♂	145.5 ± 10.8[b]	175.8 ± 5.3[a]	182.0 ± 18.8[a]	$F_{2,46}$ = 5.373	$F_{1,46}$ = 0.416	$F_{2,46}$ = 0.099
Total digestive tract length index	♀	148.0 ± 11.5	188.8 ± 14.3	186.6 ± 11.0	P < 0.05	P > 0.05	P > 0.05
食道长系数(%)	♂	7.0 ± 1.4[b]	12.3 ± 1.3[a]	14.1 ± 1.9[a]	$F_{2,46}$ = 14.994	$F_{1,46}$ = 0.285	$F_{2,46}$ = 5.153
Oesophagus length index	♀	7.7 ± 1.3	17.2 ± 0.8	10.3 ± 1.2	P < 0.05	P > 0.05	P < 0.05
胃长系数(%)	♂	26.6 ± 1.4[b]	40.4 ± 1.1[a]	37.6 ± 3.3[a]	$F_{2,46}$ = 14.852	$F_{1,46}$ = 1.589	$F_{2,46}$ = 8.915
Stomach length index	♀	33.2 ± 2.1	32.7 ± 1.5	45.2 ± 2.4	P < 0.05	P > 0.05	P < 0.05
小肠长系数(%)	♂	95.9 ± 9.7	104.5 ± 4.8	114.4 ± 16.4	$F_{2,46}$ = 1.619	$F_{1,46}$ = 0.006	$F_{2,46}$ = 0.430
Small intestine length index	♀	90.2 ± 9.0	117.3 ± 13.9	109.4 ± 11.7	P > 0.05	P > 0.05	P > 0.05
大肠长系数(%)	♂	16.0 ± 1.2	18.6 ± 1.8	15.8 ± 0.9	$F_{2,46}$ = 2.492	$F_{1,46}$ = 5.549	$F_{2,46}$ = 1.040
Large intestine length index	♀	16.9 ± 1.7	21.6 ± 1.1	21.6 ± 2.8	P > 0.05	P < 0.05	P > 0.05

双因素方差分析比较各项指标的性别和季节差异；单因素方差分析比较大肠长系数雌、雄蛙的季节差异。同一行中不同字母代表季节间的差异显著。

Sexual and seasonal differences-two way ANOVA. Seasonal differences of large intestine index for any gender-one way ANOVA. The different letters in the same line represent significant seasonal difference.

3 讨 论

黑斑侧褶蛙消化道各段的湿重、干重及长度系数有性别差异的指标，均表现为雌蛙高于雄蛙；食道、小肠和大肠的湿重系数及食道长和胃长系数秋季或春季都高于夏季，表现出一定的弹性特征，这与各器官的功能及其生活环境的多样性是相适应的。

3.1 黑斑侧褶蛙消化道重量的性别和季节差异 黑斑侧褶蛙除食道湿重系数无性别差异外，总消化道及各段的湿重系数雌蛙均高于雄蛙；食道、小肠和大肠的湿重系数都在春季或秋季最高，夏季最低。当环境条件发生改变时，脊椎动物的消化系统是反应最为灵活的系统之一(Starck 1999, 2005, McWilliams et al. 2001, Naya et al. 2004, 2007, Karasov et al. 2011)。胃肠道代表了能量摄入和能量分配两者之间的功能性的联结，因而在器官进化过程中，可能经历许多选择性的压力(Secor 2001)。经验数据表明，两栖动物消化道的重量具有性别差异和季节动态(Naya et al. 2004)。Juszczyk 等(1966)测定了 5 个不同年龄段雌性和雄性林蛙消化道重量及胃肠道组织学结构的季节动态，发现消化道的发育具有明显的季节性，并与年取食周期相关，且处于高取食活动期的雌蛙消化道的重量高于雄蛙。安第斯刺蟾胃和小肠的湿重受食物条件影响较大，在摄食期间最高，禁食期其次，冬眠时处于最低水平(Naya et al. 2009b)。对多种夏眠蛙类的研究表明，消化道的重量在夏眠期间均显著下降(Cramp et al. 2005a, b, Secor 2005a, Secor et al. 2010)。例如，与摄食期相比，1 周的短期禁食对戈式拨土蛙(*Cyclorana alboguttata*)的胃和大肠的湿重无明显影响，但小肠的湿重明显下降，且随着夏眠时间的延长(3 个月和 9 个月)，胃、小肠和大肠的湿重均明显降低

(Cramp et al. 2005b)。然而,成年牛蛙(*R. catesbeiana*)的肠道湿重并不随着食物成分的变化而改变(Toloza et al. 1990)。除食物外,环境温度也会影响两栖类消化道的结构和功能。与21℃正常摄食组相比,21℃下禁食2周对豹蛙(*R. pipens*)大肠内容物和黏膜的细菌总数及细菌的种类均无明显影响,但在4℃下冷诱导1周或模拟冬眠状态3周后,细菌总数及其种类均显著下降(Goslling et al. 1982)。我们捕捉黑斑侧褶蛙的地点为聊城大学校园内的池塘,该处有较多的杂草和昆虫,有利于黑斑侧褶蛙的隐蔽和摄食。胃主要执行机械消化的功能,小肠则是消化和吸收食物的主要器官。7月份、10月初和翌年的5月中旬,分别是黑斑侧褶蛙的繁殖期、冬眠前的准备期和冬眠后的觅食高峰期,黑斑侧褶蛙总消化道干重和胃干重系数雌蛙大于雄蛙,可能与雌蛙出眠后积极参与繁殖活动,需要贮备和消耗更多的能量有关。雄蛙的胃干重系数与其他干重系数的季节性变化趋势相似,都在秋季较高,春、夏季较低;雌蛙的胃干重系数却秋季最低,春季最高,但小肠干重系数仍在秋季最高,春季和夏季最低,这可能与蛙体内营养物质的重新分配和转化有关。冬眠前黑斑侧褶蛙的消化吸收能力增强,这为体内合成更多的脂肪创造了条件,为顺利冬眠奠定了良好的物质基础。尽管我们没有测定冬眠期黑斑侧褶蛙消化道的重量,但可以预测,随着食物资源的匮乏和环境温度的急剧下降,其消化道的重量也会降低。

3.2　黑斑侧褶蛙消化道长度的性别和季节差异　一种细趾蟾(*Leptodactylus ocellatus*)的肠道长度具有明显的季节性变化,且与年取食周期和繁殖状态密切相关。其中,雄蟾肠道长度的季节性波动与年取食周期有关;雌蟾主要与繁殖周期有关,其季节性变化比雄蟾更为明显(Naya et al. 2003)。安第斯刺蟾胃和小肠的长度在自由取食组最长,禁食组其次,冬眠组最短(Naya et al. 2009b),且小肠长度随纬度而变化,但大肠长度无纬度差异(Naya et al. 2009a)。自由取食组、禁食组和夏眠组相比,多种蛙类小肠的长度均逐渐下降,至夏眠期降到最低值(Cramp et al. 2005a, b, Secor 2005a, Secor et al. 2010)。黑斑侧褶蛙消化道总长和消化道各段的长度系数除大肠长系数雌蛙高于雄蛙外,均无性别差异;总消化道长、食道长和胃长系数均在秋季和春季最大,夏季最小;小肠长和大肠长系数也表现出了相似的变化趋势,但无季节性差异。我们认为,这种弹性变化与黑斑侧褶蛙的摄食习性和消化生理相关。秋、春季适当延长的食道和胃,有助于其吞咽和贮存较大的食物,略显膨大的小肠则有助于食物消化和吸收过程的完成,而变粗的大肠有利于水分的重吸收和食物残渣的排出。

两栖动物经过亿万年的进化,已进化出一套应对环境胁迫的适应性机制。随着全球变暖,其生存正面临着前所未有的威胁。消化道的重量和长度对外界环境因素的改变具有高度的敏感性,并可迅速做出响应。我们的研究发现,在较为温和的夏、秋和春季,黑斑侧褶蛙消化道的重量和长度也会随着季节更替而发生适应性改变,这种弹性变化有助于提高黑斑侧褶蛙的生存和适应能力。

致谢　感谢聊城大学农学院赵志军教授提供便利的实验条件及实验全程给予的支持和帮助!安徽农业大学2012级硕士研究生瞿康山,本科生黄淑丽、咸振飞、傅朝波和王杰等同学参与部分实验过程。

参　考　文　献

Cramp R L, Franklin C E. 2005a. Arousal and re-feeding rapidly restores digestive tract morphology following aestivation in green-striped burrowing frogs. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 142(4): 451–460.

Cramp R L, Franklin C E, Meyer E A. 2005b. The impact of prolonged fasting during aestivation on the structure of the small intestine in the green-striped burrowing frog, *Cyclorana alboguttata*. Acta Zoologica, 86(1): 13–24.

Goslling J, Loesche W J, Nace G W. 1982. Response of intestinal flora of laboratory-reared leopard frogs (*Rana pipens*) to cold and fasting. Applied and Environmental Microbiology, 44(1): 67–71.

Juszczyk W, Obrzut K, Zamachowski W. 1966. Morphological changes in the alimentary canal of the common frog (*Rana temporaria* L.) in the annual cycle. Acta Biologica Cracoviensia Series Zoologia, 9: 239 – 246.

Karasov W H, Martinez Del Rio C, Carviedes-Vidal E. 2011. Ecological physiology of diet and digestive systems. Annual Review of Physiology, 73(1): 69 – 93.

McWilliams S R, Karasov W H. 2001. Phenotypic flexibility in digestive system structure and function in migratory birds and its ecological significance. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 128(3): 579 – 593.

Naya D E, Bozinovic F. 2004. Digestive phenotypic flexibility in post-metamorphic amphibians: studies on a model organism. Biological Research, 37(3): 365 – 370.

Naya D E, Farfat G, Mendez M, et al. 2005. Digestive performance in the Andean toad *Bufo spinulosus*: flexibility or hard-wired physiology? Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 140(2): 165 – 170.

Naya D E, Karasov W H, Bozinovic F. 2007. Phenotypic plasticity in laboratory mice and rats: a meta-analysis of current ideas on gut size flexibility. Evolutionary Ecology Research, 9(8): 1363 – 1374.

Naya D E, Maneyro R, Camargo A, et al. 2003. Annual changes in gut length of South American common frog (*Leptodactylus ocellatus*). Biociencias, 11(1): 47 – 52.

Naya D E, Veloso C, Bozinovic F. 2008. Physiological flexibility in the Andean lizard *Liolaemus bellii*: seasonal changes in energy acquisition, storage and expenditure. Journal of Comparative Physiology B: Biochemical Systemic and Environmental Physiology, 178(8): 1007 – 1015.

Naya D E, Veloso C, Bozinovic F. 2009a. Gut size variation among *Bufo spinulosus* populations along an altitudinal (and dietary) gradient. Annales Zoologici Fennici, 46(1): 16 – 20.

Naya D E, Veloso C, Sabat P, et al. 2009b. The effect of short- and long-term fasting on digestive and metabolic flexibility in the Andean toad, *Bufo spinulosus*. The Journal of Experimental Biology, 212(14): 2167 – 2175.

Pan H Z, Chen H H, Zhu L J, et al. 2009. Adaptive changes of gastro-entero-pancreatic system endocrine cells in the black-spotted pond frog *Rana nigromaculata* after fasting. Current Zoology, 55(4): 301 – 308.

Piersma T, Drent J. 2003. Phenotypic flexibility and the evolution of organismal design. Trends in Ecology & Evolution, 18(5): 228 – 233.

Secor S M. 2001. Regulation of digestive performance: a proposed adaptive response. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 128(3): 563 – 577.

Secor S M. 2005a. Physiological responses to feeding, fasting and estivation for anurans. The Journal of Experimental Biology, 208(13): 2595 – 2608.

Secor S M. 2005b. Evolutionary and cellular mechanisms regulating intestinal performance of amphibians and reptiles. Integrative and Comparative Biology, 45(2): 282 – 294.

Secor S M, Lignot J H. 2010. Morphological plasticity of vertebrate aestivation. Progress in Molecular and Subcellular Biology, 49: 183 – 208.

Seliverstova E V, Prutskova N P. 2012. Morphofunctional changes in the small intestine epithelium of the frog *Rana temporaria* in the course of hibernation. Journal of Evolutionary Biochemistry and Physiology, 48(3): 295 – 305.

Starck J M. 1999. Structural flexibility of the gastro-intestinal tract of vertebrates-implications for evolutionary morphology. Zoologischer Anzeiger, 238(1): 87 – 101.

Starck J M. 2005. Structural flexibility of the digestive system of tetrapods-patterns and processes at the cellular and tissue level // Starck J M, Wang T. Physiological and Ecological Adaptations to Feeding in Vertebrates. Enfield, New Hampshire: Science Publishers, 175 – 200.

Toloza E M, Diamond J M. 1990. Ontogenetic development of nutrient transporters in bullfrog intestine. American Journal of Physiology: Gastrointestinal and Liver Physiology, 258(5): 760 – 769.

曹玉萍, 白明, 马荣, 等. 2000. 黑斑蛙蛰眠前后形态生理生态变化初探. 四川动物, 19(3): 159 – 162.

吴云龙. 1965. 黑斑蛙自然冬眠时肥满度与某些内脏器官的变化. 动物学杂志, 7(3): 116 – 119.