文章编号: 1000−0615(2016)04−0566−11 DOI: 10.11964/jfc.20150709984

草鱼体组成的数学描述

陈拥军[1,2*]， 邹 滔[1]， 林仕梅[1]， 罗 莉[1]， 李 云[1]

(1. 西南大学动物科技学院，水产科学重庆市市级重点实验室，重庆 400715;
2. 西南大学生命科学学院，淡水鱼类资源与生殖发育教育部重点实验室，重庆 400715)

摘要：为了对草鱼体组成进行定量描述，本研究从中外文数据库收集并采纳了51个草鱼营养生理相关研究的数据，数据点约3700个，草鱼体质量为1.52~694.80 g。通过数据整理、相关性分析和线性回归分析，结果显示，草鱼蛋白质含量和内脏重(y，g)与体质量(x，g)间的线性关系分别为y=0.1604x–0.3645，R^2=0.994；y=0.1059x–0.3097，R^2=0.9875。随着草鱼体质量增加，草鱼脂肪和灰分含量(尤其是脂肪含量)受饲料组成的影响逐渐增加。草鱼全鱼每沉积1 g蛋白质伴随着4.57 g水分保留，而每沉积1 g脂肪会导致水分含量减少0.95 g。草鱼肝脏每沉积1 g脂肪会导致其水分含量减少0.66 g，说明草鱼不同组织沉积脂肪导致的水分损失率不尽相同。本研究亦表明，肠系膜是草鱼脂肪沉积的重要部位，肠系膜、肝脏和肌肉脂肪的积累是全鱼脂肪含量上升的重要原因，全鱼脂肪累积伴随着内脏重的增加。本研究的执行有利于定量描述草鱼体组成规律，为草鱼的生产和销售提供指导作用。

关键词: 草鱼；体组成；形态学参数；定量描述

中图分类号: S 917.4 **文献标志码:** A

现代水产养殖面临着成本上升、利润空间缩小、低环境负荷及消费者需求多样化等多方面的挑战。使用营养数学模型在一定程度上可较准确地预测养殖鱼类的摄食量[1]、营养素的排泄[1-2]、营养素的利用效率[3]、体增长以及体组成[4-5]，因而可避免生产实践中的过量投饲(根据水温及体质量预测摄食量)、减少养殖实践操作的成本(理化分析、耗材试剂及人工成本)、降低环境污染等。同时，营养数学模型的应用还可了解鱼类的近似组成、饲料利用效率及营养素沉积效率的界限，揭示营养素在鱼体的沉积规律，有利于准确调控鱼体的营养组成，生产符合人类需求的水产品[5]。

研究表明，鱼类全鱼、肝脏及肌肉的近似组成(水分、蛋白质、脂肪和灰分)容易受到生长阶段、饲料组成、季节变化等因素影响[6]。尽管已有个别研究借助回归分析来预测养殖鱼类的体组成，但数据来源仅限于单个实验[7-8]。草鱼(*Ctenopharyngodon idella*)是我国最重要的淡水经济鱼类之一，其产量居于我国淡水鱼类之首。2013年，我国草鱼总产量为约506.99万t，比产量第二的鲢(*Hypophthalmichthys molitrix*)高出约121.91万t[9]。目前，关于草鱼营养生理的研究已十分丰富。因此，本研究收集了现有中外数据库中有关草鱼的体组成和形态学数据，加以整理分析，利用数学公式来描述草鱼的体组成，揭示其体组成的生物学规律。

1 材料与方法

1.1 数据收集

本研究从中外数据库收集到了含草鱼常规营养组成及形态学指标数据的文献53篇[10-62]，文献

收稿日期：2015-07-21 **修回日期**：2016-01-18

资助项目：国家自然科学基金(31502181)；中国博士后科学基金面上资助(2015M582505)；重庆市项目博士后资助(Xm2015045)；中央高校基本科研业务费(XDJK2015C080)

通信作者：陈拥军，E-mail: joy616722@hotmail.com

的时间跨度为2002—2015年，草鱼体质量的跨度为1.52~5500.00 g。收集的文献囊括了蛋白质与氨基酸水平、碳水化合物水平、脂肪与脂肪酸水平、矿物盐水平、饲料添加剂、原料评估等对草鱼体组成的潜在影响。

本研究所涉及的体组成包括草鱼全鱼、肌肉(白肌)和肝脏的常规营养组成，即水分(%)、粗脂肪(%)、粗蛋白(%)和灰分含量(%)。常规营养组成参照标准操作方法进行测定[63]。本研究所涉及的形态学参数包括脏体系数(VSI，%)、肠脂系数(IPF，%)和肝体系数(HSI，%)。所有指标均是在养殖实验结束后，草鱼摄食最后一餐并禁食24 h后测定的。本研究所涉及指标的单个数据并不是每尾鱼的实际测定值，而是指文献报道中每个实验处理组的平均值，即包含了多个重复多尾鱼的平均值。

1.2 数据整理

经过数据输入与统计，涉及草鱼全鱼和肌肉组成的文献有45篇[10-54]。草鱼全鱼组成的体质量跨度为1.52~1070.17 g。但是，仅1篇文献的草鱼体质量范围为900.50~1070.17 g[53]，其余均集中在1.52~423.90 g，所以本研究采纳后者进行后续分析。草鱼肌肉组成的体质量范围为5.05~5500.00 g，但绝大部分文献体质量均集中在5.05~694.80 g，仅1篇文献的体质量范围为3850~5500 g[54]，因而采用前者进行数据分析。涉及草鱼形态学参数的文献有34篇[27-52, 55-62]，相对草鱼体组成而额外多出的文献的体质量上限均低于687.02 g[55-62]。

1.3 数据分析

本研究中，所有数据均以平均值±标准差(mean±SD)表示。采用SPSS 11.5统计软件的相关性分析和线性回归分析来探索变量间的相互关系，相关分析的显著性水平设置为0.05。当Pearson相关系数$|r|>0.8$时，视为两变量间存在强相关性，并进行后续线性回归分析。

回归直线方程：$y = \mathrm{a}x + \mathrm{b}$。其中，$y$代表因变量，a代表回归直线的斜率，$x$代表自变量，b为回归直线在x轴的截距。

2 结果

2.1 数据收集与整理概述

通过数据搜索与核实，本研究总共收集并采纳了约3700个数据。其中，全鱼组成共1407个数据，肌肉组成共843个数据，肝脏组成共451个数据，形态学参数共1003个数据(表1)。草鱼体质量的变动范围为1.52~694.80 g，即数据反映的是草鱼幼鱼阶段的体组成情况。尽管收集的全鱼组成数据对应的草鱼体质量范围为1.52~423.90 g，

表1 草鱼体组成的数学统计

Tab. 1 Chemical characteristics and physical composition of grass carp

参数 parameter	数据量(n) data volume	平均值/% mean value	变动范围/% variable range	体质量范围/g body weight range
全鱼水分 whole-body moisture	356	74.92±2.43	65.03~81.70	1.52~423.90
全鱼蛋白 whole-body protein	353	14.39±1.35	10.80~18.29	1.52~423.90
全鱼脂肪 whole-body lipid	375	7.20±2.06	3.28~14.80	1.52~423.90
全鱼灰分 whole-body ash	323	2.02±0.44	1.96~4.69	1.52~423.90
肌肉水分 muscle moisture	237	79.29±1.35	73.70~82.62	5.05~694.80
肌肉蛋白 muscle protein	250	17.62±1.36	14.03~23.12	5.05~694.80
肌肉脂肪 muscle lipid	262	1.55±0.64	0.65~3.86	4.43~694.80
肌肉灰分 muscle ash	94	1.45±0.71	0.83~3.73	10.91~694.80
肝脏水分 liver moisture	259	62.17±5.64	45.8~74.3	4.43~373.84
肝脏脂肪 liver lipid	192	16.86±7.65	2.29~38.40	4.43~373.84
脏体系数 viscerosomatic index	328	10.10±1.42	6.87~15.59	4.43~687.02
肝体系数 hepatosomatic index	371	2.55±0.55	1.20~4.31	4.43~687.02
肠脂系数 intraperitoneal fat ratio	304	2.28±0.99	0.64~7.06	4.43~687.02

但约88%的数据点对应的草鱼体质量低于100 g(图1-a)。肌肉组成数据对应的草鱼体质量为5.05~694.80 g，约79%的数据点对应的草鱼体质量低于100 g(图1-b)。草鱼全鱼组成各成分的数据量大小相近(n=323~375)，随着草鱼体质量(g)增加，全鱼水分(74.92%±2.43%)和蛋白含量(14.39%±1.35%)较为恒定，全鱼灰分含量(2.02%±0.44%)次之，全鱼脂肪含量(7.20%±2.06%)波动幅度较大。肌肉水分、蛋白和脂肪的数据量相当(n=237~262)，肌肉水分含量(79.29%±1.35%)较为稳定，肌肉蛋白含量(17.62%±1.36%)次之，肌肉脂肪含量(1.55%±0.64%)波动幅度较大(表1)。

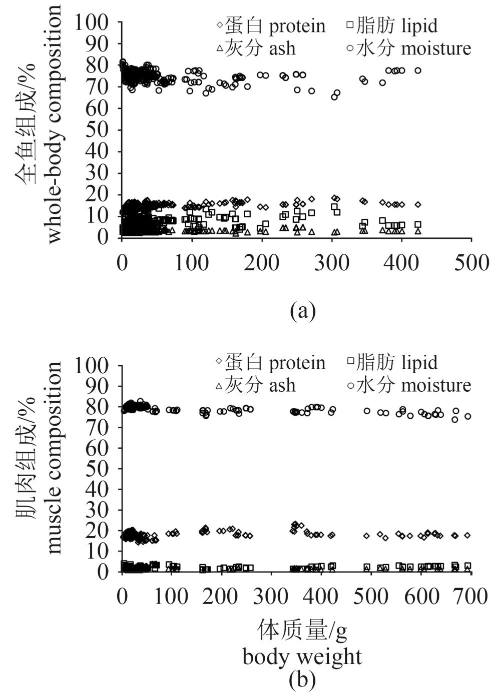

图 1 草鱼全鱼(a)和肌肉(b)组成数据

Fig. 1 Data of whole-body (a) and muscle (b) composition of grass carp

2.2 草鱼全鱼、肝脏及肌肉组成

草鱼蛋白、脂肪和灰分含量以及内脏重均与草鱼体质量呈极显著正相关(P=0.000，r>0.930)(表2)。随着草鱼体质量增加，全鱼蛋白、脂肪和灰分含量以及内脏重逐渐增加(图2)。回归分析表明，草鱼蛋白含量(y)与草鱼体质量(x)的线性关系为y=0.1604x–0.3645，R^2=0.994(公式1，图2-a)；草鱼脂肪含量(y)与草鱼体质量(x)的线性关系为y=0.0777x–0.0526，R^2=0.8643(公式2，图2-b)；草鱼灰分含量(y)与草鱼体质量(x)的线性关系为y=0.0344x–0.081，R^2=0.9426(公式3，图2-c)；草鱼内脏重(y)与草鱼体质量(x)的线性关系为y=0.1059x–0.3097，R^2=0.9875(公式4，图2-d)。

全鱼蛋白与全鱼水分之间呈现极显著正相关关系(P=0.000，r=0.992)。全鱼水分与全鱼脂肪

表 2 本研究相关分析的数据量、显著性水平及相关系数

Tab. 2 Data volume, significance and coefficient of the correlation analysis in this study

图例 figures	数据量(n) data volume	显著性水平(P) significance	相关系数(r) correlation coefficient
图2-a Fig. 2-a	353	0.000	0.997
图2-b Fig. 2-b	375	0.000	0.930
图2-c Fig. 2-c	323	0.000	0.971
图2-d Fig. 2-d	328	0.000	0.994
图3-a Fig. 3-a	344	0.000	0.992
图3-b Fig. 3-b	356	0.000	–0.805
图3-c Fig. 3-c	225	0.000	–0.485
图3-d Fig. 3-d	192	0.000	–0.904
图4-a Fig. 4-a	225	0.000	0.265
图4-b Fig. 4-b	240	0.000	0.515
图5-a Fig. 5-a	256	0.000	0.523
图5-b Fig. 5-b	255	0.000	0.765
图5-c Fig. 5-c	257	0.381	

(P=0.000，r=−0.805)、肌肉水分与肌肉脂肪(P=0.000，r=−0.485)以及肝脏水分与肝脏脂肪之间均呈现极显著负相关(P=0.000，r=−0.904)(表2)。线性回归分析表明，草鱼全鱼水分含量(y)与全鱼蛋白含量(x)的线性关系为y=4.571x+1.993，R^2=0.9844(公式5，图3-a)；草鱼全鱼水分含量(y)与全鱼脂肪含量(x)的线性关系为y=−0.9522x+81.757，R^2=0.6487(公式6，图3-b)；草鱼肝脏水分含量(y)与肝脏脂肪含量(x)的线性关系为y=−0.6623x+73.321，R^2=0.8166(公式7，图3-d)。

虽然草鱼肌肉脂肪与全鱼脂肪以及肝脏脂肪与全鱼脂肪均存在显著正相关关系(P=0.000)，但相关系数r均低于0.8(表2，图4)。

2.3 形态学参数与全鱼脂肪的相关性

VSI与全鱼脂肪间以及IPF与全鱼脂肪之间均呈现极显著正相关关系(P=0.000)，但相关系数r均低于0.8。HSI与全鱼脂肪之间并不存在显著相关关系(P=0.385) (图5)。

3 讨论

虽然本研究所收集的53篇文献的草鱼体质量跨度为1.52~5500.00 g[10-62]，但仅2篇文献的草鱼体质量大于900.50 g[53-54]，其余文献的草鱼体质量范围均集中在1.52~694.80 g。本研究中草鱼均处于幼鱼阶段，营养物质的积累规律较为一致，有利于本研究运用数学公式预测草鱼体组成的准确性。

本研究表明，草鱼蛋白含量、脂肪含量、灰分含量和内脏重均与草鱼体质量存在良好的线性关系(R^2>0.864)。随着草鱼体质量增加，草鱼的实际蛋白含量和内脏重与预测值偏差较小。然而，当草鱼体质量增加至150 g以上时，同一体质量下，全鱼灰分含量的最大值可能是最低值的2倍 [43, 48]，而全鱼脂肪含量的最大值可能为最低值的3倍 [39, 43]。因此，当草鱼体质量已知时，其蛋白含量和内脏重可通过公式1和4进行较为准确的预测。根据公式4计算出鱼体的内脏重后，也就能对鱼体可食部分的重量进行初步预测。由于鱼类脂肪组成易受饲料投饲策略[7]、能量水平[24, 27, 30-31]及投喂率[64]影响，要准确预测草鱼的脂肪和灰分含量，可能需依赖更为精准的数学模型将这些因素纳入。

本研究表明，草鱼幼鱼体质量每增加1 g，其蛋白、脂肪、灰分和内脏重分别增加约

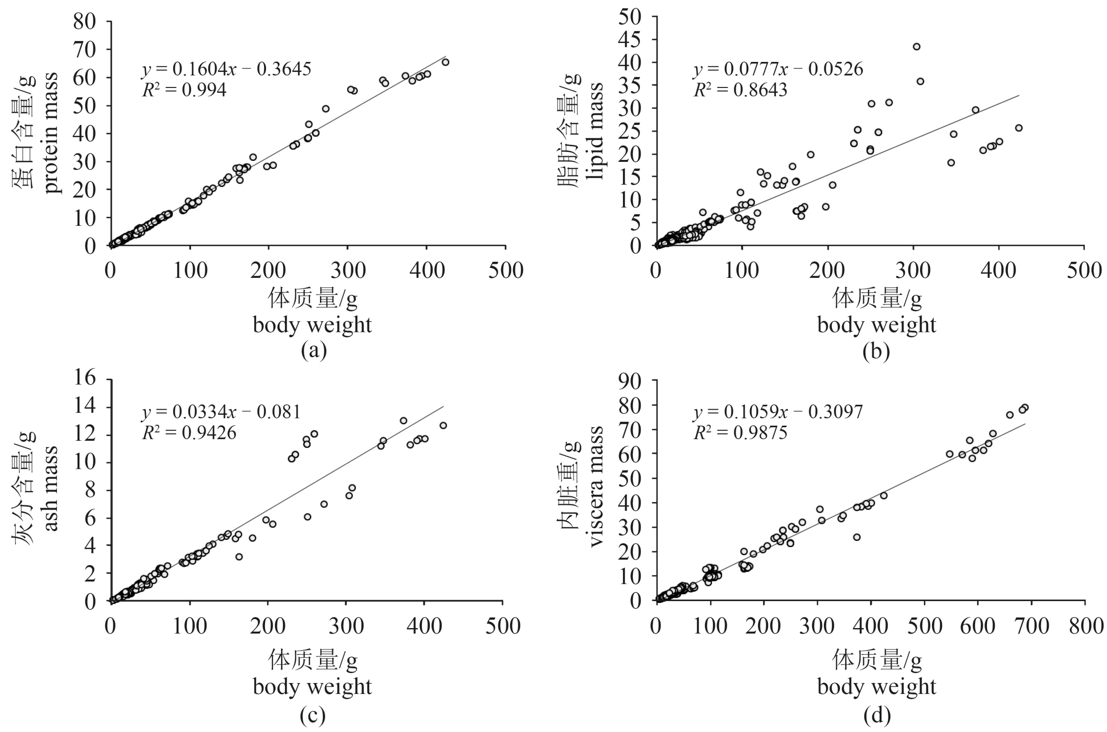

图 2 蛋白(a)、脂肪(b)、灰分(c)及内脏重(d)与草鱼体质量的线性关系

Fig. 2 Linear relationship of protein (a), lipid (b), ash (c) and viscera mass (d) with body weight of grass carp

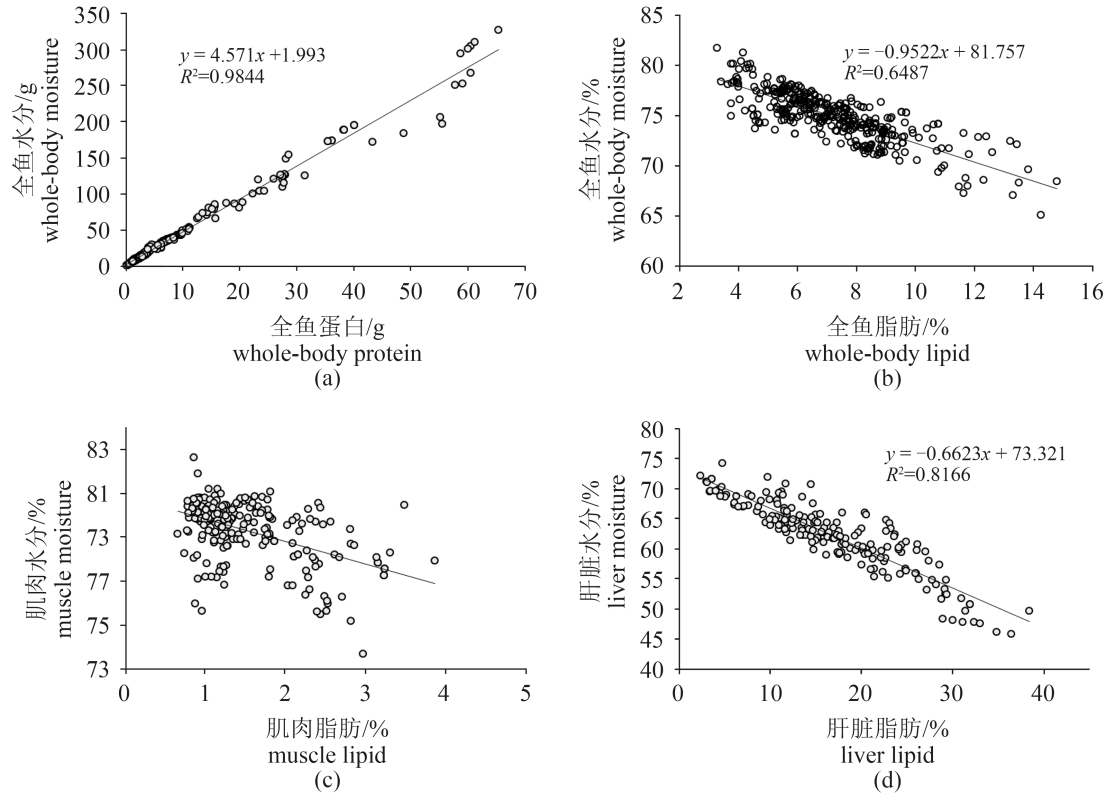

图 3 草鱼全鱼蛋白(a)、全鱼脂肪(b)、肌肉脂肪(c)和肝脏脂肪(d)含量与水分含量的关系

Fig. 3 Relationship of protein (a) and lipid content in the whole-body (b), muscle (c) and liver (d) of grass carp with moisture content

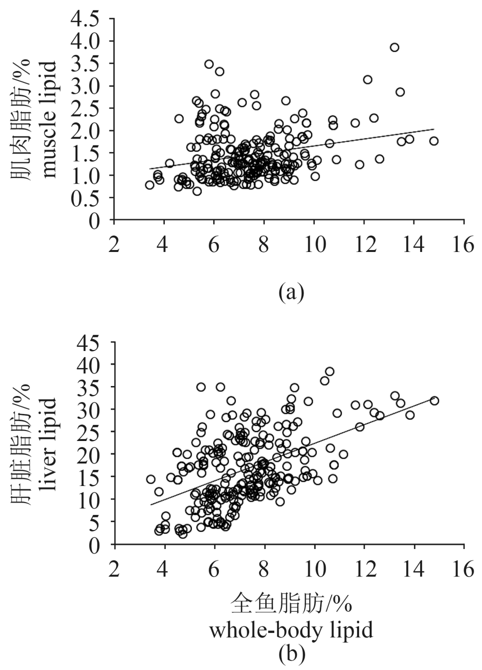

图 4 草鱼肌肉(a)和肝脏(b)脂肪含量与全鱼脂肪含量的相关性

Fig. 4 Correlation of muscle (a) and liver (b) lipid with whole-body lipid content of grass carp

0.160，0.078、0.033和0.106 g。据报道，虹鳟(*Oncorhynchus mykiss*)体质量每增加1 g，其蛋白、脂肪、灰分和内脏重分别增加约0.164、0.166、0.018和0.115 g[65]。这说明，鱼类食性不同，其体组成的物理和化学特征均有较大差异。同一食性的不同鱼种，其体组成的物理及化学特征的差异有多大还有待进一步比较研究。本研究表明，草鱼每沉积1 g蛋白质，鱼体便会保留4.57 g水分。在虹鳟体内，每1 g蛋白质在鱼体沉积会导致3.9 g水分保留[65]，这部分解释了虹鳟全鱼水分(70.9%±4.5%)低于草鱼全鱼水分(74.9%±2.4%)的原因。由于草鱼全鱼蛋白和水分含量之间的良好线性关系(R^2=0.9844)，当水分含量已知时，可通过公式5预测全鱼的蛋白质含量。

当今，鱼体的脂肪含量和脂肪沉积部位越来越受到消费者的关注。消费者对不同渔产品的需求也不尽相同：对于大西洋鲑(*Salmo salar*)，肌肉是其重要的脂肪储存部位，通过营养调节适当增加其脂肪含量可能会提升肌肉口感；但对于草鱼

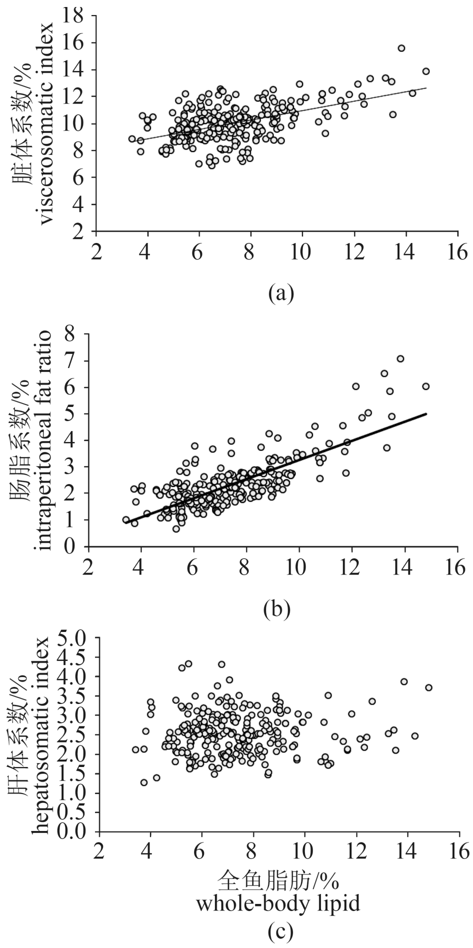

图 5　草鱼脏体系数(a)、肠脂系数(b)和肝体系数(c)与全鱼脂肪含量的相关性

Fig. 5　Correlation of viscerosomatic index (a), intraperitoneal fat ratio (b) and hepatosomatic index (c) with whole-body lipid content (%) of grass carp

而言，肠系膜是其脂肪蓄积的重要部位，饲料可消化能水平增加可能会导致出现脂肪肝[27]和大肚腩现象[29]，不利于草鱼的生产销售。本研究表明，无论是草鱼全鱼、肌肉还是肝脏，其水分含量与脂肪含量之间均呈现极显著负相关关系，这也与先前众多研究结果一致[13, 24, 27, 29-32, 40-41, 45]，但是肌肉水分与脂肪含量间的相关性较弱(r=–0.485)。本研究发现，草鱼每沉积1 g脂肪，鱼体便会减少0.952 g水分；肝脏每沉积1 g脂肪，肝脏水分仅减少0.662 g。虹鳟全鱼每沉积1 g脂肪便会损失1.062 g水分，可食部分每沉积1 g脂肪便会损失1.162 g水分，而内脏团每沉积1 g脂肪便会损失0.862 g水分[65]。这说明营养素在体内的沉积规律随鱼种不同而不同，并且同一鱼种不同组织器官的营养素沉积规律也不一致。另外，本研究也表明，鱼体的水分含量与其蛋白和脂肪含量均密切相关。这也为提升饲料蛋白水平会导致全鱼水分含量增加[13, 32, 45]，而提升饲料能量水平会导致全鱼水分含量下降等研究结果[27, 29, 41]提供了解释。

本研究发现，全鱼脂肪含量与肌肉和肝脏的脂肪含量均呈现极显著正相关关系。一方面，肌肉占据了养殖鱼类体质量的绝大部分[66-67]，肌肉脂肪含量的提升会促使鱼体脂肪积累；另一方面，肝脏作为鱼体脂肪合成最重要的部位，肝脏的脂肪积累(脂肪合成速率大于脂肪分解速率)也可能对其他组织和全鱼脂肪积累做出贡献。此外，本研究还发现草鱼全鱼脂肪含量与VSI和IPF呈现极显著正相关，但与HSI并不显著相关，这说明肠系膜是草鱼脂肪的重要沉积部位；当全鱼脂肪水平上升时，伴随着内脏质量的升高；内脏质量升高的部分原因为肠脂积累的增加，而不是肝脏质量增加所致。

综上，本研究首次运用营养数学模型描述了草鱼的体组成特征，并得出如下结论：草鱼幼鱼蛋白含量和内脏重可通过公式1和4进行预测；草鱼鱼体蛋白质的积累会导致全鱼水分增加，而鱼体脂肪的积累会导致全鱼水分含量下降；全鱼脂肪积累上升的主要原因为肝脏、肠系膜和肌肉脂肪含量的上升。从本研究可以看出，现有关于草鱼营养生理的研究仍主要集中在幼鱼阶段，且80%的研究中草鱼终末体质量小于100 g，这不利于揭示不同生长阶段草鱼体组成规律的差异，尤其是性成熟对草鱼营养素沉积的影响。未来有关草鱼营养生理的研究需使用较大规格的草鱼作为实验对象，一方面有利于明晰草鱼整个生命周期的体组成变化规律，另一方面，也能为生产实践中草鱼的生产销售提供指导。

参考文献：

[1] Cho C Y, Bureau D P. Development of bioenergetic models and the Fish-PrFEQ software to estimate production, feeding ration and waste output in aquaculture[J]. Aquatic Living Resources, 1998, 11(4): 199–210.

[2] Hua K, de Lange C F M, Niimi A J, *et al*. A factorial model to predict phosphorus waste output of rainbow trout (*Oncorhynchus mykiss*)[J]. Aquaculture Research, 2008, 39(10): 1059–1068.

[3] Hua K, Bureau D P. Development of a model to estimate digestible lipid content of salmonid fish feeds[J]. Aquaculture, 2009, 286(3–4): 271–276.

[4] Dumas A, France J, Bureau D P. Evidence of three growth stanzas in rainbow trout (*Oncorhynchus mykiss*) across life stages and adaptation of the thermal-unit growth coefficient[J]. Aquaculture, 2007, 267(1–4): 139–146.

[5] Dumas A, France J, Bureau D. Modelling growth and body composition in fish nutrition: where have we been and where are we going [J]. Aquaculture Research, 2010, 41(2): 161–181.

[6] Love R M. The chemical biology of fishes: advances 1968–1977, vol. 2[M]. London: Academic Press, 1980: 943.

[7] Shearer K D. Factors affecting the proximate composition of cultured fishes with emphasis on salmonids[J]. Aquaculture, 1994, 119(1): 63–88.

[8] Jobling M. Nutrient partitioning and the influence of feed composition on body composition[M]//Houlihan D, Boujard T, Jobling M. Food intake in fish. Oxford: Blackwell Science, 2001: 354–375.

[9] 中华人民共和国国家统计局. 中国统计年鉴2013[M]. 北京: 中国统计出版社, 2013.
National Bureau of Statistics of the People’s Republic of China. China Statistical Yearbook 2013[M]. Beijing: China Statistics Press, 2013 (in Chinese).

[10] 高春生, 范光丽, 李建华, 等. 纤维素酶对草鱼生长性能和饲料消化率及体成分的影响[J]. 中国农学通报, 2006, 22(10): 473–475.
Gao C S, Fan G L, Li J H, *et al*. Effects of cellulase on growth performance, feed digestive rate and whole body composition in grass carp[J]. Chinese Agricultural Science Bulletin, 2006, 22(10): 473-475 (in Chinese).

[11] 高春生, 王艳玲, 李建华, 等. β-葡聚糖酶对草鱼生长性能和饲料消化率的影响[J]. 饲料研究, 2006(7): 41–42.
Gao C S, Wang Y L, Li J H, *et al*. Influence of β-gluconase on growth and feed digestibility in *Ctenopharyngodon idellus* [J]. Feed Research, 2006(7): 41–42 (in Chinese).

[12] 高文. 草鱼幼鱼苏氨酸需要量的研究[D]. 重庆: 西南大学, 2009.
Gao W. Determination of the dietary threonine requirement for juvenile grass carp, *Ctenopharyngodon idella*[D]. Chongqing: Southwest University, 2009 (in Chinese).

[13] 蒋湘辉, 刘刚, 金广海, 等. 饲料蛋白质和能量水平对草鱼生长和鱼体组成的影响[J]. 水产学杂志, 2010, 23(1): 24–27.
Jiang X H, Liu G, Jin G H, *et al*. Effect of dietary protein and lipid levels on growth and body composition of *Ctenopharyngodon idellus*[J]. Chinese Journal of Fisheries, 2010, 23(1): 24–27 (in Chinese).

[14] 刘迁. 草鱼“肝胆综合症”病理变化及菜籽粕对其肝脏毒性的研究[D]. 武汉: 华中农业大学, 2009.
Liu Q. Pathological changes of grass carp (*Ctenopharyngodon idellus*) with hepatobiliary syndrome and the toxicity of rapeseed meal on liver of grass carp[D]. Wuhan: Huazhong Agricultural University, 2009 (in Chinese).

[15] 王纪亭, 万文菊, 康明江, 等. 复合酶制剂对草鱼生长性能、饲料养分消化率及免疫力的影响[J]. 大连水产学院学报, 2009, 24(5): 417–422.
Wang J T, Wan W J, Kang M J, *et al*. Effects of multi-enzyme on growth, digestibility and immunity of grass carp *Ctenopharyngodon idellus*[J]. Journal of Dalian Fisheries University, 2009, 24(5): 417–422 (in Chinese).

[16] 袁丹宁. 饲料中添加钴对草鱼幼鱼生长和生理、生化指标的影响[D]. 武汉: 华中农业大学, 2009.
Yuan D N. Effects of dietary cobalt on growth performance and physiological, biochemical parameter in juvenile *Ctenopharyngodon idellus*[D]. Wuhan: Huazhong Agricultural University, 2009 (in Chinese).

[17] Cai X, Luo L, Xue M, *et al*. Growth performance, body composition and phosphorus availability of juvenile grass carp (*Ctenopharyngodon idellus*) as affected by diet processing and replacement of fishmeal by detoxified castor bean meal[J]. Aquaculture Nutrition, 2005, 11(4): 293–299.

[18] Gao Y J, Yang H J, Liu Y J, *et al*. Effects of graded levels of threonine on growth performance, biochemical parameters and intestine morphology of juvenile grass carp *Ctenopharyngodon idella*[J]. Aquaculture, 2014, 424–425: 113–119.

[19] Köprücü K, Sertel E. The effects of less-expensive plant protein sources replaced with soybean meal in the juvenile diet of grass carp (*Ctenopharyngodon idella*): growth, nutrient utilization and body composition[J].

Aquaculture International, 2012, 20(3): 399–412.

[20] Liu L W, Luo Y L, Hou H L, *et al*. Partial replacement of monocalcium phosphate with neutral phytase in diets for grass carp, *Ctenopharyngodon idellus*[J]. Journal of Applied Ichthyology, 2013, 29(3): 520–525.

[21] Liu T L, Wen H, Jiang M, *et al*. Effect of dietary chromium picolinate on growth performance and blood parameters in grass carp fingerling, *Ctenopharyngodon idellus*[J]. Fish Physiology and Biochemistry, 2010, 36(3): 565–572.

[22] Tan Q S, Liu Q, Chen X X, *et al*. Growth performance, biochemical indices and hepatopancreatic function of grass carp, *Ctenopharyngodon idellus*, would be impaired by dietary rapeseed meal[J]. Aquaculture, 2013, 414–415: 119–126.

[23] Wang B, Liu Y, Feng L, *et al*. Effects of dietary arginine supplementation on growth performance, flesh quality, muscle antioxidant capacity and antioxidant-related signalling molecule expression in young grass carp (*Ctenopharyngodon idella*)[J]. Food Chemistry, 2015, 167: 91–99.

[24] Yuan X C, Zhou Y, Liang X F, *et al*. Molecular cloning, expression and activity of pyruvate kinase in grass carp *Ctenopharyngodon idella*: effects of dietary carbohydrate level[J]. Aquaculture, 2013, 410–411: 32–40.

[25] Wu Y P, Feng L, Jiang W D, *et al*. Influence of dietary zinc on muscle composition, flesh quality and muscle antioxidant status of young grass carp (*Ctenopharyngodon idella* Val.)[J]. Aquaculture Research, 2015, 46(10): 2360–2373.

[26] Zhang L, Feng L, Jiang W D, *et al*. The impaired flesh quality by iron deficiency and excess is associated with increasing oxidative damage and decreasing antioxidant capacity in the muscle of young grass carp (*Ctenopharyngodon idellus*)[J]. Aquaculture Nutrition, 2016, 22(1): 191–201.

[27] 杜震宇. 草鱼对脂肪的利用和对脂肪酸β-氧化的研究[D]. 广州: 中山大学, 2005.
Du Z Y. Consequences of fat feeding on growth and body lipids in a herbivorous fish (Grass carp, *Ctenopharyngodon idella*): mechanisms related to fatty acid oxidation[D]. Guangzhou: Sun Yat-sen University, 2005 (in Chinese).

[28] 冯健, 刘栋辉. 草鱼日粮中小肽对幼龄草鱼生长性能的影响[J]. 水生生物学报, 2005, 29(1): 20–25.
Feng J, Liu D H. Effect of dietary small peptides on growth performance of grass carp, *Ctenopharyngodon idella*[J]. Acta Hydrobiologica Sinica, 2005, 29(1): 20–25 (in Chinese).

[29] 甘炼. 草鱼(*Ctenopharyngodon idellus*)对饲料中外源赖氨酸利用的研究[D]. 广州: 中山大学, 2011.
Gan L. The utilization of crystal lysine for grass carp (*Ctenopharyngodon idellus*) in practical feeds[D]. Guangzhou: Sun Yat-sen University, 2011 (in Chinese).

[30] 高文. 草鱼(*Ctenopharyngodon idella*)和罗非鱼(*Oreochromis niloticus*×*O. aureus*)对饲料糖和脂肪利用比较研究[D]. 广州: 中山大学, 2009.
Gao W. Comparative studies on the utilization of dietary carbohydrate and lipid by grass carp (*Ctenopharyngodon idella*) and tilapia (*Oreochromis niloticus*×*O. aureus*)[D]. Guangzhou: Sun Yat-sen University, 2009 (in Chinese).

[31] 郭小泽. 饲料中非蛋白能量源对草鱼脂肪蓄积及脂肪代谢的影响研究[D]. 武汉: 华中农业大学, 2013.
Guo X Z. Effect of dietary non-protein energy sources on fat deposition and lipid metabolism of grass carp (*Ctenopharyngodon idellus*)[D]. Wuhan: Huazhong Agricultural University, 2013 (in Chinese).

[32] 金艳. 不同营养素水平对草鱼体内代谢物谱及基因表达的影响[D]. 广州: 中山大学, 2014.
Jin Y. Effects of different nutrients levels on metabolic profile and gene expression of grass carp (*Ctenopharyngodon idella*)[D]. Guangzhou: Sun Yat-sen University, 2014 (in Chinese).

[33] 梁键钧. 草鱼幼鱼的矿物质营养研究[D]. 广州: 中山大学, 2012.
Liang J J. Mineral nutrition of juvenile grass carp (*Ctenopharyngodon idella*)[D]. Guangzhou: Sun Yat-sen University, 2012 (in Chinese).

[34] 马贵华, 曹双俊, 黄亮. 多酚对草鱼生长、肝脂及免疫功能的影响[J]. 饲料工业, 2010, 31(4): 37–39.
Ma G H, Cao S J, Huang L. Effects of dietary polyphenols on growth performance, liver lipid content and immune function of grass carp[J]. Feed Industry, 2010, 31(4): 37-39 (in Chinese).

[35] 马贵华, 刘文珍, 戴银根, 等. α-苯基苯并吡喃对草鱼生长、肝脂及免疫功能的影响[J]. 湖北农业科学, 2010,

49(7): 1674–1676.
Ma G H, Liu W Z, Dai Y G, *et al*. Effects of phenylbenzopyran on on growth performance, liver fat metabolism and immune function of grass carp[J]. Hubei Agricultural Sciences, 2010, 49(7): 1674–1676 (in Chinese).

[36] 聂乾忠. 大蒜素对草鱼鱼种阶段生产性能及抗病力影响研究[D]. 长沙: 湖南农业大学, 2003.
Nie Q Z. Effects of dietary with different level of allitridium supplementation on the growth, body composition and disease resistance of grass carp (*Ctenopharyngodon idellus*) fingerlings[D]. Changsha: Hunan Agricultural University, 2003 (in Chinese).

[37] 苏传福, 罗莉, 文华, 等. 日粮铁对草鱼生长, 营养成分和部分血液指标的影响[J]. 淡水渔业, 2007, 37(1): 48–52.
Su C F, Luo L, Wen H, *et al*. Effects of dietary iron on growth performance, nutritional composition and some blood indices of grass carp (*Cenopharyngodon idellus*)[J]. Freshwater Fisheries, 2007, 37(1): 48–52 (in Chinese).

[38] 苏传福. 草鱼幼鱼硒的营养需要研究[D]. 重庆: 西南大学, 2008.
Su C F. Studies on dietary selenium requirements of juvenile grass carp, *Ctenopharyngodon idellus*[D]. Chongqing: Southwest University, 2008 (in Chinese).

[39] 谭芳芳, 叶元土, 肖顺应, 等. 补充微囊赖氨酸和蛋氨酸对草鱼生长性能的影响[J]. 动物营养学报, 2010, 22(3): 804–810.
Tan F F, Ye Y T, Xiao S Y, *et al*. Effects of microcapsule lysine and methionine supplementation on growth performance of grass crap (*Ctenopharyngodon idellus*)[J]. Chinese Journal of Animal Nutrition, 2010, 22(3): 804-810 (in Chinese).

[40] 田娟. 脂肪和肉碱水平对草鱼生长性能、脂肪代谢酶和瘦素表达的影响[D]. 上海: 上海海洋大学, 2009.
Tian J. Effect of dietary lipid and carnitine on growth performance, lipid metabolism enzymes and leptin expression of grass carp, *Ctenopharyngodon idella*[D]. Shanghai: Shanghai Ocean University, 2009 (in Chinese).

[41] 田丽霞. 草鱼糖代谢研究[D]. 广州: 中山大学, 2002.
Tian L X. Studies on carbohydrate metabolism of grass carp, *Ctenopharyngodon idella* (C. et V.)[D]. Guangzhou: Sun Yat-sen University, 2002 (in Chinese).

[42] 王胜. 草鱼幼鱼蛋白质和主要必需氨基酸需求的研究[D]. 广州: 中山大学, 2006.
Wang S. Studies on protein and essential amino acid requirements of grass carp, *Ctenopharyngodon idella* (C. et V.)[D]. Guangzhou: Sun Yat-sen University, 2006 (in Chinese).

[43] 严全根, 朱晓鸣, 杨云霞, 等. 饲料中棉粕替代鱼粉蛋白对草鱼的生长、血液生理指标和鱼体组成的影响[J]. 水生生物学报, 2014, 38(2): 362–369.
Yan Q G, Zhu X M, Yang Y X, *et al*. Effect of replacement of fish meal with cottonseed meal on growth, hematological physiology and body composition of grass carp[J]. Acta Hydrobiologica Sinica, 2014, 38(2): 362–369 (in Chinese).

[44] 赵华林, 钟鸣, 冯健, 等. 草鱼幼鱼实用日粮中添加紫花苜蓿草粉效果评价[J]. 水生生物学报, 2011, 35(3): 467–472.
Zhao H L, Zhong M, Feng J, *et al*. Evaluation of dry clover meal as a feed protein resource in practical diets of juvenile grass carp, *Ctenopharyngodon idella*[J]. Acta Hydrobiologica Sinica, 2011, 35(3): 467–472 (in Chinese).

[45] Chen Y J, Tian L X, Yang H J, *et al*. Effect of protein and starch level in practical extruded diets on growth, feed utilization, body composition, and hepatic transaminases of juvenile grass carp, *Ctenopharyngodon idella*[J]. Journal of the World Aquaculture Society, 2012, 43(2): 187–197.

[46] Dong G F, Zou Q, Wang H, *et al*. Conjugated linoleic acid differentially modulates growth, tissue lipid deposition, and gene expression involved in the lipid metabolism of grass carp[J]. Aquaculture, 2014, 432: 181–191.

[47] Gao Y J, Yang H J, Guo D Q, *et al*. Dietary arginine requirement of juvenile grass carp *Ctenopharyngodon idella* (Valenciennes in Cuvier & Valenciennes, 1844)[J]. Aquaculture Research, 2015, 46(12): 3070–3078.

[48] Guo X Z, Liang X F, Fang L, *et al*. Effects of lipid-lowering pharmaceutical clofibrate on lipid and lipoprotein metabolism of grass carp (*Ctenopharyngodon idellal* Val.) fed with the high non-protein energy diets[J]. Fish Physiology and Biochemistry, 2015, 41(2):

331–343.

[49] Ji H, Li J, Liu P. Regulation of growth performance and lipid metabolism by dietary n-3 highly unsaturated fatty acids in juvenile grass carp, *Ctenopharyngodon idellus*[J]. Comparative Biochemistry and Physiology Part B: Biochemistry and Molecular Biology, 2011, 159(1): 49–56.

[50] Jiang M, Huang F, Zhao Z Y, *et al*. Dietary thiamin requirement of juvenile grass carp, *Ctenopharyngodon idella*[J]. Journal of the World Aquaculture Society, 2014, 45(4): 461–468.

[51] Köprücü K. Effects of dietary protein and lipid levels on growth, feed utilization and body composition of juvenile grass carp (*Ctenopharyngodon idella*)[J]. Journal of Fisheries Sciences, 2012, 6(3): 243–251.

[52] Li C, Liu P, Ji H, *et al*. Dietary n-3 highly unsaturated fatty acids affect the biological and serum biochemical parameters, tissue fatty acid profile, antioxidation status and expression of lipid-metabolism-related genes in grass carp, *Ctenopharyngodon idellus*[J]. Aquaculture Nutrition, 2015, 21(3): 373–383.

[53] 马恒甲, 叶金云, 郭建林, 等. 饲料中添加植酸酶对草鱼生长、体组成及各组织磷含量的影响[J]. 上海海洋大学学报, 2011, 20(6): 845–852.
Ma H J, Ye J Y, Guo J L, *et al*. Effect of phytase on growth, body composition and phosphorus content in tissues of juvenile grass carp (*Ctenopharyngodon idellus*) fed plant protein based diet[J]. Journal of Shanghai Ocean University, 2011, 20(6): 845-852 (in Chinese).

[54] Khan M A, Jafri A K, Chadha N K. Growth, reproductive performance, muscle and egg composition in grass carp, *Ctenopharyngodon idella* (Valenciennes), fed hydrilla or formulated diets with varying protein levels[J]. Aquaculture Research, 2004, 35(13): 1277–1285.

[55] 金素雅. 四种菜籽饼粕在草鱼饲料中的应用研究[D]. 苏州: 苏州大学, 2011.
Jin S Y. The study on the four different rapeseed meals in the diet of *Ctenopharyngodon idellus*[D]. Suzhou: Soochow University, 2011 (in Chinese).

[56] 李宾, 叶元土, 蔡春芳, 等. 不同棉粕和向日葵仁粕对草鱼生长、鱼体组成的影响[J]. 中国粮油学报, 2011, 26(8): 75–83.
Li B, Ye Y T, Cai C F, *et al*. Effects of different cottonseed meal and sunflower seed meal on growth and body composition of grass carp (*Ctenopharymgodon idellus*)[J]. Journal of the Chinese Cereals and Oils Association, 2011, 26(8): 75-83 (in Chinese).

[57] 刘平. 赖氨酸甲酯对草鱼生长性能和饲料利用的影响及其作用机理的探讨[D]. 杭州: 浙江大学, 2007.
Liu P. Effects of lysine methyl ester on growth performance and feed utilization in grass carp and approaching to its mechanism[D]. Hangzhou: Zhejiang University, 2007 (in Chinese).

[58] 唐武斌. 烁生肽替代鱼粉对草鱼和黄颡鱼生长及水体水质的影响[D]. 武汉: 华中农业大学, 2008.
Tang W B. Effects of source peptide replacing fish meal on water quality and growth of juvenile grass carp (*Ctenopharyngodon idellus*) and yellow catfish (*Pelteobagrus fulvidraco*)[D]. Wuhan: Huazhong Agricultural University, 2008 (in Chinese).

[59] Li J, Liang X F, Tan Q S, *et al*. Effects of vitamin E on growth performance and antioxidant status in juvenile grass carp *Ctenopharyngodon idellus*[J]. Aquaculture, 2014, 430: 21–27.

[60] Tian J J, Ji H, Oku H, *et al*. Effects of dietary arachidonic acid (ARA) on lipid metabolism and health status of juvenile grass carp, *Ctenopharyngodon idellus*[J]. Aquaculture, 2014, 430: 57–65.

[61] Yang H J, Tian L X, Huang J W, *et al*. Dietary taurine can improve the hypoxia-tolerance but not the growth performance in juvenile grass carp *Ctenopharyngodon idellus*[J]. Fish Physiology and Biochemistry, 2013, 39(5): 1071–1078.

[62] Zhao Y, Hu Y, Zhou X Q, *et al*. Effects of dietary glutamate supplementation on growth performance, digestive enzyme activities and antioxidant capacity in intestine of grass carp (*Ctenopharyngodon idella*)[J]. Aquaculture Nutrition, 2015, 21(6): 935–941.

[63] AOAC. Official methods of analysis of AOAC international[M]. Arlington: Association of the Official Analytical Chemists, 1995.

[64] Dumas A, de Lange C F M, France J, *et al*. Quantitative description of body composition and rates of nutrient deposition in rainbow trout (*Oncorhynchus mykiss*)[J]. Aquaculture, 2007, 273(1): 165–181.

[65] Bureau D P, Hua K, Cho C Y. Effect of feeding level on

growth and nutrient deposition in rainbow trout (*Oncorhynchus mykiss* Walbaum) growing from 150 to 600 g[J]. Aquaculture Research, 2006, 37(11): 1090–1098.

[66] Mommsen T P. Paradigms of growth in fish[J]. Comparative Biochemistry and Physiology-Part B: Biochemistry and Molecular Biology, 2001, 129(2–3): 207–219.

[67] Alexander E L R, Dooley K C, Pohajdak B, *et al*. Things we have learned from tilapia islet xenotransplantation[J]. General and Comparative Endocrinology, 2006, 148(2): 125–131.

Quantitative description of body composition in grass carp (*Ctenopharyngodon idella*)

CHEN Yongjun[1,2*], ZOU Tao[1], LIN Shimei[1], LUO Li[1], LI Yun[1]

(1. *Key Laboratory of Aquatic Science of Chongqing*, *College of Animal Science and Technology*, *Southwest University*, *Chongqing* 400715, *China*;
2. *Key Laboratory of Freshwater Resources and Reproductive Development of Ministry of Education*, *School of Life Science*, *Southwest University*, *Chongqing* 400715, *China*)

Abstract: To quantify the body cmposition of grass carp,about 3700 datasets were adopted from 51 studies regarding body composition and morphological parameters of grass carp with body weights ranging from 1.52 to 694.80 g after data searching and collecting from academic database. Through data classification,correlation analysis and linear regression analysis,the overall results in the present experiment suggested that close linear relationships of whole-body protein content and viscera weight (y, g) with body weight of grass carp (x, g) were obtained respectively: y=0.1604x–0.3645, R^2=0.994; y=0.1059x–0.3097, R^2=0.9875. With an increase of body weight,whole-body lipid and ash contents (especially the lipid content) of grass carp are more susceptible to dietary manipulations. Deposition of 1 g protein resulted in a retention of 4.57 g moisture,while accumulation of 1 g lipid entailed a decrease of 0.95 g moisture in the whole-body of grass carp. In the liver,deposition of 1 g lipid entailed a decrease of 0.66 g moisture,suggesting that the loss rate of moisture driven by lipid deposition is tissue specific in grass carp. The present study also demonstrated that mesentery is an important site for lipid deposition in grass carp,and an increase of lipid accumulation in mesentery,liver and muscle contributes to whole-body lipid deposition. In addition,an increase of whole-body lipid content is accompanied by increased viscera weight. The results in this study are helpful to quantify the body composition of grass carp and provide scientific guidance for its practical production.

Key words: *Ctenopharymgodon idella*; body composition; morphological indices; quantitative description

Corresponding author: CHEN Yongjun. E-mail: joy616722@hotmail.com

Funding projects: National Natural Science Foundation of China (31502181); China Postdoctoral Science Foundation (2015M582505); Chongqing Postdoctoral Science Special Foundation (Xm2015045); Fundamental Research Funds for the Central Universities (XDJK2015C080)