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饲料脂肪含量对两种规格的军曹鱼生长、体组成和血清生化指标的影响

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摘要: 实验旨在确定2种规格军曹鱼的脂肪需求, 同时探索不同含量的脂肪对2种规格军曹鱼体组成及血清生化指标的影响。以鱼粉、酪蛋白和豆粕为蛋白源, 鱼油为脂肪源, 通过添加不同配比的鱼油配制6种脂肪水平[5.27%、8.22%、10.81%、14.26%、17.32%和20.94% (占干重)]的等氮实验饲料。挑选(38.24±0.30) g (25尾/箱, 40 g规格)和(529.17±5.67) g (10尾/箱, 500 g规格)2种规格的军曹鱼, 置于浮式网箱(1.3 m×1.3 m×2.5 m)中每日饱食投喂2次, 分别进行10周和8周的摄食生长实验。结果表明: 随着饲料脂肪含量的增加, 2种规格军曹鱼特定生长率(SGR)和饲料效率(FER)均先上升再下降, 而脏体比(VSI)与肥满度(CF)均显著升高($P<0.05$)。另外, 随着饲料脂肪水平的增加, 40 g规格的军曹鱼肝体比(HSI)、鱼体、肝脏和肌肉脂肪含量均显著升高, 鱼体水分和蛋白含量显著下降($P<0.05$), 而500 g规格的军曹鱼各处理之间未发现显著差异($P>0.05$)。随着饲料脂肪水平的增加, 40 g规格的军曹鱼, 血清总甘油三酯(TG)、血清总胆固醇(TC)、高密度脂蛋白-胆固醇(HDL-C)、低密度脂蛋白-胆固醇(LDL-C)及血糖(Glu)含量显著增加($P<0.05$), 而500 g规格的军曹鱼, 除血清TG在各处理之间呈现出显著差异外($P<0.05$), 其余指标在各处理之间均未发现显著差异($P>0.05$)。综上所述, 以SGR和FER为评价指标, 40 g左右规格的军曹鱼脂肪需求量为13.97%—14.16%, 500 g左右规格的军曹鱼脂肪需求量为13.18%—13.47%。

关键词: 特定生长率; 饲料效率; 体组成; 血清生化指标; 脂肪需求; 军曹鱼

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随着养殖产业的不断发展, 优质蛋白源, 尤其是鱼粉的供需不平衡势必会成为阻碍产业健康可持续发展的障碍。蛋白质、脂肪和糖类都可作为能量源为生物体供能, 脂肪和糖类均具有一定的蛋白节约效应^[1]。相较于价格较高的蛋白质类和利用效率有限地糖类, 单位能值更高的脂肪越来越受到人们的关注^[2, 3]。另外, 除了供能之外, 被吸收的脂肪还可为鱼体正常生长代谢提供必需脂肪酸^[4]。当饲料中脂肪含量不足时, 可使养殖鱼类出现脂溶性维生素和必需脂肪酸缺乏症, 同时还会出现饲料蛋白利用率低下等症状^[5]。但是, 近年来随着高脂饲料的使用, 脂肪在鱼体的异常沉积正越来越受到人们的关注^[6]。饲料中过量的脂肪会导致脂肪沉积在腹腔和组织中^[7-9]。脂肪的异常过度沉积不仅会造成脂肪原料的浪费进而提高生产成本, 而且会影

响到鱼类的代谢与免疫能力, 还会直接影响养殖鱼的品质^[2, 6, 10]。另外, 随着鱼类的生长发育, 鱼类在不同生长阶段其消化^[5, 11]和代谢能力^[5, 12]会有所不同, 因此鱼类在不同生长阶段对营养物质的需求存在着显著的差异^[13, 14], 尤其是作为主要能量源的脂肪^[3, 5, 15]。通过生长实验确定出不同生长阶段养殖鱼类的脂肪需求量, 无疑可以通过最大程度地利用蛋白原料, 降低生产成本来保证水产养殖产业的健康可持续发展。

军曹鱼(*Rachycentron canadum* L.)隶属于鲈形目(Perciformes)中的鲈亚目(Percoidei)、军曹鱼科(Rachycentridae)、军曹鱼属(*Rachycentron*), 体细长、头扁平、近圆筒状^[16], 体披细小圆鳞, 属于暖水广盐性鱼中底层肉食性海水鱼类; 无鳔, 需要靠不断游动保持身体平衡; 其不耐饥饿具有残食习

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性^[17]。生长快、抗病力强、产量高的军曹鱼无细棘骨,同时肉厚质细、肉质鲜美是制作生鱼片的上好材料^[18]。随着人工繁殖以及海水网箱养殖技术的发展,军曹鱼已成为我国东南沿海地区近海网箱养殖的重要品种^[19]。目前,对于军曹鱼脂肪需求的研究主要集中在幼鱼阶段^[8],而对于大规格的军曹鱼,尤其是不同规格的军曹鱼的脂肪营养需求的研究尚未见报道。本研究通过配制不同脂肪水平的饲料投喂2种规格的军曹鱼,以 FER 和 SGR 为评定指标,构建二次回归曲线来估算不同生长阶段的军曹鱼的脂肪需求量。同时,探讨饲料脂肪水平对军曹鱼鱼体、肝脏和肌肉组成、血清生化指标的影响,为不同规格的军曹鱼高效配合饲料的开发提供理论依据。

1 材料与方法

1.1 饲料配方与制作

原料(主要蛋白源:鱼粉、酪蛋白和豆粕;糖源:

小麦粉和小麦淀粉)粉碎后过40目筛,后按逐级放大的原则手工配合高效混合机(0.5-V型,上海天祥健台制药机械有限公司)均匀混合原料。之后,手工混入鱼油和磷脂油并加入适宜的水,挤条并加工为6种脂肪含量的等氮的(2种规格:4和6 mm)硬颗粒饲料(表1)。冷气房中空气晾干至水分10%左右后储存备用(-20°C)。

1.2 饲养管理

将从广东湛江雷州购来的同一批孵化的军曹鱼苗置于广东湛江广东粤海饲料公司南三岛实验基地 $1.5\text{ m}\times 1.5\text{ m}\times 2.5\text{ m}$ 浅海网箱中进行实验,每个处理3个重复。在实验开始前,投喂商业饲料至实验鱼达到相应规格。称重分鱼[40 g规格组(38.24 ± 0.30) g, 25尾/箱; 500 g规格组(529.17 ± 5.67) g, 10尾/箱]前禁食24 h。实验分别持续10周和8周,每天08:00和17:00进行2次饱食投喂(缓慢投喂至实验鱼不再抢食为止),记录饲料每个网箱每日的投喂量。实验期间环境如下:水温 $27\text{—}32^{\circ}\text{C}$,盐度21‰—

表1 饲料配方及主要营养成分组成(% ,干重)

Tab. 1 The formulation and proximate composition of the experimental diets (% , dry matter)

原料Ingredient (%)	组别Group					
	处理1 Diet 1	处理2 Diet 2	处理3 Diet 3	处理4 Diet 4	处理5 Diet 5	处理6 Diet 6
鱼粉Fish meal ^a	31.10	31.10	31.10	31.10	31.10	31.10
酪蛋白Casein ^a	10.00	10.00	10.00	10.00	10.00	10.00
豆粕Soybean meal ^a	17.00	17.00	17.00	17.00	17.00	17.00
小麦粉Wheat meal ^a	18.00	18.00	18.00	18.00	18.00	18.00
小麦淀粉Wheat starch ^b	19.35	16.35	13.35	10.35	7.35	4.35
鱼油Fish oil	0.00	3.00	6.00	9.00	12.00	15.00
大豆卵磷脂Soy lecithin	1.50	1.50	1.50	1.50	1.50	1.50
矿物质混合物Mineral mixture ^c	1.00	1.00	1.00	1.00	1.00	1.00
维生素混合物Vitamin mixture ^d	2.00	2.00	2.00	2.00	2.00	2.00
乙氧基喹Ethoxyquin	0.05	0.05	0.05	0.05	0.05	0.05
主要营养成分(% ,干重)Proximate composition (% , dry matter)						
粗蛋白Crude protein (%)	44.48	44.88	44.53	44.67	44.31	44.55
粗脂肪Crude lipid (%)	5.27	8.22	10.81	14.26	17.32	20.94
灰分Ash (%)	8.97	8.88	8.87	8.81	8.70	8.61

注: ^a 鱼粉、酪蛋白、豆粕和小麦粉均来自广东粤海饲料集团(中国, 广东); ^b 小麦淀粉来自鄄城明珠淀粉厂(中国, 山东); ^c 矿物质混合物 (mg or g/kg diet): NaF, 2 mg; KI, 0.8 mg; $\text{CoCl}_2\cdot 6\text{H}_2\text{O}$ (1%), 50 mg; $\text{CuSO}_4\cdot 5\text{H}_2\text{O}$, 10 mg; $\text{FeSO}_4\cdot \text{H}_2\text{O}$, 80 mg; $\text{ZnSO}_4\cdot \text{H}_2\text{O}$, 50 mg; $\text{MnSO}_4\cdot \text{H}_2\text{O}$, 60 mg; $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$, 1200 mg; $\text{Ca}(\text{H}_2\text{PO}_3)_2\cdot \text{H}_2\text{O}$, 3000 mg; NaCl, 100 mg; zoelite, 10.45 g; ^d 维生素混合物 (mg or g/kg diet): thiamin (B_1), 25 mg; riboflavin, 45 mg; pyridoxine HCl, 20 mg; vitamin B_{12} , 0.1 mg; vitamin K_3 , 10 mg; inositol, 800 mg; pantothenic acid, 60 mg; niacin acid, 200 mg; folic acid, 20 mg; biotin, 1.20 mg; retinal acetate, 32 mg; cholecalciferol, 5 mg; α -tocopherol, 120 mg; ascorbic acid, 2000 mg; cholinechloride, 2000 mg; ethoxyquin 150 mg; wheat middling, 14.52 g

Note: ^a Fish meal, Casein, Soybean meal and wheat meal obtained from Guangdong Yuehai Feed Group Co. Ltd. (Guangzhou, China); ^b Wheat starch, obtained from Juancheng Mingzhu Starch Factory (Shandong, China); ^c Mineral premix (mg or g/kg diet): NaF, 2 mg; KI, 0.8 mg; $\text{CoCl}_2\cdot 6\text{H}_2\text{O}$ (1%), 50 mg; $\text{CuSO}_4\cdot 5\text{H}_2\text{O}$, 10 mg; $\text{FeSO}_4\cdot \text{H}_2\text{O}$, 80 mg; $\text{ZnSO}_4\cdot \text{H}_2\text{O}$, 50 mg; $\text{MnSO}_4\cdot \text{H}_2\text{O}$, 60 mg; $\text{MgSO}_4\cdot 7\text{H}_2\text{O}$, 1200 mg; $\text{Ca}(\text{H}_2\text{PO}_3)_2\cdot \text{H}_2\text{O}$, 3000 mg; NaCl, 100 mg; zoelite, 10.45 g; ^d Vitamin premix (mg or g/kg diet): thiamin (B_1), 25 mg; riboflavin, 45 mg; pyridoxine HCl, 20 mg; vitamin B_{12} , 0.1 mg; vitamin K_3 , 10 mg; inositol, 800 mg; pantothenic acid, 60 mg; niacin acid, 200 mg; folic acid, 20 mg; biotin, 1.20 mg; retinal acetate, 32 mg; cholecalciferol, 5 mg; α -tocopherol, 120 mg; ascorbic acid, 2000 mg; cholinechloride, 2000 mg; ethoxyquin 150 mg; wheat middling, 14.52 g

23‰, pH 7.6—7.8, 氨氮水平<0.05 mg/L, 溶解氧 $\geq$ 6.0 mg/L。

1.3 样品收集与分析

样品收集 分鱼时各预留30尾鱼进行体成分分析。在养殖实验结束后, 禁食24h, 利用丁香酚(1:10000)麻醉后, 迅速计数并称重, 每个网箱随机取3尾鱼迅速测量体重和体长并储存于-20℃用于全鱼成分分析。再从每个网箱随机取3尾实验鱼, 使用抗凝剂(肝素钠)处理过的无菌注射器取血后, 取下针头将血液注入离心管中冰上静置。4℃条件离心(3500×g)10min, 取上清液, 将血清于-80℃保存。采完血后迅速测定体重及体长, 解剖并对内脏和肝脏称重, 收集肝脏和肌肉于-20℃保存用作成分分析的样品。

饲料、全鱼及组织成分分析 饲料、全鱼及组织水分、粗蛋白及灰分分别使用烘箱(105℃)、全自动凯氏定氮仪(Kjeltec™ 8400, FOSS, Tecator, Sweden)和马弗炉(550℃, 12h)参照AOAC的方法测定^[20]。饲料及全鱼粗脂肪采用AOAC中描述的索氏抽提法测定^[20]。肝脏及肌肉脂肪采用氯仿甲醇(v:v=2:1)联合抽提法测定^[21], 糖原参照Hassid和Abraham描述的方法测定^[22]。

血清生化指标分析 使用Mindray公司提供的试剂盒, 配合LX-20型Beckman全自动生化分析仪, 血糖、血清总蛋白、血清总胆固醇、血清总甘油三酯、高密度脂蛋白-胆固醇和低密度脂蛋白-胆固醇分别用Barham等^[23]、Peters^[24]、Richmond等^[25]、Schettler和Nussel^[26]、Gordon等^[27]和Okada等^[28]所描述的方法进行测定。

1.4 公式及统计方法

存活率(SR, %)=终末鱼数目/初始鱼数目×100%

特定生长率(SGR, %/d)=(Ln末重-Ln初重)/天数×100%

饲料效率(FER)=鱼体增重(湿重)/饲喂饲料(干重)

肝体比(HSI, %)=肝重/体重×100%

脏体比(VSI, %)=内脏团重/体重×100%

肥满度(CF)=体重(g)/[体长(cm)]³×100

使用SPSS 17.0对所得数据进行单因素方差分析(ANOVA), 若结果显示差异显著($P<0.05$), 再用Tukey's检验进行多重比较分析。所有数值用平均值±标准误表示。

2 结果

2.1 生长指标

随着脂肪含量的升高, 40 g规格和500 g规格军

曹鱼特定生长率(SGR)先分别由1.76和0.21升高到2.13和0.46, 之后均呈现出降低趋势($P<0.05$); 40 g规格和500 g规格军曹鱼饲料效率(FER)先分别从0.48和0.09升高到0.70和0.20, 之后均呈现出降低趋势($P<0.05$)。以SGR为评定指标, 利用二次曲线模型为拟合模型, 40 g和500 g规格的军曹鱼的脂肪需求量分别为: 13.79%和13.49%; 以FER为评定指标, 利用二次曲线模型为拟合模型, 40 g和500 g规格的军曹鱼的脂肪需求量分别为14.56%和13.10% (图1、图2)。综上所述, 40 g规格军曹鱼的脂肪需求量为13.79%—14.56%, 500 g规格军曹鱼的脂肪需求量为13.10%—13.49%。对于2种不同规格的军曹鱼, 相较于饲喂低脂(高糖脂比)饲料的实验鱼, 饲喂高脂(低糖脂比)饲料的处理鱼均呈现出更高的脏体比(VSI)和肥满度(CF)。而鱼体肝体比(HSI)只在40 g规格的军曹鱼处理组中发现显著性差异, 500 g规格处理组中却未发现显著差异(表2)。

2.2 全鱼及组织组成

随着饲料中脂肪含量的增加, 40 g规格军曹鱼

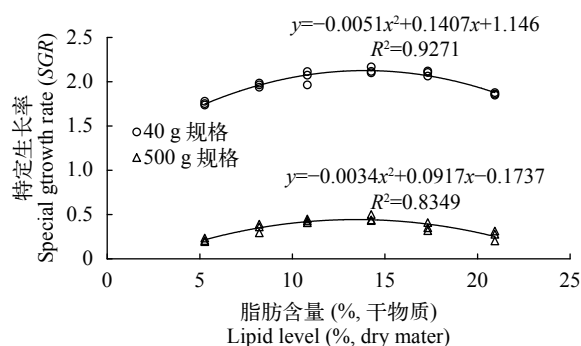


图1 脂肪含量对2种规格的军曹鱼特定生长率(SGR)的影响
Fig. 1 Relationship between different lipid levels and SGR of cobia at two body sizes

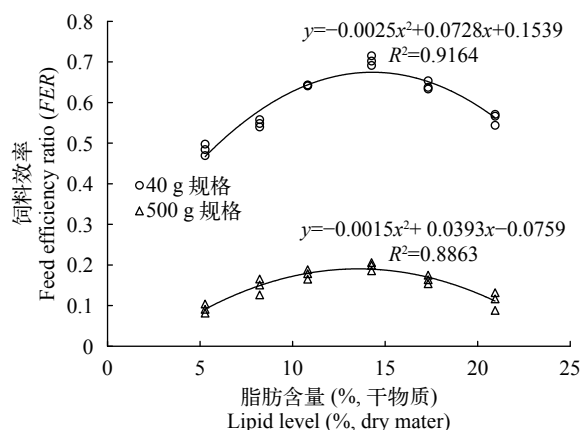


图2 脂肪含量对2种规格的军曹鱼饲料效率(FER)的影响
Fig. 2 Relationship between different lipid levels and FER of cobia at two body sizes

其体水分和蛋白含量显著降低,而体脂含量显著升高($P<0.05$),而在500 g规格组却未发现显著差异($P>0.05$)。在肝脏和肌肉中,40 g规格军曹鱼组织脂肪含量均随饲料中脂肪的增加显著升高,而组织水分则呈现出相反的趋势($P<0.05$),而500 g规格军曹鱼各处理之间却未发现显著性差异($P>0.05$) (表3—5)。

2.3 血清生化指标

随着饲料脂肪水平的升高,2个不同生长阶段的军曹鱼其血清总甘油三酯(TG)水平均显著升高($P<0.05$),而血清总胆固醇(TC)、低密度脂蛋白-胆固醇(LDL-C)、高密度脂蛋白-胆固醇(HDL-C)和血糖(GLU)含量却只在40 g规格处理组间发现显著差异($P<0.05$),在500 g规格处理组中则未发现显著差异($P>0.05$) (表6)。

3 讨论

3.1 生长指标

本实验发现,2种规格的军曹鱼的存活率都不受摄入饲料中脂肪含量变化的影响。这与黄尾鲷(*Seriola dumerilii*)、黄颡鱼(*Pseudobagrus fulvi-*

draco)、斜带石斑鱼(*Epinephelus coioides*)、大黄鱼(*Pseudosciaena crocea* R.)等的研究结果一致^[29—32]。作为重要的能量源,随着饲料中脂肪含量的增加,2种规格的军曹鱼SGR与FER均呈现出先上升再下降的趋势。这之前对大黄鱼^[32]、斜带石斑鱼^[5]、团头鲂(*Megalobrama amblycephala*)^[15]等研究的结果一致。这主要是因为,当饲料中脂肪水平由不足提高到适宜水平时,饲料中必须脂肪酸的含量及总能水平提高,进而起到促进鱼体生长和节约蛋白质的作用^[33,34]。而当饲料中脂肪的含量超过最适需求量时,脂肪可能会在肝脏等组织中出现异常沉积,进而影响鱼体的正常生长代谢,起到抑制生长的作用^[2,6,9,32,35—37]。另外,本研究还发现,随着鱼体规格的增大,SGR呈降低趋势,这与之前的研究结果是一致的^[12,13,38,39]。较小的鱼类由于代谢强度较高,其食欲更为旺盛^[40],因此随着鱼体规格的增大摄食率(FR)会出现减小的现象^[39,41]。同时,随着军曹鱼的生长发育,其尾鳍形状会发生显著变化,稚鱼期为尖形,幼鱼期为圆形,再经由截尾、凹尾,成鱼期为叉尾形^[42]。从这一变化不难推测,随着军曹鱼的生长发育,其游泳能力逐渐增强,代谢水平也

表2 军曹鱼2个不同生长阶段成活率(SR)、特定增长率(SGR)、饲料效率(FER)、脏体比(VSI)、肝体比(HSI)、肥满度(CF)(%,湿重;均值±标准误)*

编号No.	脂肪含量Lipid level (%)	SR (%)	SGR (%/d)	FER	VSI (%)	HSI (%)	CF
实验1 Trial 1 初始体重: (38.24±0.30) g							
处理1 Diet 1	5.27	96.00±2.31	1.76±0.01 ^d	0.48±0.01 ^d	7.95±0.34 ^c	1.29±0.01 ^d	0.88±0.03 ^c
处理2 Diet 2	8.22	96.00±2.31	1.96±0.01 ^{bc}	0.55±0.01 ^c	9.59±0.47 ^{bc}	1.36±0.04 ^{cd}	0.92±0.02 ^{bc}
处理3 Diet 3	10.81	98.67±1.33	2.05±0.05 ^{ab}	0.64±0.00 ^b	9.64±0.57 ^{bc}	1.41±0.02 ^{cd}	1.00±0.04 ^{bc}
处理4 Diet 4	14.26	98.67±1.33	2.13±0.02 ^a	0.70±0.01 ^a	10.52±0.71 ^b	1.47±0.02 ^c	1.08±0.03 ^{ab}
处理5 Diet 5	17.32	97.33±1.33	2.10±0.02 ^a	0.64±0.01 ^b	11.65±0.59 ^{ab}	1.63±0.03 ^b	1.16±0.03 ^a
处理6 Diet 6	20.94	96.00±2.31	1.86±0.01 ^{cd}	0.56±0.01 ^c	13.47±0.43 ^a	1.78±0.03 ^a	1.22±0.04 ^a
F		0.483	40.012	153.888	47.148	12.79	15.291
P		0.782	<0.001	<0.001	0.001<	0.001<	0.001<
实验2 Trial 2 初始体重: (529.17±5.67) g							
处理1 Diet 1	5.27	100.00±0.00	0.21±0.02 ^c	0.09±0.01 ^d	6.99±0.18 ^d	1.04±0.12	0.92±0.01 ^c
处理2 Diet 2	8.22	100.00±0.00	0.35±0.05 ^{ab}	0.15±0.01 ^{bc}	7.37±0.15 ^{cd}	1.14±0.10	0.98±0.01 ^{bc}
处理3 Diet 3	10.81	100.00±0.00	0.43±0.02 ^a	0.18±0.01 ^{ab}	8.48±0.10 ^{abc}	1.27±0.10	1.07±0.05 ^{abc}
处理4 Diet 4	14.26	100.00±0.00	0.46±0.04 ^a	0.20±0.01 ^a	8.06±0.29 ^{bcd}	1.38±0.13	1.07±0.05 ^{abc}
处理5 Diet 5	17.32	100.00±0.00	0.36±0.05 ^{ab}	0.16±0.01 ^{ab}	8.80±0.39 ^{ab}	1.15±0.03	1.17±0.04 ^{ab}
处理6 Diet 6	20.94	96.67±3.33	0.26±0.06 ^{bc}	0.11±0.01 ^{cd}	9.36±0.20 ^a	1.38±0.06	1.23±0.08 ^a
F		1.000	15.524	20.923	2.185	13.851	5.866
P		0.458	0.001<	0.001<	0.12	0.001<	0.001<

注: *数值为三个重复的平均值, 标相同字母上标表示组间经Tukey多重检验差异不显著($P>0.05$); 下同

Note: *Date are means of triplicate. Means in the same row sharing the same superscript letter are not significantly different determined by the Turkey's test ($P>0.05$); the same applies below

随之升高。因此,综合以上因素推测摄食率的下降或维持自身新陈代谢所消耗能量的增加是导致特定生长率下降的主要原因。

3.2 全鱼及组织组成

研究表明鱼体脂肪主要受食物等外源性因素

影响^[43]。本研究发现,40 g规格的军曹鱼饲料脂肪含量的升高显著降低了体蛋白质的含量,而500 g规格的军曹鱼却未受饲料脂肪含量变化的影响,这与大黄鱼的研究结果是一致的^[32]。摄入过多脂肪时,脂肪主要会在肠系膜和肝脏等组织中沉积下来^[6]。

表 3 两种规格的军曹鱼全鱼组成(% , 湿重; 均值±标准误)

Tab. 3 Effect of lipid level on whole-body composition of cobia at two body weight (% , wet weight; Means±SEM)

编号No.	脂肪含量Lipid level (%)	水分Moisture (%)	蛋白质Crude protein (%)	脂肪Crude lipid (%)	灰分Ash (%)
实验1 Trial 1 初始体重: (38.24±0.30) g					
处理1 Diet 1	5.27	73.44±0.05 ^a	18.01±0.05 ^a	5.86±0.06 ^f	3.33±0.13
处理2 Diet 2	8.22	73.12±0.24 ^{ab}	17.48±0.15 ^{ab}	6.51±0.09 ^c	3.14±0.17
处理3 Diet 3	10.81	71.77±0.34 ^c	17.40±0.13 ^b	7.97±0.14 ^d	2.96±0.04
处理4 Diet 4	14.26	71.60±0.18 ^c	17.18±0.07 ^{bc}	8.48±0.06 ^c	3.25±0.11
处理5 Diet 5	17.32	72.19±0.28 ^{bc}	16.69±0.18 ^c	9.01±0.15 ^b	3.36±0.09
处理6 Diet 6	20.94	71.82±0.16 ^c	15.94±0.08 ^d	9.87±0.10 ^a	3.06±0.07
<i>F</i>		11.551	36.662	201.570	2.035
<i>P</i>		<0.001	<0.001	<0.001	0.122
实验2 Trial 2 初始体重: (529.17±5.67) g					
处理1 Diet 1	5.27	77.67±0.70	15.33±0.26	6.14±0.08	3.60±0.16
处理2 Diet 2	8.22	77.11±1.64	16.23±0.66	6.15±0.06	3.44±0.23
处理3 Diet 3	10.81	74.89±0.80	15.78±0.52	6.20±0.05	3.56±0.08
处理4 Diet 4	14.26	75.96±1.03	15.11±0.61	6.32±0.14	3.50±0.12
处理5 Diet 5	17.32	76.57±0.26	15.93±0.27	6.25±0.09	3.76±0.11
处理6 Diet 6	20.94	76.51±0.64	15.46±0.28	6.18±0.08	3.56±0.04
<i>F</i>		1.034	0.793	0.592	0.643
<i>P</i>		0.441	0.575	0.707	0.672

表 4 两种规格的军曹鱼肝脏组成(% , 湿重; 均值±标准误)

Tab. 4 Effect of lipid level on liver composition of cobia at two body weight (% , wet weight; Means±SEM)

编号No.	脂肪含量Lipid level (%)	水分Moisture (%)	蛋白质Crude protein (%)	脂肪Crude lipid (%)	糖原Glucogen (mg/g)
实验1 Trial 1 初始体重: (38.24±0.30) g					
处理1 Diet 1	5.27	73.84±0.55 ^a	12.77±0.25	12.35±0.35 ^c	4.33±0.42 ^a
处理2 Diet 2	8.22	73.21±0.31 ^{ab}	12.98±0.14	13.69±0.44 ^{bc}	4.05±0.20 ^a
处理3 Diet 3	10.81	71.84±0.51 ^{abc}	13.30±0.14	15.20±0.35 ^b	3.46±0.26 ^{ab}
处理4 Diet 4	14.26	72.44±0.69 ^{abc}	12.14±0.67	17.41±0.33 ^a	3.42±0.21 ^{ab}
处理5 Diet 5	17.32	71.22±0.52 ^{bc}	11.92±0.57	17.68±0.68 ^a	3.20±0.33 ^{ab}
处理6 Diet 6	20.94	70.56±0.28 ^c	12.52±0.45	17.39±0.34 ^a	2.49±0.21 ^b
<i>F</i>		6.079	1.485	27.077	5.298
<i>P</i>		0.005	0.265	<0.001	0.008
实验2 Trial 2 初始体重: (529.17±5.67) g					
处理1 Diet 1	5.27	74.79±0.52	14.36±0.76	7.69±0.90	4.50±0.06
处理2 Diet 2	8.22	76.24±0.24	14.00±1.17	6.90±0.90	4.56±0.29
处理3 Diet 3	10.81	75.66±0.87	13.20±0.34	8.47±0.76	5.06±0.34
处理4 Diet 4	14.26	75.59±0.46	11.96±0.67	10.00±0.96	5.37±0.24
处理5 Diet 5	17.32	75.21±0.68	12.88±0.48	8.68±1.56	5.44±0.16
处理6 Diet 6	20.94	73.71±0.97	11.46±0.21	11.57±0.49	5.38±0.13
<i>F</i>		1.696	2.743	2.917	3.583
<i>P</i>		0.210	0.071	0.060	0.033

这可能是造成鱼体 VSI 和 CF 上升的主要原因。军曹鱼幼鱼全鱼脂肪含量随着饲料中脂肪含量的升高显著升高($P<0.05$), 而500 g规格的军曹鱼体脂肪并

无显著性差异($P>0.05$)。根据40 g和500 g规格的军曹鱼的体组成变化趋势, 可以推测在军曹鱼生长的过程中, 鱼体对饲料脂肪的利用能力逐渐加强, 这

表 5 两种规格的军曹鱼肌肉组成(% , 湿重; 均值±标准误)

Tab. 5 Effect of lipid level on muscle composition of cobia at two body weight (% , wet weight; Means±SEM)

编号 No.	脂肪含量 Lipid level (%)	水分 Moisture (%)	蛋白质 Crude protein (%)	脂肪 Crude lipid (%)	灰分 Ash (%)	糖原 Glucogen (mg/g)
实验1 Trial 1 初始体重: (38.24±0.30) g						
处理1 Diet 1	5.27	78.72±0.29 ^a	19.41±0.20	5.27±0.11 ^b	1.52±0.04	0.18±0.01 ^a
处理2 Diet 2	8.22	77.95±0.10 ^{ab}	19.77±0.14	5.41±0.09 ^b	1.48±0.04	0.15±0.01 ^{ab}
处理3 Diet 3	10.81	76.84±0.35 ^{ab}	20.16±0.23	5.55±0.06 ^b	1.47±0.03	0.15±0.00 ^{ab}
处理4 Diet 4	14.26	76.47±0.17 ^{abc}	20.17±0.11	5.52±0.10 ^b	1.47±0.01	0.14±0.02 ^{ab}
处理5 Diet 5	17.32	75.79±0.31 ^{bc}	20.19±0.41	6.18±0.10 ^a	1.62±0.02	0.10±0.01 ^{bc}
处理6 Diet 6	20.94	74.09±1.12 ^c	21.20±0.80	6.58±0.17 ^a	1.60±0.04	0.08±0.01 ^c
<i>F</i>		10.068	2.31	22.526	4.674	11.517
<i>P</i>		0.001	0.109	<0.001	0.013	<0.001
实验2 Trial 2 初始体重: (529.17±5.67) g						
处理1 Diet 1	5.27	79.30±0.45	18.42±0.28	5.50±0.45	1.33±0.01	0.14±0.01 ^a
处理2 Diet 2	8.22	77.91±0.45	18.97±0.40	5.50±0.42	1.38±0.02	0.14±0.00 ^a
处理3 Diet 3	10.81	78.18±0.28	18.21±0.06	5.50±0.04	1.39±0.01	0.09±0.01 ^b
处理4 Diet 4	14.26	78.88±0.69	18.35±0.30	5.38±0.54	1.31±0.04	0.09±0.01 ^b
处理5 Diet 5	17.32	79.28±0.51	18.45±0.39	5.62±0.59	1.40±0.03	0.07±0.01 ^b
处理6 Diet 6	20.94	79.12±0.46	18.51±0.28	5.76±0.24	1.33±0.02	0.06±0.01 ^b
<i>F</i>		1.486	0.715	0.092	1.893	14.164
<i>P</i>		0.265	0.624	0.992	0.169	<0.001

表 6 两种规格的军曹鱼血清生化指标(% , 湿重; 均值±标准误)

Tab. 6 Effect of lipid level on serum biochemical indices of cobia at two body weight (% , wet weight; Means±SEM)

编号 No.	脂肪含量 Lipid level (%)	TG (mmol/L)	TC (mmol/L)	TP (g/L)	LDL-C (mmol/L)	HDL-C (mmol/L)	GLU (mmol/L)
实验1 Trial 1 初始体重: (38.24±0.30) g							
处理1 Diet 1	5.27	1.03±0.05 ^c	1.52±0.06 ^c	28.5±0.2	0.0768±0.0130 ^c	0.4518±0.0511 ^d	0.90±0.29 ^c
处理2 Diet 2	8.22	1.05±0.07 ^c	1.76±0.03 ^b	28.8±0.3	0.0886±0.0092 ^{bc}	0.5923±0.0429 ^{cd}	1.95±0.32 ^c
处理3 Diet 3	10.81	1.31±0.02 ^b	1.76±0.01 ^b	27.8±0.4	0.1101±0.0039 ^{abc}	0.7100±0.0784 ^{bc}	2.45±0.23 ^{bc}
处理4 Diet 4	14.26	1.37±0.05 ^b	1.79±0.01 ^{ab}	27.6±1.1	0.1063±0.0088 ^{abc}	0.7473±0.0633 ^{bc}	3.70±0.54 ^{ab}
处理5 Diet 5	17.32	1.36±0.03 ^b	1.88±0.02 ^{ab}	27.2±0.7	0.1269±0.0059 ^{ab}	0.9159±0.0091 ^{ab}	4.11±0.15 ^a
处理6 Diet 6	20.94	1.59±0.03 ^a	1.92±0.01 ^a	27.4±0.8	0.1298±0.0034 ^a	1.0305±0.0373 ^a	3.96±0.30 ^{ab}
<i>F</i>		23.494	21.826	0.869	6.659	16.496	15.41
<i>P</i>		<0.001	<0.001	0.529	0.003	<0.001	<0.001
实验2 Trial 2 初始体重: (529.17±5.67) g							
处理1 Diet 1	5.27	0.69±0.15 ^b	1.45±0.16	28.1±1.7	0.1031±0.0166	1.0208±0.1751	3.10±0.53
处理2 Diet 2	8.22	0.90±0.21 ^{ab}	1.78±0.15	27.6±0.4	0.1117±0.0118	0.4410±0.2075	2.71±0.59
处理3 Diet 3	10.81	1.12±0.24 ^{ab}	1.93±0.14	27.9±1.8	0.0986±0.0167	0.9687±0.1406	3.27±0.87
处理4 Diet 4	14.26	0.90±0.18 ^{ab}	1.59±0.10	26.4±3.4	0.1066±0.0054	0.9571±0.1145	2.02±0.79
处理5 Diet 5	17.32	1.25±0.13 ^{ab}	1.47±0.14	23.7±1.2	0.0967±0.0201	0.6918±0.0871	2.72±0.21
处理6 Diet 6	20.94	1.63±0.18 ^a	1.64±0.19	23.9±2.5	0.0899±0.0191	0.6236±0.0528	4.02±0.57
<i>F</i>		3.159	1.544	0.939	0.24	2.791	1.131
<i>P</i>		0.048	0.249	0.49	0.937	0.067	0.396

注: TG. 总甘油三酯Triglyceride; TC. 总胆固醇Total cholesterol; TP. 总蛋白Total protein; LDL-C. 低密度脂蛋白-胆固醇Low density lipoprotein-cholesterol; HDL-C. 高密度脂蛋白-胆固醇Low density lipoprotein-cholesterol; GLU. 葡萄糖Glucose

与斜带石斑鱼^[5]、大黄鱼^[32]上的研究结果是一致的。同时, 这可能也是脂肪在500 g规格的军曹鱼肝脏和肌肉等组织的沉积未显现出显著差异, 进而未显著影响其肝体比($P>0.05$)的原因。对2个不同规格的军曹鱼投喂相同营养组成的饲料, 养殖实验结束后, 其脂肪沉积的效果却存在着差异。这可能是由于鱼体规格不同, 鱼体或组织的蛋白或脂肪含量存在差异造成的, 另外, 不同规格军曹鱼之间的代谢差异可能也影响了最终的生长效果。

3.3 血清生化指标

与哺乳动物类似, 鱼类脂类转运主要通过脂蛋白(Lipoproteins)经由外源性和内源性2个循环^[44]。小肠中乳糜微粒(CM)转运小肠从食物中吸收的脂类的方式称为外源性途径, 而内源性途径是指肝脏中极低密度脂蛋白(VLDL)向外分泌脂类并转化为中间密度脂蛋白(IDL)和低密度脂蛋白(LDL)^[45, 46]。另外, 还存在着主要作用是将各组织中的胆固醇再运送回肝脏进行代谢的高密度脂蛋白(HDL)^[32]。摄食高脂饲料的军曹鱼幼鱼血清总甘油三酯、血清总胆固醇、LDL-C水平显著升高, 这与草鱼(*Ctenopharngon idellus*)^[47, 48]、红鳍东方鲀(*Takifugu rubripes*)^[49]、大黄鱼^[50]和大菱鲆(*Scophthal musmaximus* L.)^[51]上的研究结果是一致的。高水平的脂肪摄入并经由肠道消化吸收, 最终使血清TG含量升高。同时, 血清中高水平的总甘油三酯表明摄食高脂饲料组军曹鱼肝脏VLDL分泌量的增加。血管上皮细胞膜上的受体识别了VLDL后被LPL降解, 并最终转化为LDL^[51]。之前的研究表明: 鱼体主要通过以下途径对脂肪的转运进行调控, 当摄入脂肪含量过低时, 鱼体可经由apoB 100抑制VLDL的组装和分泌^[52, 53]。而摄入高脂饲料(具有高水平的n-3 LC-PUFA)时, 则可降低肝脏VLDL分泌^[54]并且增加乳糜颗粒的代谢和清除^[55—57]来降低血浆TG浓度, 以便于抑制肝脏脂肪的过度沉积。随着军曹鱼的生长发育, 该脂肪调节途径的调节能力也会显著提高。因此, 为阐明海水肉食性鱼类糖脂代谢之间的关系, 还需对不同水平的糖和糖脂比的饲料对军曹鱼糖脂代谢关键酶的活性及表达水平的影响进行研究。

综上所述, 以SGR和FER为评定指标, 40 g规格军曹鱼的脂肪需求量为13.79%—14.56%; 500 g规格军曹鱼的脂肪需求量为13.10%—13.49%。随着饲料脂肪水平的增加, 血清TG、VSI与CF均显著升高。而小规格的军曹鱼血清TC、HDL-C、LDL-C和GLU以及鱼体、肝脏和肌肉的脂肪含量均显著升高, 鱼体蛋白含量却显著下降; 而对较大规格的

军曹鱼影响却不显著。

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THE EFFECT OF DIFFERENT LIPID LEVELS ON THE GROWTH PERFORMANCE, BODY COMPOSITION AND PLASMA BIOCHEMICAL INDICES IN COBIA (*RACHYCENTRON CANADUM* L.) AT TWO DIFFERENT SIZES

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Abstract: The purpose of this study was to investigate dietary lipid requirement and the effect of different lipid levels on the body composition and plasma biochemical indices in cobia (*Rachycentron canadum* L.) at two different body sizes (initial weight: 40 g vs. 500 g). Six isonitrogenous diets were formulated using fish meal, soybean meal and wheat meal as the protein source and fish oil as lipid source, with six different lipid contents of 5.27%, 8.22%, 10.81%, 14.26%, 17.32% and 20.94% (at a dry matter basis), respectively. Fish at two different growth stages were randomly distributed to seawater floating net cages (1.5 m×1.5 m×2.5 m) at a density of 25 and 10 fish per net cage, respectively. Each diet was fed to triplicate groups of fish twice daily to satiation for 10 weeks (40 g) and 8 weeks (500 g), respectively. Specific growth rate (*SGR*) and feed efficiency ratio (*FER*) significantly increased and then decreased with increasing dietary lipid levels at both developmental stages. The Viscerosomatic index (*VSI*) and Condition factor (*CF*) increased significantly with the increase of dietary lipid levels. Significantly higher Hepatosomatic index (*HSI*), whole-body, liver and muscle lipid contents and lower moisture and protein contents were observed in fish feed the diets containing higher lipid among small fish groups, but no significant difference was detected among large body size groups among above parameters. In addition, the contents of TC, TG, HDL-C, LDL-C and Glu increased significantly with the increasing lipid levels among small fish groups, there was no significant effect among large fish groups in these indices except TG. The overall results showed that based on *SGR* and *FER*, the diet containing 13.97%—14.16% and 13.18%—13.47% lipid was most suitable for the cobia culture at the body size of 40 g and 500 g, respectively.

Key words: *SGR*; *FER*; Body composition; Plasma biochemical indices; Requirement of lipid; Cobia