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DIETARY PROTEIN AND LIPID ON GROWTH PERFORMANCE, BODY COMPOSITION AND DIGESTIVE ENZYME ACTIVITIES OF WINTERLING *CULTER ALBURNUS*♀×*MEGALOBRAMA TERMINALIS*♂

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饲料蛋白和脂肪水平对太湖鲂鲌冬片鱼种生长、体组成和消化酶活性的影响

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摘要: 为优化太湖鲂鲌配合饲料配方, 设计3个饲料蛋白水平(36%、39%和42%)和3个脂肪水平(6%、8%和10%)的3×3因子实验, 配制9种实验饲料(P36L6、P36L8、P36L10、P39L6、P39L8、P39L10、P42L6、P42L8和P42L10), 分别饲喂9组3重复平均体重为8.59 g的太湖鲂鲌冬片鱼种60d, 以探讨饲料中不同含量的蛋白和脂肪对太湖鲂鲌冬片鱼种生长、饲料利用、体成分和肠道消化酶等的影响。结果表明: 实验鱼摄食蛋白水平为39%和42%的6种饲料(P39L6、P39L8、P39L10、P42L6、P42L8和P42L10) 后, 其鱼体增重率和饲料系数在组间无显著差异(P>0.05), 但鱼体增重率均比摄饲料蛋白水平为36%的3种饲料(P36L6、P36L8和P36L10)的实验组要高(P<0.05), 而饲料系数则较低; 在同一饲料蛋白水平时, 饲料脂肪水平变化对蛋白质沉积率无显著影响; 摄食蛋白质水平为39%饲料的3个实验组的蛋白质沉积率均高于饲料蛋白为36%的3个实验组。饲料同一脂肪水平时, 饲料蛋白水平从39%提高到42%对蛋白质沉积率有降低的趋势, 但差异不显著; 脏体指数(VSI)与饲料脂肪水平(L)呈正相关(VSI=0.223L+4.611, R=0.746, P=0.000); 全鱼粗脂肪随饲料蛋白的升高而降低, 但随饲料脂肪水平的升高而增加; 摄食3种低脂肪水平(6%)的饲料(P36L6、P39L6和P42L6)的太湖鲂鲌肌肉粗脂肪含量均显著低于摄食其他6种脂肪水平较高(8%和10%)饲料组; 摄食3种蛋白水平为36%的饲料(P36L6、P36L8和P36L10)后, 太湖鲂鲌肠道淀粉酶活性显著高于蛋白水平39%和42%的饲料组; 太湖鲂鲌肠道蛋白酶和脂肪酶活性均不受饲料蛋白和脂肪水平及其交互作用的影响; 因此, 能使实验鱼获得良好生长和饲料利用的适宜饲料蛋白和脂肪水平分别为39%和6%。过低的饲料蛋白水平和过高的饲料脂肪水平易导致鱼体脂肪积累过多。

关键词: 蛋白水平; 脂肪水平; 生长; 体成分; 肠道消化酶; 太湖鲂鲌冬片鱼种
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鱼类配合饲料成本最高的组分是蛋白质, 其在饲料配方中适宜的含量对设计最优成本配方至关重要。配合饲料中脂肪可为鱼类提供能量及必需脂肪酸, 其在饲料配方中的适宜水平可起到节约蛋白质的作用[1]。故研究鱼类的蛋白和脂肪适宜需求量, 一方面可以在不影响鱼类生长及健康情况下最大限度降低饲料成本, 另一方面还起到保护水生态环境的作用。

太湖鲂鲌(*Culter alburnus* ♀ × *Megalobrama terminalis* ♂)是翘嘴鲌(*Culter alburnus* ♀)和三角鲂(*Megalobrama terminalis* ♂)通过属间远缘杂交获得的(新品种登记号: GS-02-001-2017), 具有体型优、生长快、肌间刺少[2—4]等杂交优势, 发展势头良好。但太湖鲂鲌营养需求方面的研究还较少, 目前, 仅见对太湖鲂鲌幼鱼(1.22 g)饲料蛋白水平的需求研究[5], 本实验通过调整饲料中蛋白和脂肪水平, 探讨这两种营养素对太湖鲂鲌隔冬鱼种生长、饲料利用、体成分及肠道消化酶活性等指标的影响, 从而了解该阶段太湖鲂鲌饲料适宜的蛋白和脂肪水平, 不仅可以完善太湖鲂鲌营养需求数据, 还可以为其饲料配方设计提供理论依据。

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1 材料与方法

1.1 实验鱼

实验用太湖鲂鲌冬片鱼种为本所试验基地同一批鱼种, 驯养时间为2周, 之后随机挑选675尾体质健壮的鱼种(初始平均体重约为8.59 g)平均分养到27个水槽中, 每3个水槽投喂1种实验饲料。

1.2 实验饲料

根据课题组及前人研究结果[5—8], 设计3个饲料蛋白水平(36%、39%和42%)和3个饲料脂肪水平(6%、8%和10%)的3×3因子实验, 配制9种实验饲料(P36L6、P36L8、P36L10、P39L6、P39L8、P39L10、P42L6、P42L8和P42L10), 实验饲料主要蛋白原料为秘鲁鱼粉、鸡肉粉、豆粕等, 脂肪原料为鱼油, 其详细原料组成和营养成分见表 1。饲料制作主要流程: 先将所有原料采用高速粉碎机粉碎, 并逐一过60目电动筛, 之后按照配方比例将原料称好置于盆内, 较少的原料采取逐级稀释方法, 以达到混合均匀的目的, 加入鱼油, 用手揉搓开油脂粒并过40目筛, 最后加入15%左右的水, 用DS32-Ⅱ型双螺杆实验饲料机于95℃挤压成长3 mm, 直径0.5 mm的颗粒, 在室温下风干后, 于4℃保存备用。

1.3 饲养管理

养殖实验共进行60d。实验鱼饲养在循环水养殖系统中, 系统包括27只容积500 L (盛水300 L)的圆柱形玻璃钢水槽, 每个水槽配备充气头, 并保持连续充气。在实验鱼随机分到每个水槽后, 保持每天8:00和16:00各投喂1餐实验饲料, 投喂方式为少量多次投喂至接近饱食。投喂时间约为30—45min, 日投喂量为鱼体重2.5%左右。实验期间监测水温(26—28)℃, 溶解氧(5.12—6.85) mg/L, 氨氮(0.10—0.23) mg/L, 亚硝酸氮(0.02—0.09) mg/L。

1.4 取样和成分分析

在养殖实验结束后, 将所有太湖鲂鲌冬片鱼种饥饿2d, 统计每个实验水槽鱼体总重及数量, 用于计算生长及成活率等指标; 每个水槽随机取4尾实

表 1 实验饲料配方和营养组成分析表(g/kg, 干物质)

Tab. 1 Formulation and proximate analysis of the trial diets (g/kg, on dry matter basis)

原料Ingredient	饲料Diet								
	P36L6	P39L6	P42L6	P36L8	P39L8	P42L8	P36L10	P39L10	P42L10
秘鲁鱼粉Fish meal	211.3	239.0	268.0	211.3	239.0	268.0	211.3	239.0	268.0
鸡肉粉Chicken meat meal	52.0	60.0	69.0	52.0	60.0	69.0	52.0	60.0	69.0
豆粕Soybean meal	132.0	155.0	168.0	132.0	155.0	168.0	132.0	155.0	168.0
血粉Blood meal	27.0	31.0	35.0	27.0	31.0	35.0	27.0	31.0	35.0
菜粕Rapeseed meal	23.0	26.0	30.0	23.0	26.0	30.0	23.0	26.0	30.0
棉籽粕Cottonseed meal	45.0	50.0	55.5	45.0	50.0	55.5	45.0	50.0	55.5
螺旋藻粉*Spirulina* sp. powder	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0	3.0
面粉Wheat flour	406.5	338.4	277.6	406.5	338.4	277.6	406.5	338.4	277.6
酵母发酵物Yeast extract	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
鱼油Fish oil	26.2	23.6	20.4	46.2	43.6	40.4	66.2	63.6	60.4
维生素预混物Vitamin mix[1]	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
矿物质预混物Mineral mix[2]	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
磷酸二氢钙$Ca(H_2PO_4)_2$	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0	15.0
氯化胆碱Choline chloride	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
纤维素Cellulose	40.0	40.0	40.0	20.0	20.0	20.0	0	0	0
组成分析Proximate analysis									
粗蛋白Crude protein	369.1	393.2	424.1	366.1	393.7	424.4	365.0	388.3	416.1
粗脂肪Crude lipid	55.6	58.0	54.6	75.5	74.8	75.8	97.0	96.7	93.9
粗灰分Crude ash	72.3	77.4	91.3	75.0	77.7	86.0	71.7	77.0	86.3

注: [1]维生素预混物(g/kg 预混料): 维生素A醋酸酯 1.60; 维生素D_3 0.12; 维生素E醋酸酯 8.00; 维生素K_3 16.00; 硫胺素 4.00; 核黄素 4.00; 泛酸 12.00; 吡哆醇4.00; 叶酸 1.00; 尼克酸30; 维生素B_{12} 0.04; 肌醇80.00; 包膜维C 40; 玉米淀粉 801.24; [2]矿物质预混物(g/kg 预混料): $FeSO_4·7H_2O$ 75; $CuSO_4·H_2O$ 1.5; $ZnSO_4·7H_2O$ 50; $MnSO_4·H_2O$ 2.5; NaCl 150; $MgSO_4$ 200; KI 0.25; Na_2SeO_3 0.025; $CoCl_3·6H_2O$ 2.5; 沸石粉518.225

Note: [1]Vitamin mix (g/kg mix): retinol acetate1.60; cholecalciferol 0.12; *α*-tocopherol acetate 8.00; menadione 16.00; thiamin 4.00; riboflavin 4.00; pantothenic acid 12.00; pyridoxine 4.00; folic acid 1.00; niacin 30; cyanocobalamin 0.04; inositol 80.00; coated vitamin C 40; corn starch 801.24; [2]Mineral mix (g/kg mix): $FeSO_4·7H_2O$ 75; $CuSO_4·H_2O$ 1.5; $ZnSO_4·7H_2O$ 50; $MnSO_4·H_2O$ 2.5; NaCl 150; $MgSO_4$ 200; KI 0.25; Na_2SeO_3 0.025; $CoCl_3·6H_2O$ 2.5; zeolite 518.225

验鱼, 用于全鱼常规营养组成测定; 另取4尾实验鱼取背肌, 用于肌肉常规营养组成测定; 另取8尾实验鱼分别测量体重、体长, 用于计算肥满度; 将8尾实验鱼于冰盘解剖后分离内脏、肝脏和肠道, 并称量脏体重、肝脏重和肠道重, 用于计算体形指标。

实验饲料、全鱼和肌肉的水分、粗蛋白、粗脂肪和粗灰分等营养组成参照AOAC的方法进行[9]。

肠道消化酶活性检测方法: 实验鱼麻醉后(MS222, 浓度为1∶10000), 每水槽随机取6尾鱼于冰盘上解剖并分离肠道, 在剔除脂肪块和内容物后混合为1个样本置于匀浆瓶中, 并加入10倍肠道重的磷酸盐缓冲液(pH 7.4, NaCl 50 mmol/L, Na_2HPO_4-NaH_2PO_4 154 mmol/L)制作匀浆液, 随后于4℃、10000×g离心10min制得粗酶液。蛋白酶活性测定采用福林试剂法[10], 淀粉酶活性测定参照 Bernfeld[11]的方法, 脂肪酶活性采用南京建成生物工程研究所试剂盒测定, 粗酶液中蛋白质浓度采用考马斯亮蓝法[12]测定。

1.5　指标及其计算方法

成活率(Survival rate, SR; %)=100×(每槽最终尾数/每槽初始尾数); 鱼体增重率(Weight gain rate, WGR; %)=100×[鱼体最终重量(Final body weight, FBW)－鱼体初始重量(Initial body weight, IBW)]/鱼体初始重量; 饲料系数(Feed conversion ratio; FCR)=干饲料摄入总重/鱼体总增重; 蛋白沉积率(Protein retention, PR; %)=100×(实验末鱼体总蛋白量–起始鱼体总蛋白量)/摄入饲料总蛋白量; 肥满度(Condition factor, CF; g/cm^3)=100×鱼体重/(鱼体长)^3; 脏体比(Viscera-somatic index, VSI)=100×内脏重/鱼体重; 肠体比(Gut-somatic index; GS)=100×肠道重/体重; 肝体比(Hepato-somatic index; HSI)=100×肝胰脏重/体重。

1.6　数理统计方法

采用SPSS16.0软件对所得数据进行统计分析, 用单因子方差分析(One-way ANOVA)比较各饲料组间各指标平均值差异的显著性, 用双因子方差分析(Two-way ANOVA)检验蛋白水平、脂肪水平及其交互作用对各指标平均值影响的显著性。如P<0.05, 则进行SNK多重比较分析。各指标数据均以平均值±标准误表示。

2　结果

2.1　太湖鲂鲌生长情况

太湖鲂鲌生长和饲料利用情况见表 2。饲料蛋白水平对太湖鲂鲌WGR和FCR均有显著影响(P<0.05)。实验鱼摄食蛋白水平分别为39%和42%的6种饲料(P39L6、P39L8、P39L10 、PP42L6、P42L8和P42L10)后, 其WGR和FCR在组间无显著差异(P>0.05), 但与蛋白水平为36%的3种饲料(P36L6、P36L8和 P36L10)的实验组相比, WGR要高, 而FCR则较低(P<0.05); 在相同饲料蛋白水平时, 饲料脂肪水平变化对WGR影响不显著(P>0.05); 在饲料蛋白水平为36%时, 脂肪水平分别为6%和8%的两个实验组(P36L6和 P36L8)的 FCR无显著差异(P>0.05), 但均高于脂肪水平为10%的实验组(P36L10)(P<0.05); PR受饲料蛋白和脂肪水平影响显著(P<0.05), 但在同一蛋白水平时脂肪的变动对PR无显著影响(P>0.05)。摄食蛋白水平为39%饲料的3个实验组的PR均高于饲料蛋白为36%的3个实验组(P<0.05)。饲料脂肪水平相同时, 蛋白水平从39%提高到42%, PR均有下降的趋势, 但差异不显著(P>0.05); 实验鱼成活率不受饲料蛋白和脂肪水平及其交互作用影响(P>0.05)。

2.2　太湖鲂鲌体形指标

太湖鲂鲌肥满度等指标见表 3。太湖鲂鲌的CF、HSI和GSI不受饲料蛋白和脂肪水平及其交互作用影响(P>0.05), VSI受饲料蛋白和脂肪水平影响显著(P<0.05)。摄食P42L6饲料实验鱼的VSI与摄食P36L6、P39L6和P42L8饲料的实验组无显著差异(P>0.05), 而显著低于摄食P36L8、P36L10、P39L8、P39L10和P42L10饲料实验组(P<0.05); 实验鱼的VSI与饲料脂肪水平(L)呈正相关(VSI=0.223L+4.611, R=0.746, P=0.000)。

2.3　太湖鲂鲌全鱼体组成

如表 4所示, 全鱼水分和粗脂肪受饲料蛋白和脂肪水平影响显著(P<0.05)。饲料蛋白水平最高或饲料脂肪水平最低时全鱼水分较高而全鱼粗脂肪较低(P<0.05); 全鱼粗脂肪随饲料蛋白的升高而降低(P<0.05), 但随饲料脂肪水平的升高而增加(P<0.05); 饲料蛋白水平、脂肪水平及其交互作用对全鱼粗蛋白和粗灰分影响不显著(P>0.05)。

2.4　太湖鲂鲌肌肉组成

如表 5所示, 饲料蛋白和脂肪水平及其交互作用对太湖鲂鲌肌肉的水分、粗蛋白和粗灰分影响不显著(P>0.05), 但肌肉粗脂肪含量受饲料蛋白和脂肪水平影响显著(P<0.05)。摄食低脂肪、高蛋白水平饲料(P42L6)的实验鱼肌肉粗脂肪含量为最低(P<0.05); 摄食3种低脂肪水平(6%)饲料(P36L6、P39L6和P42L6)的太湖鲂鲌肌肉粗脂肪含量均显著低于摄食其他6种脂肪水平较高(8%和10%)饲料的实验组(P<0.05), 并且摄食该6种饲料的实验鱼肌肉粗脂肪含量无显著差异(P>0.05)。

2.5 太湖鲂鲌肠道消化酶活性

如表 6所示, 饲料蛋白、脂肪水平及其交互作用均对实验鱼肠道蛋白酶和脂肪酶活性无显著影响($P>0.05$), 但饲料蛋白和脂肪水平对肠道淀粉酶活性有显著影响($P<0.05$)。太湖鲂鲌摄食蛋白为36%的饲料后肠道淀粉酶活性均显著高于蛋白水平为39%和42%的实验组($P<0.05$), 而且以摄食P36L6饲料实验鱼的肠道淀粉酶活性为最高($P<0.05$)。饲料蛋白水平为39%和42%的6个实验组间肠道淀粉酶活性无显著差异($P>0.05$)。

3 讨论

本实验研究发现, 当饲料蛋白水平为36%时, 太湖鲂鲌鱼种生长较慢而FCR较高, 这可能主要与P36L6、P36L8和P36L10 三种饲料中饲料蛋白所提供氨基酸水平不足有关; 另一方面, 饲料蛋白水平从36%提高到39%, 太湖鲂鲌的WGR显著提高, FCR显著降低, 但随着饲料蛋白水平进一步提高至42%时, WGR和FCR变化均不显著。这表明饲料蛋白水平39%即可满足太湖鲂鲌鱼种正常生长所需要的最低氨基酸水平。该结果比作者早前研究报道的太湖鲂鲌幼鱼(1.22 g)对蛋白质需求量(42.9%—43.8%)[5]要低, 说明太湖鲂鲌与其他鱼类相似, 随着鱼体长大对配合饲料中蛋白质的需求量也有所下降[1]。同时也反映出42%的饲料蛋白有点浪费, 因为鱼类摄食过高蛋白水平的饲料后, 多余的饲料蛋白被用作能量分解[13]。这从摄饲料蛋白水平为42%饲料实验组的PR比摄食饲料蛋白为39%饲料的实验组要相对较低得到证实。饲料蛋白水平在满足太湖鲂鲌鱼种需求后, 饲料脂肪水平变化对鱼体生长和饲料系数无显著影响, 而且在同一饲料蛋白水平时, 饲料脂肪水平变化对蛋白质积累也均无显著影响。本研究结果表明太湖鲂鲌鱼种饲料中适宜脂肪水平为6%即可。该结果与对三角鲂(其父本) 鱼种的研究结果[6]相同, 而比对翘嘴鲌(其母本)鱼种的研究结果[7, 8]略低。

有研究表明, 鱼类摄入较多的糖类, 会诱发其机体的脂肪合成酶活性提高, 促进糖源转变为脂肪,

表 2 实验饲料对太湖鲂鲌生长和饲料利用的影响

Tab. 2 Effects of experimental feed on growth and feed utilization of the fish in Taihu Lake

饲料Diet	初均重IBW (g)	终均重FBW (g)	增重率WGR (%)	成活率SR (%)	饲料系数FCR	蛋白沉积率PR (%)
P36L6	8.64±0.04	27.68±0.95^{b}	220.42±10.69^{b}	96.19±3.81	1.46±0.04^{a}	31.87±1.00^{d}
P36L8	8.54±0.11	26.98±0.25^{b}	216.00±6.60^{b}	97.14±0.00	1.50±0.01^{a}	31.77±0.98^{d}
P36L10	8.63±0.06	28.23±0.72^{b}	227.27±10.11^{b}	96.19±0.95	1.36±0.04^{b}	33.44±1.17^{cd}
P39L6	8.55±0.02	32.69±0.71^{a}	282.28±8.53^{a}	98.09±0.95	1.15±0.02^{c}	37.78±0.21^{ab}
P39L8	8.73±0.05	32.50±0.58^{a}	272.49±4.37^{a}	97.14±1.65	1.18±0.01^{c}	37.30±0.18^{ab}
P39L10	8.50±0.24	33.12±0.82^{a}	289.98±2.31^{a}	98.09±0.95	1.10±0.02^{c}	40.07±0.42^{a}
P42L6	8.62±0.09	31.71±0.59^{a}	267.97±4.87^{a}	99.05±0.95	1.17±0.02^{c}	35.68±0.80^{bc}
P42L8	8.48±0.10	34.41±1.19^{a}	305.60±13.55^{a}	95.24±3.43	1.12±0.01^{c}	36.23±0.61^{b}
P42L10	8.59±0.04	34.39±0.93^{a}	300.27±9.53^{a}	97.14±1.65	1.09±0.06^{c}	37.17±0.71^{ab}
P36		27.63±0.39^{X}	221.23±4.94^{X}	96.51±1.14	1.44±0.03^{X}	32.36±0.59^{X}
P39		32.77±0.37^{Y}	281.58±3.81^{Y}	97.78±0.63	1.14±0.01^{Y}	38.38±0.45^{Z}
P42		33.50±0.65^{Y}	291.28±7.71^{Y}	97.143±1.26	1.13±0.03^{Y}	36.64±0.50^{Y}
L6		30.69±0.86	256.89±10.25	97.78±1.24	1.26±0.05^{V}	35.10±0.94^{V}
L8		31.30±1.18	264.70±13.84	96.51±1.14	1.27±0.06^{V}	35.11±0.91^{V}
L10		31.91±1.03	272.50±12.11	97.14±0.67	1.17±0.05^{W}	37.17±1.06^{W}
p		0	0	0.717	0	0
L		0.196	0.109	0.717	0.001	0.004
P*L		0.266	0.094	0.817	0.384	0.909

注: 在同一列中, 不同饲料组间有显著差异用不同上标小写字母表示($P<0.05$); 不同蛋白水平处理间有显著差异用上标字母X、Y或Z表示; 不同脂肪水平处理间有显著差异用U、V或W表示; 下同

Note: In a column, mean values with different low case alphabetic superscripts indicate significantly difference among dietary treatments ($P<0.05$); mean values with various alphabetic superscripts as X, Y or Z indicate significantly difference among dietary protein treatments and as U, V or W between dietary lipid treatments; The same applies bellow

使鱼体脂肪贮存增加[14, 15]。在本实验条件下, 实验饲料蛋白水平下调是通过增加面粉来调节的, 从而提高了碳水化合物水平, 可能是引起实验鱼摄食蛋白水平较低的饲料后, 全鱼脂肪含量较高的主要原因。另一方面, 鱼类摄食脂肪水平超过其自身需求的饲料后, 也会造成鱼体脂肪积累增多[1, 16]。因此, 太湖鲂鲌全鱼脂肪含量随着饲料脂肪水平升高而提高。本实验还发现, 太湖鲂鲌全鱼脂肪提高同时, 也伴随着VSI和肌肉脂肪含量的升高, 说明实验鱼长期摄食蛋白水平不足和过高脂肪的饲料后会导致最终鱼产品可食部比例下降和鱼肉中脂肪积累增多。

表 3　饲养60d后的太湖鲂鲌体形指标

Tab. 3　Body profiles of the fish fed different diets for 60d

饲料 Diet	肥满度 CF (g/cm^3)	脏体比 VSI	肝体比 HSI	肠体比 GSI
P36L6	1.41±0.07	6.25±0.32^{bcd}	1.01±0.04	2.11±0.07
P36L8	1.35±0.04	6.58±0.14^{abc}	1.04±0.10	1.84±0.06
P36L10	1.36±0.03	6.88±0.10^{ab}	1.01±0.01	1.80±0.10
P39L6	1.42±0.06	5.80±0.05^{cd}	0.93±0.03	1.77±0.21
P39L8	1.38±0.05	6.54±0.12^{abc}	1.08±0.02	2.03±0.22
P39L10	1.41±0.04	7.08±0.12^{a}	1.11±0.07	2.01±0.10
P42L6	1.38±0.07	5.73±0.10^{d}	0.97±0.03	1.880.06
P42L8	1.43±0.06	6.07±0.19^{cd}	1.05±0.06	1.79±0.14
P42L10	1.35±0.03	6.60±0.24^{abc}	0.94±0.03	1.98±0.07
P36	1.37±0.01	6.57±0.14^{X}	1.02±0.03	1.91±0.06
P39	1.40±0.02	6.50±0.18^{X}	1.04±0.03	1.94±0.08
P42	1.39±0.02	6.13±0.16^{Y}	0.99±0.03	1.88±0.07
L6	1.40±0.02	5.96±0.12^{U}	0.97±0.02	1.92±0.09
L8	1.39±0.02	6.39±0.11^{V}	1.05±0.04	1.88±0.06
L10	1.37±0.01	6.85±0.11^{W}	1.02±0.03	1.93±0.05
p	0.441	0.013	0.436	0.842
L	0.493	0	0.153	0.879
P*L	0.260	0.581	0.286	0.123

表 4　饲养60d后的太湖鲂鲌全鱼体组成

Tab. 4　Whole fish body composition of the fish fed different diets for 60d

饲料 Diet	水分 Moisture	粗蛋白 Crude protein	粗脂肪 Crude lipid	粗灰分 Crude ash
P36L6	70.36±0.07^{bc}	16.47±0.07	10.26±0.17^{bc}	3.04±0.07
P36L8	68.82±0.08^{e}	16.72±0.28	11.48±0.35^{ab}	3.21±0.16
P36L10	69.31±0.17^{cde}	16.08±0.23	11.79±0.17^{a}	2.97±0.07
P39L6	70.63±0.41^{b}	16.49±0.21	9.72±0.37^{c}	3.28±0.08
P39L8	69.72±0.25^{bcde}	16.61±0.14	10.69±0.22^{abc}	3.13±0.06
P39L10	69.13±0.09^{de}	16.60±0.12	11.17±0.08^{ab}	3.36±0.03
P42L6	71.43±0.13^{a}	16.97±0.15	8.26±0.10^{d}	3.21±0.10
P42L8	70.20±0.28^{bcd}	16.69±0.32	9.89^{c}±0.17	3.26±0.11
P42L10	69.57±0.52^{bcde}	16.64±0.08	10.80±0.58^{abc}	3.24±0.07
P36	69.49±0.23^{X}	16.42±0.14	11.18±0.26^{X}	3.08±0.06
P39	69.83±0.26^{X}	16.57±0.09	10.53±0.25^{Y}	3.26±0.05
P42	70.40±0.32^{Y}	16.77±0.11	9.65±0.41^{Z}	3.24±0.05
L6	70.81±0.20^{V}	16.64±0.11	9.41±0.32^{U}	3.18±0.06
L8	69.58±0.23^{W}	16.67±0.13	10.69±0.26^{V}	3.20±0.06
L10	69.34±0.17^{W}	16.44±0.12	11.25±0.23^{W}	3.19±0.07
p	0.002	0.134	0	0.060
L	0	0.312	0	0.952
P*L	0.236	0.345	0.365	0.164

鱼类对饲料的利用效率取决于消化酶的活性及其对不同饲料组分的反应程度[17]。研究认为鱼类肠道蛋白酶活性随饲料蛋白质水平提高而呈升高的趋势, 但在多数研究发现当饲料蛋白水平升高到一定程度后, 蛋白酶活性升高不再有持续性[18—23]。本实验中太湖鲂鲌饲料蛋白在适宜水平上下小幅变动不足以促发肠道蛋白酶活性的显著变化, 与对乌鳢(*Channa argus*)[23]、黄姑鱼(*Nibea albiflora*)[24]和团头鲂(*Megalobrama amblycephala*)[25]等的研究结果一致。本实验发现太湖鲂鲌饲料蛋白水平升高同时, 饲料中糖含量下降引起肠道淀粉酶活性随之下降。与对太湖鲂鲌幼鱼[5]及刺鲃(*Barbudes caldwell*)[18]、杂交鲌(*Erythroculter ilishaeformis* ♀× *Ancherythroculter nigrocauda* ♂)[19]和遮目鱼(*Chanos chanos*)[22]等研究结论相同。饲料脂肪水平变化影响鱼类肠道脂肪酶活性已有较多报道。当饲料脂肪水平不足时, 提高饲料脂肪水平可诱使消化腺和

表 5　饲养60d后的太湖鲂鲌肌肉组成

Tab. 5　Muscle composition of the fish fed different diets for 60d

饲料 Diet	水分 Moisture	粗蛋白 Crude protein	粗脂肪 Crude lipid	粗灰分 Crude ash
P36L6	78.97±0.13	19.19±0.18	1.41±0.17^{b}	1.32±0.01
P36L8	78.52±0.38	19.16±0.21	1.88±0.02^{a}	1.31±0.01
P36L10	78.34±0.38	19.14±0.09	1.85±0.06^{a}	1.29±0.06
P39L6	78.77±0.09	19.23±0.15	1.42±0.01^{b}	1.31±0.02
P39L8	78.84±0.19	18.72±0.11	1.70±0.08^{a}	1.30±0.02
P39L10	78.38±0.43	19.24±0.28	1.64±0.03^{a}	1.26±0.06
P42L6	78.89±0.11	19.01±0.16	1.05±0.04^{c}	1.28±0.02
P42L8	78.26±0.18	19.26±0.23	1.69±0.04^{a}	1.32±0.04
P42L10	78.88±0.10	18.920.02	1.78±0.02^{a}	1.31±0.03
P36	78.61±0.19	19.16±0.08	1.71±0.09^{X}	1.31±0.02
P39	78.67±0.14	19.07±0.13	1.59±0.05^{Y}	1.29±0.02
P42	78.68±0.15	19.06±0.09	1.51±0.12^{Y}	1.30±0.02
L6	78.88±0.07	19.14±0.09	1.30±0.07^{V}	1.30±0.01
L8	78.54±0.16	19.05±0.12	1.76±0.04^{W}	1.31±0.01
L10	78.53±0.16	19.10±0.10	1.75±0.04^{W}	1.28±0.03
p	0.927	0.734	0.001	0.839
L	0.197	0.804	0	0.681
P*L	0.282	0.175	0.006	0.861

表 6 饲养60d后的太湖鲂鲌肠道消化酶活性

Tab. 6 Intestinal digestive enzyme activities of the fish fed different diets for 60d

饲料 Diet	蛋白酶 Protease (U/mg)	淀粉酶 Amylase (U/mg)	脂肪酶 Lipase (U/g)
P36L6	18.12±1.23	17.77±0.50^{d}	6.26±0.14
P36L8	17.80±2.05	13.12±0.37^{bc}	6.04±0.28
P36L10	19.76±2.29	14.00±0.76^{c}	4.87±0.78
P39L6	19.25±1.84	11.49±0.46^{ab}	5.18±0.21
P39L8	18.571.74	10.64±0.79^{a}	4.71±1.01
P39L10	20.13±1.65	10.27±0.50^{a}	4.58±0.16
P42L6	21.32±0.93	9.60±0.29^{a}	5.35±0.26
P42L8	15.211.58	9.43±0.40^{a}	4.81±0.51
P42L10	17.12±0.78	11.29±0.58^{ab}	5.18±0.64
P36	18.55±1.00	14.96±0.77^{X}	5.72±0.32
P39	19.31±0.90	10.80±0.35^{Y}	4.82±0.31
P42	17.88±1.07	10.11±0.37^{Y}	5.11±0.26
L6	19.56±1.00	12.95±0.77^{U}	5.60±0.32
L8	17.19±0.90	11.06±0.35^{V}	5.19±0.32
L10	19.00±1.07	11.85±0.37^{V}	4.87±0.26
p	0.572	0	0.134
L	0.206	0.002	0.273
P*L	0.310	0.001	0.664

肠道脂肪酶活性随之提高[24—33], 但饲料脂肪水平达到一定量后继续提高, 则脂肪酶活性不再变化[26—32], 甚至下降[31—33]。本实验饲料脂肪水平变化不影响实验鱼肠道脂肪酶活性, 可能与实验饲料脂肪水平变幅较小有关[23, 34], 同样也能印证 6%饲料脂肪水平已达到太湖鲂鲌饲料的适宜水平。

总之, 在本实验条件下, 饲料蛋白为39%, 脂肪为6%较为适宜。太湖鲂鲌摄食低蛋白高脂肪饲料会造成体脂过多积累。

参考文献:

[1] National Research Council (NRC). Nutrient Requirements of Fish and Shrimp [S]. Washington DC, USA: National Academy Press, 2011: 67-68.

[2] Gu Z M, Jia Y Y, Ye J Y, *et al*. Studies on morphological characteristics and genetic analysis of the hybrid F_1, *Erythroculter ilishaeformis* ♀ × *Megalobrama amblycephala* ♂ [J]. *Journal of Fisheries of China*, 2008, **32**(4): 533-544. [顾志敏, 贾永义, 叶金云, 等. 翘嘴红鲌(♀)×团头鲂(♂)杂交种F_1的形态特征及遗传分析 [J]. 水产学报, 2008, **32**(4): 533-544.]

[3] Jia Y Y, Gu Z M, Ye J Y, *et al*. Analysis on genetic variations of *Erythroculter ilishaeformis* (♀) × *Megalobrama amblycephala* (♂) hybrids F_1 by SRAP markers [J]. *Journal of Shanghai Ocean University*, 2011, **20**(2): 198-203. [贾永义, 顾志敏, 叶金云, 等. 翘嘴红鲌(♀)×团头鲂(♂)杂交种F_1的SRAP标记分析 [J]. 上海海洋大学学报, 2011, **20**(2): 198-203.]

[4] Jiang W P, Jia Y Y, Liu S L, *et al*. Comparative analysis of intermuscular bones in hybrid F1, F2 of (*C. alburnus*) (♀)×(*M. amblycephala*)(♂) and its parents [J]. *Acta Hydrobiologica Sinica*, 2016, **40**(2): 277-286. [蒋文枰, 贾永义, 刘士力, 等. 鲌鲂F1、F2及其亲本肌间骨的比较分析 [J]. 水生生物学报, 2016, **40**(2): 277-286.]

[5] Chen J M, Huang A X, Tian R P, *et al*. Effects of dietary protein level on growth performance, body composition and digestive enzyme activities of juvenile hybrid of *Culter alburnus* (♀) × *Megalobrama terminalis* (♂) [J]. *Chinese Journal of Animal Nutrition*, 2019, **31**(10): 4843-4851. [陈建明, 黄爱霞, 田儒品, 等. 饲料蛋白质水平对太湖鲂鲌幼鱼生长性能、体组成和消化酶活性的影响 [J]. 动物营养学报, 2019, **31**(10): 4843-4851.]

[6] Ma H J, Liu X Y, Feng X Y, *et al*. Effects of protein and lipid levels on growth performance and body composition of juvenile *Megalobrama terminalis* (Richardson) [J]. *Feed Industry*, 2014, **35**(14): 19-25. [马恒甲, 刘新轶, 冯晓宇, 等. 不同蛋白质、脂肪水平对三角鲂生长性能及体成分的影响 [J]. 饲料工业, 2014, **35**(14): 19-25.]

[7] Chen J M, Ye J Y, Pan Q, *et al*. Preliminary study on dietary lipid requirements of juvenile fish of *Erythroculter ilishaeformis* [J]. *Journal of Aquaculture*, 2005, **26**(2): 18-19. [陈建明, 叶金云, 潘茜, 等. 翘嘴鲌鱼种饲料中脂肪适宜水平的初步研究 [J]. 水产养殖, 2005, **26**(2): 18-19.]

[8] Zhang Y, Song L, Liu R, *et al*. Effects of dietary protein and lipid levels on growth, body composition and flesh quality of juvenile topmouth culter, *Culter alburnus* Basilewsky [J]. *Aquaculture Research*, 2015, **47**(8): 1-9.

[9] AOAC (Association of Official Analytical Chemists International). Official Methods of Analysis of AOAC international [M]. 16th ed. Arlington, Virginia: AOAC International: 1997.

[10] Biochemical Microbiology Teaching and Research Office of Biology Department of Sun Yat-sen University. Introduction to Biochemical Technology [M]. Beijing: People's Education Press, 1978: 53-54. [中山大学生物系生化微生物学教研室. 生化技术导论 [M]. 北京: 人民教育出版社, 1978: 53-54.]

[11] Bernfeld P. Amylase α and β: Colorimetric Assay Method [M]//Colowiwick S P, Kaplan N O (Eds.), Methods in Enzymology. New York: Academy Press Incorporation, 1955: 149-158.

[12] Bradford M M. A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dry binding [J]. *Analytical Biochemistry*, 1976, **72**(1/2): 248-254.

[13] Kim K, Kayes T B, Amundson C H. Quantitative protein requirement of Arctic charr, *Salvelinus alpinus* (L) [J]. *Journal of Fish Biology*, 1983, **22**(6): 705-712.

[14] Mohanty S S, Samantaray K. Effects of varying levels of

dietary protein on the growth performance and feed conversion efficiency of snake head, *Channa striata*, fry [J]. *Aquaculture Nutrition*, 1996, **2**(2): 89-94.
[15] Yang S D, Lin T S, Liou C H, *et al*. Influence of dietary protein levels on growth performance, carcass composition and liver lipid classes of juvenile *Spinibarbus hollandi* [J]. *Aquaculture Research*, 2003, **34**(8): 661-666.
[16] Pei Z, Xie S, Lei W, *et al*. Comparative study on the effect of dietary lipid level on growth and feed utilization for gibel carp and Chinese longsnout catfish [J]. *Aquaculture Nutrition*, 2004, **10**(4): 209-216.
[17] Pérez-Jiménez A, Cardenete G, Morales A E, *et al*. Digestive enzymatic profile of *Dentex dentex* and response to different dietary formulations [J]. *Comparative Biochemistry and Physiology Part A*: *Molecular & Integrative Physiology*, 2009(154A): 157-164.
[18] Lü Y P, Chen J M, Ye J Y, *et al*. Effects of diet protein level on the growth, body composition and digestive enzyme activities of the *Barbudes caldwell* juvenile [J]. *Journal of Agricultural Biotechnology*, 2009, **17**(2): 276-281. [吕耀平, 陈建明, 叶金云, 等. 饲料蛋白质水平对刺鲃幼鱼的生长、胴体营养组成及消化酶活性的影响 [J]. 农业生物技术学报, 2009, **17**(2): 276-281.]
[19] Guo W, Yin H, Mo A J, *et al*. Effects of dietary protein levels on growth, digestion and metabolism of *Siniperca chuatsi* [J]. *Journal of Huazhong Agricultural University*, 2023, **42**(4): 215-224. [郭薇, 尹恒, 莫爱杰, 等. 饲料蛋白水平对鳜生长、消化和代谢的影响 [J]. 华中农业大学学报, 2023, **42**(4): 215-224.]
[20] Jiang W H, Yang X, Zhou Q B, *et al*. Requirement level of dietary protein for *Monopterus albus* [J]. *Acta Hydrobiologica Sinica*, 2022, **46**(8): 1205-1214. [姜文灏, 杨鑫, 周秋白, 等. 黄鳝饲料蛋白质需求量的研究 [J]. 水生生物学报, 2022, **46**(8): 1205-1214.]
[21] Shao Q J, Su X F, Xu Z R. Effects of dietary protein levels on growth performance and digestive enzyme activities of jade perch *Scortum bacoo* [J]. *Journal of Zhejiang University* (Agriculture & Life Science), 2004, **30**(5): 553-556. [邵庆均, 苏小凤, 许梓荣. 饲料蛋白水平对宝石鲈增重和胃肠道消化酶活性影响 [J]. 浙江大学学报(农业与生命科学版), 2004, **30**(5): 553-556.]
[22] Jana S N, Garg S K, Barman U K, *et al*. Effect of varying dietary protein levels on growth and production of *Chanos chanos* (Forsskal) in inland saline groundwater: laboratory and field studies [J]. *Aquaculture International*, 2006, **14**(5): 479-498.
[23] Sagada G, Chen J, Shen B, *et al*. Optimizing protein and lipid levels in practical diet for juvenile north snakehead fish (*Channa argus*) [J]. *Animal Nutrition*, 2017(3): 156-163.
[24] Wang L, Hu S, Lou B, *et al*. Effect of different dietary protein and lipid levels on the growth, body composition, and intestinal digestive enzyme activities of juvenile yellow drum *Nibea albiflora* (Richardson) [J]. *Journal of Ocean University of China*, 2018, **17**(5): 1261-1267.
[25] Luo G, Xu J, Teng Y, *et al*. Effects of dietary lipid levels on the growth, digestive enzyme, feed utilization and fatty acid composition of Japanese sea bass (*Lateolabrax japonicus* L.) reared in freshwater [J]. *Aquaculture Research*, 2010, **41**(2): 210-219.
[26] Ma B, Wang L, Lou B, *et al*. Dietary protein and lipid levels affect the growth performance, intestinal digestive enzyme activities and related genes expression of juvenile small yellow croaker (*Larimichthys polyactis*) [J]. *Aquaculture Reports*, https://doi.org/10.1016/j.aqrep.2020.100403.
[27] Li X, Jiang Y, Liu W, *et al*. Protein-sparing effect of dietary lipid in practical diets for blunt snout bream (*Megalobrama amblycephala*) fingerlings: effects on digestive and metabolic responses [J]. *Fish Physiology and Biochemistry*, 2012, **38**(2): 529-541.
[28] Qiang J, He, J, Yang H, *et al*. Dietary lipid requirements of larval genetically improved farmed tilapia, *Oreochromis niloticus* (L.), and effects on growth performance, expression of digestive enzyme genes, and immune response [J]. *Aquaculture Research.*, 2017, **48**(6): 2827-2840.
[29] Lu Y P, Wang L, Zhang X X, *et al*. Effects of dietary lipid levels on growth, muscle composition, activities of digestive enzyme and immunity of juvenile red claw crayfish *Cherax quadricarinatus* [J]. *Feed Industry*, 2018, **39**(24): 17-23. [鲁耀鹏, 汪蕾, 张秀霞, 等. 饲料脂肪水平对红螯螯虾幼虾生长、肌肉组分、消化酶活力和免疫力的影响 [J]. 饲料工业, 2018, **39**(24): 17-23.]
[30] Mohanta K N, Mohanty S N, Jena J K, *et al*. Optimal dietary lipid level of silver barb, *Puntius gonionotus* fingerlings in relation to growth, nutrient retention and digestibility, muscle nucleic acid content and digestive enzyme activity [J]. *Aquaculture Nutrition*, 2008, **14**(4): 350-359.
[31] Liu Y Y, Yu H B, Wu W Y, *et al*. Effects of dietary lipid levels on growth, body composition, digestive enzyme activities, serum biochemical indexes and antioxidant performance of *Polyodon spathula* [J]. *Journal of Fisheries of China*, 2018, **42**(12): 1940-1956. [刘阳洋, 于海波, 武文一, 等. 饲料脂肪水平对匙吻鲟生长、体组成、消化酶活性、血清生化及抗氧化性能的影响 [J]. 水产学报, 2018, **42**(12): 1940-1956.]
[32] Zhang W, Dan Z, Zhuang Y, *et al*. Effects of dietary lipid levels on growth, digestive enzyme activities, antioxidant capacity, and lipid metabolism in turbot (*Scophthalmus maximus* L.) at three different stages [J]. *Aquaculture Nutrition*, https://doi.org/10.1155/2022/1042263.
[33] Sivaramakrishnan T, Sahu N P, Jain K K, *et al*. Optimum dietary lipid requirement of *Pangasianodon hypophthalmus* juveniles in relation to growth, fatty acid profile,

body indices and digestive enzyme activity [J]. *Aquaculture International*, 2016, **25**(2): 941-954.

[34] Aliyu-Paiko M, Hashim R, Shu-Chien A C. Influence of dietary lipid/protein ratio on survival, growth, body indices and digestive lipase activity in Snakehead (*Channa striatus*, Bloch 1793) fry reared in re-circulating water system [J]. *Aquaculture Nutrition*, 2010, **16**(5): 466-474.

DIETARY PROTEIN AND LIPID ON GROWTH PERFORMANCE, BODY COMPOSITION AND DIGESTIVE ENZYME ACTIVITIES OF WINTERLING *CULTER ALBURNUS* ♀× *MEGALOBRAMA TERMINALIS* ♂

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Abstract: To optimize the feed formulation of a hybrid fish, *Culter alburnus* ♀ × *Megalobrama terminalis* ♂, a 3×3 factorial feeding trial was conducted. Nine diets were prepared with varying protein levels (36%, 39% and 42%) and lipid levels (6%, 8% and 10%) to evaluate production responses, including growth, feed utilization, body composition, and activity of digestive enzymes. The diets, labeled as P36L6, P36L8, P36L10, P39L6, P39L8, P39L10, P42L6, P42L8, and P42L10, were fed to 9 triplicate groups of fish with an initial average body weight of 8.59 g for 60d. Weight gain rates (WGR) and feed conversion ratios (FCR) of fish fed diets with protein levels of 39% and 42% (P39L6, P39L8, P39L10, P42L6, P42L8, and P42L10) did not show significantly differences among treatments ($P>0.05$). However, fish fed diets with a protein level of 36% (P36L6, P36L8, and P36L10) exhibited lower WGR and higher FCR ($P<0.05$). Protein retention (PR) of fish fed diets with one level of dietary protein were not significantly different, but fish fed diets with a dietary protein level of 39% (P39L6, P39L8, and P39L10) had higher PR compared to those of fish fed diets with 36% dietary protein (P36L6, P36L8, and P36L10). PR were not significantly different between treatments of fish fed diets with one level of dietary lipid and dietary protein level of either 39% or 42%; Viscera-somatic index (VSI) positively correlated with dietary lipid level (L) (VSI=0.223L+4.611, R=0.746, P=0.000). Whole fish body lipid tended to decrease with increasing dietary protein level and increase with increasing dietary lipid level. Fish fed diets with a dietary lipid level of 6% (P36L6, P39L6, and P42L6) had lower muscle lipid compared to those fed diets with 8% and 10% dietary lipid levels. Fish fed diets with a protein level of 36% (P36L6, P36L8, and P36L10) exhibited higher intestinal amylase activities compared to those fed diets with higher dietary protein levels. Intestinal protease and lipase activities were not significantly influenced by dietary protein level, lipid level or their interaction. Based on these results, it can be concluded that a dietary protein level of 39% and a dietary lipid level of 6% are suitable for maintaining good growth performance and feed utilization in the trial fish. Low dietary protein and high dietary lipid may lead to additional body lipid deposition.

Key words: Dietary protein; Dietary lipid; Growth performance; Body composition; Digestive enzyme activities; *Culter alburnus* ♀ × *Megalobrama terminalis* ♂